Life History Characteristics, Distribution, and Habitat Use of Westslope Cutthroat Trout in the St. Maries River Basin, Idaho

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by

John W. Heckel IV

Major Professor: Michael C. Quist, Ph.D.

Committee Members: Brian P. Kennedy, Ph.D.; Daniel J. Schill, Ph.D.

Department Administrator: Lisette P. Waits, Ph.D.

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Authorization to Submit Thesis

This thesis of John W. Heckel IV, submitted for the degree of Master of Science with a Major in Natural Resources and titled "Life History Characteristics, Distribution, and Habitat Use of Westslope Cutthroat Trout in the St. Maries River Basin, Idaho," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ________________________ Date: __________
Michael C. Quist, Ph.D.

Committee Members:

________________________ Date: __________
Brian P. Kennedy, Ph.D.

________________________ Date: __________
Daniel J. Schill, Ph.D.

Department Administrator: ________________________ Date: __________
Lisette P. Waits, Ph.D.

Abstract

The distribution and abundance of Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) in relation to habitat characteristics remains unknown across large portions of its distribution, which includes the St. Maries River basin in northern Idaho. Furthermore, the population structure of WCT in the St. Maries River basin, and whether adfluvial WCT use the St. Maries River basin and contribute to the Coeur d'Alene Lake WCT population is unknown. The goals of this research were multifaceted. One goal was to provide a foundational understanding of WCT distribution and abundance in tributaries of the St. Maries River, Idaho, and to evaluate how the distribution and abundance of WCT were related to habitat characteristics. The second goal of this research was to use strontium isotopes (i.e., $^{87}Sr/^{86}Sr$) derived from ambient water and sagittal otoliths to assess spatial variability throughout the Coeur d'Alene Lake watershed and its sub-basins, and describe the population structure of WCT in the St. Maries River basin using otolith microchemistry. Westslope Cutthroat Trout were abundant where there was suitable habitat and absent in locations with poor habitat or in the presence of Brook Trout *Salvelinus fontinalis*. Additionally, migratory (i.e., fluvial, adfluvial) and nonmigratory (i.e., resident) life history strategies were detected throughout the system. The results of this research suggest that life history diversity and connectivity to good habitat have contributed to WCT population viability in the St. Maries River basin.

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Dedication

This work is dedicated to my wife, Joanne. Her continuous support through my graduate research helped me stay motivated and positive during difficult times. This is also dedicated to my son, Clarence, who was a bright star every day while completing my thesis research and writing.

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Chapter 1: General Introduction

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) is a coldwater salmonid native to western North America (Behnke 2002; Shepard et al. 2005). It is a species of high social importance due to its popularity among anglers, a species of high ecological importance due to its role in aquatic ecosystems, and a species of special concern in most of western North America (Fredericks et al. 1997; Shepard et al. 2005). Westslope Cutthroat Trout occupy coldwater systems varying from high-elevation, low-productivity, headwater streams to high-productivity, large river systems (Rieman and Apperson 1989; Shepard et al. 2005; Sloat et al. 2005).

Historically, WCT were one of the most widely distributed of all Cutthroat Trout subspecies (Allendorf and Leary 1988; Behnke 1992; Young et al. 2018). They ranged from portions of the Fraser and South Saskatchewan river basins in Canada; the Missouri, and Columbia river basins in Montana, Idaho, and Washington; the John Day River basin in Oregon; and the Methow River and Lake Chelan basins in Washington (Shepard 2005; Young et al. 2018). In Idaho, WCT occupied nearly all waters in the central and northern parts of the state (Rieman and Apperson 1989). In the Spokane River basin, WCT are native upstream of Spokane Falls in Coeur d'Alene Lake and its tributaries (Behnke 1992). However, there have been factors limiting WCT abundance and density. Introduction of nonnative fishes, hybridization, overharvest, habitat loss, and habitat degradation have contributed to a reduction of WCT distribution throughout Idaho and the western United States (Allendorf and Leary 1988; Rieman and Apperson 1989; Behnke 1992; Schmetterling 2001; Northwest Power 2005; Shepard et al. 2005; Muhlfeld et al. 2009).

Harvest records indicate that the Coeur d'Alene Tribe harvested around 42,000 WCT per year in the Coeur d'Alene Lake system (Scholz et al. 1985). The railway, steamboats, and highways brought travelers to the region and Cutthroat Trout were highly sought because of their abundance and high susceptibility to capture (Schott 1950; Rankel 1971). In the late 19th and early 20th centuries, anglers reported catching 50-100 Cutthroat Trout weighing up to 2.5 kilograms each in a few hours in the Coeur d'Alene Lake system (Rankel 1971). In addition to angler overexploitation, mining and timber harvest had deleterious effects on water quality, riparian habitat, and fish habitat (Ellis 1940; Strong and Webb 1970; Mink et al. 1971; IDEQ 2003). Research was conducted in the Coeur d'Alene Lake basin to better understand WCT abundance and distribution, and why declines were occurring (Jeppson 1960; Averett 1962; Rankel 1971; Lukens 1978; Thurow and Bjornn 1978; Rieman and Apperson 1989; Wells et al. 2004; Parametrix 2006; Firehammer 2012). In general, research concluded that overexploitation was the main factor that contributed to declines in WCT populations in systems containing good habitat (Thurow and Bjornn 1978; Rieman and Apperson 1989; Mallet 2013).

Efforts to improve the WCT fishery in the Coeur d'Alene Lake basin began in the St. Joe River in the 1970s when restrictive angling regulations were implemented (Thurow and Bjornn 1978). In the Coeur d'Alene River, restrictive angling regulations were also implemented in the watershed. A mixture of angler noncompliance with restrictive regulations (Lewynsky 1986) and poor habitat conditions were attributed to a suppressed WCT population (Hunt and Bjornn 1995; DuPont et al. 2004). More recently, habitat improvement projects occurred throughout the Coeur d'Alene River system, which resulted in higher abundances and densities of WCT in the Coeur d'Alene River basin (DuPont et al.

2004). Although WCT populations appear to be robust and thriving in the St. Joe and Coeur d'Alene rivers, the neighboring St. Maries River does not support the same high-quality WCT fishery (Ryan et al. 2013). At best, the St. Maries River supports a marginal fishery that is predominantly focused on an unknown number migratory fish entering the system from Coeur d'Alene Lake or the St. Joe River.

Unlike other watersheds in northern Idaho (e.g., Coeur d'Alene, St. Joe, Lochsa, and Selway rivers) the St. Maries River basin does not have an abundance of suitable habitat throughout the watershed (IDEQ 2003). Consequently, the WCT fishery in the St. Maries basin is poor compared to neighboring rivers, and, therefore, has not been the focus of extensive fisheries research or monitoring. Exceptions to this are distribution surveys and creel studies conducted by the Idaho Department of Fish and Game (Horton and Mahan 1988; Apperson et al. 1988), and a telemetry study conducted by Parametrix (2006) for Avista Corporation. Although sample sizes were low (n = 17 fish tagged in the St. Maries River) and tracking was limited in the telemetry study, an interesting pattern was observed (Parametrix 2006). A higher proportion of fish in the St. Maries River were observed moving downstream and out of the system compared to fish tagged and tracked in the Coeur d'Alene and St. Joe rivers. The primary mechanism responsible for this pattern was hypothesized to be a lack of pool and run habitat in the mainstem of the St. Maries River, but downstream movement patterns are often an indication of adfluvial and fluvial migration behavior (Northcote 1997; Parametrix 2006).

The Parametrix (2006) study provided insight on factors influencing WCT in the system, but it lacks context because little is known about the life history, distribution, and how distribution relates to habitat characteristics in the St. Maries River basin. Furthermore, research conducted by Horton and Mahan (1988) and Apperson et al. (1988) did not assess life history structure of WCT nor did they describe spatio-temporal use of the mainstem St. Maries River. An understanding of WCT life history structure, distribution, and habitat use in the St. Maries River basin is important for formulating a holistic approach to guide management and conservation actions.

Thesis Organization

This thesis is divided into four chapters. Chapter two describes the distribution and abundance of Westslope Cutthroat Trout related to habitat characteristics at multiple spatial scales in tributaries of the St. Maries River. This chapter will be submitted to *Fisheries Management and Ecology*. Chapter three describes the evaluation of life history characteristics of Westslope Cutthroat Trout in the St. Maries River basin using otolith microchemistry. This chapter will be submitted to the *Canadian Journal of Fisheries and Aquatic Sciences*. Chapter four provides general conclusions and recommendations for future research drawn from this thesis.

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Chapter 2: Distribution and Abundance of Westslope Cutthroat Trout in Relation to Habitat Characteristics at Multiple Spatial Scales

Abstract

The distribution and abundance of Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) in relation to habitat characteristics remains unknown across large portions of its distribution. The goals of this research were to provide a foundational understanding of WCT distribution and abundance related to habitat characteristics in tributaries of the St. Maries River, Idaho. Backpack electrofishing and habitat assessments were conducted at 68 reaches in 35 different tributaries of the St. Maries River in 2017 and 2018. Habitat was measured at multiple spatial scales and a hurdle regression modeling approach was used to evaluate the relationship between habitat characteristics and the occurrence and abundance of WCT. A total of 652 WCT was sampled from 52 of 68 total reaches (76%). Total length (TL) of WCT sampled from tributaries varied from 23 mm to 406 mm and the average TL was 110 mm (SD = 57 mm). Age-0 WCT occurred at 26 reaches (38%) and were sampled as early as June 7 in 2017 and June 19 in 2018. At the basin-level, logistic regression indicated that the presence of WCT was positively related to stream gradient and elevation, and negatively related to road density. At the reach-level, logistic regression models indicated that the amount of instream cover, percentage of canopy cover, and mean current velocity were positively related to the presence of WCT. The presence of WCT was inversely related to the amount of fine substrate (i.e., silt, sand), presence of Brook Trout *Salvelinus fontinalis,* depth, and ratio of pools to riffles. Regression models focused on abundance indicated that gradient and road density were positively related to the abundance of WCT. Elevation was negatively correlated to the

abundance of WCT. Different patterns emerged when predicting the abundance of WCT from reach-level habitat characteristics compared to the presence-absence models. The abundance of WCT was inversely related to depth, and positively related to water temperature and the amount of instream cover in a reach. This research describes the distribution and abundance of WCT in relation to habitat characteristics, which can be used to guide fishery and habitat management decisions at multiple spatial scales (i.e., reach, watershed).

Introduction

Lotic systems are complex environments shaped by diverse biological and physical interactions that influence various life history strategies in stream fishes (Schlosser 1991; Gresswell 1994; Fausch et al. 2002). To maximize growth, reproduction, and survival, stream fishes often move long distances to access resources (e.g., food, habitat) that are crucial for completing their life cycle (Schlosser 1991; Fausch et al. 2002). Therefore, different physical habitats are required for various life stages of stream fishes, leading to spatially motivated movement patterns in a heterogeneous environment (Schlosser 1991). Understanding physical and biological interactions in lotic environments is paramount for managing and conserving aquatic resources, especially for species of high social and ecological importance. Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) occupy coldwater systems varying from high-elevation, low-productivity, headwater streams to high-productivity, large river systems (Rieman and Apperson 1989; Shepard et al. 2005; Sloat et al. 2005). Two major life history forms characterize WCT subspecies: migratory (i.e., fluvial, adfluvial; Liknes and Graham 1988; Behnke 1992) and nonmigratory (i.e., resident; Likens and Graham 1988; Downs et al. 1997). In Idaho, WCT are known to be highly mobile with individual fish moving more than 100 km in a single year (Bjornn and Mallet 1964; Schoby and Keeley 2011). All life history strategies contain mobile life stages at some spatial and temporal scale. As such, habitat heterogeneity is important for successful production.

The dynamic environments that stream fishes occupy at various temporal and spatial scales can influence population dynamics and life history strategies (Schlosser 1991; Gresswell 1994; Rieman and Dunham 2000; Fausch et al. 2002). Habitats used by adult Cutthroat Trout *Oncorhynchus clarkii* spp. differ from early rearing habitats used by juveniles (Moore and Gregory 1988; Rieman and Dunham 2000; Schmetterling 2001; Muhlfeld et al. 2009), and habitat use can vary among life history strategies (i.e., adfluvial, resident; Campbell et al. 2018). Mortality and competition for resources are high early in life (Knight et al. 1999; McGrath et al. 2008). Habitat thought to be important for subadult and adult WCT may have limited suitability for age-0 WCT (Behnke 1992). To make informed management decisions about WCT populations, it is important to gain an understanding of habitat used by age-0 WCT and age-1 and older WCT. Therefore, understanding the distribution of WCT at different life stages and how it relates to habitat characteristics is important for fisheries and habitat managers focused on protecting and restoring aquatic habitats.

The St. Maries River basin in northern Idaho has not received extensive attention in fisheries research or management. The Idaho Department of Fish and Game (IDFG) conducted creel surveys and distribution studies on WCT throughout the watershed in the 1980s (Horton and Mahan 1988; Apperson et al. 1988; Rieman and Apperson 1989). They found that WCT were distributed throughout the watershed, were often the dominant salmonid in tributaries, and they hypothesized that multiple life history strategies existed (i.e., resident, fluvial, adfluvial) in the watershed (Averett 1962; Horton and Mahan 1988; Apperson et al. 1988). Although WCT were historically distributed throughout the watershed, nonnative salmonids (i.e., Brook Trout *Salvelinus fontinalis*, Rainbow Trout *Oncorhynchus mykiss*), high water temperatures, and poor habitat were blamed for the poor fishery that essentially only existed in the spring. Over a century of intensive timber harvest, agricultural use, mining, road building, and piscicide treatments (i.e., Squoxin; Goodnight and Mauser 1974) on the mainstem of the St. Maries River have occurred (Apperson et al. 1988). Coupled with fishery investigations conducted in the 1980s, cursory habitat assessments were conducted to create a baseline index of habitat conditions in tributaries to the St. Maries River. Some land use practices were deemed deleterious, particularly intensive logging, livestock grazing, and roads (Apperson et al. 1988).

In the neighboring Coeur d'Alene River watershed, the same land use practices (i.e., logging, roads) were implicated as limitations to the WCT population, in addition to angler noncompliance with regulations (Lewynsky 1986; Hunt and Bjornn 1995; Dunnigan et al. 1998; IDEQ 2001; DuPont et al. 2004). To mediate the effects of land use practices, efforts were made to rectify the declining WCT population by implementing habitat restoration projects and establishing land easements in the Coeur d'Alene River basin (DuPont et al. 2004). In the St. Maries River watershed, changes in land and water use practices have occurred since the original population and habitat evaluations were conducted by IDFG. Before restoration projects and easements can be planned, a better understanding of where different life stages of WCT are distributed throughout the St. Maries River basin and how that distribution relates to habitat is needed. Knowledge of WCT distribution and how it relates to habitat characteristics can be used for guiding fishery and habitat management actions throughout the watershed. The objectives of this study were to provide a foundational understanding of WCT distribution and abundance in tributaries of the St. Maries River, and to evaluate how the distribution and abundance of WCT in tributaries of the St. Maries River was related to habitat characteristics.

Study Area

The St. Maries River is a 71 km-long, sixth-order tributary of the St. Joe River located in the panhandle of Idaho (Figure 2.1). The St. Maries River joins the St. Joe River approximately 24 km upstream from Coeur d'Alene Lake. Water levels in Coeur d'Alene Lake are influenced by Post Falls Dam located on the Spokane River, which is the sole outflow of Coeur d'Alene Lake. The construction of Post Falls Dam was completed in the early 20th century and the dam is owned and operated by Avista Corporation. Due to the operation of Post Falls Dam, the water level of Coeur d'Alene Lake was raised by approximately 2.5 m (DuPont 2004; Walrath et al. 2015). From late spring to autumn, a portion of the St. Maries River (about 15 km) is inundated by the elevated water level in Couer d'Alene Lake (Parametrix 2006). The St. Maries River basin drains an area of approximately 1,863 km^2, extends into four counties (Benewah, Clearwater, Latah, and Shoshone), and is characterized by alluvial sedimentary deposits resulting from the formation of ancient Lake Clarkia (Ladderud et al. 2015). Elevations in the basin vary from about 670 m to 1,600 m, and the mainstem St. Maries River has a longitudinal elevation difference of 207 m.

Land ownership in the St. Maries River watershed is mixed between private, state, federal, and tribal parcels. Land managers in the basin consist of the U. S. Forest Service, State of Idaho, IDFG, Coeur d'Alene Tribe, U. S. Bureau of Land Management, Potlatch Corporation, Stimson Lumber, and Bennett Lumber. Historical and current land use practices in the basin include railroad construction, timber harvest, mining, and agriculture. Most drainages in the St. Maries basin have sustained substantial timber harvest during the 20th century and logging currently continues throughout the watershed. Logging companies originally used waterways as a log transport system. Splash dams created migration barriers and log drives caused structural damage to waterways; river channels became straighter and less complex as log jams, woody debris, large boulders, and sharp channel bends were removed (Schott 1950; Strong and Webb 1970; IDEQ 2003; DuPont 2004). Cattle grazing in the St. Maries River basin occurs in the river valley and low-gradient sections of tributary streams. Cattle grazing influences bank stability, riparian growth, and can effect fish populations (Peterson et al. 2010). Cattle grazing occurs on Emerald Creek, Carpenter Creek, Santa Creek, Charlie Creek, Gold Center Creek, West and Middle forks of the St. Maries River, and the mainstem of the St. Maries River. As a result of historical and current land use practices in the St. Maries River basin, the St. Maries River and some tributaries are 303(d) listed based on sediment, temperature, habitat alteration, nutrients, bacteria, and dissolved oxygen (IDEQ 2003).

Methods

Field sampling

Fishes and physical habitat characteristics were sampled from tributaries in the St. Maries River basin (Figure 2.1). Habitat characteristics were examined at multiple spatial scales to investigate how large-scale (e.g., elevation) and small-scale (e.g., instream cover) factors were related to the distribution of fishes (Quist et al. 2005). A stratified sampling design was used to select the locations of sampling reaches. Tributaries of the St. Maries River were considered strata and sampling reaches were randomly selected in each stratum. Reaches varied in length based on the average wetted stream width (Lyons 1992; Simonson 1995) and were selected using a random point generator in ArcMap version 10.5.1 (Esri, Redlands, California). Reaches were delineated into macrohabitats (i.e., pools, riffles, runs, off-channel units) and began and ended at the nearest macrohabitat transition (Quist et al. 2003; Sindt et al. 2012). In 2017, sampling was conducted from May–August on 44 reaches in 33 different tributaries. In 2018, sampling was conducted from June–August on 24 reaches in 20 different tributaries. Fishes were sampled in each reach using single-pass pulsed direct current (PDC) electrofishing (Model LR-24 Backpack Electrofisher; Smith Root, Inc., Vancouver, Washington; Simonson and Lyons 1995). For all backpack electrofishing, two netters each used a 6.4 mm mesh dip net to collect fishes. Seconds of electrofishing were recorded for each macrohabitat and were used to calculate catch-per-unit-effort ([CPUE] = fish/minute of electrofishing). All fishes were identified to species and measured for total length (TL). A subsample of WCT were sacrificed (see chapter 3) and age was estimated using sagittal otoliths. Weight was measured on sacrificed WCT to the nearest tenth of a gram.

Large-scale habitat characteristics (i.e., gradient, elevation, road density, land use) were estimated at the basin-level using ArcMap and Terrain Navigator Pro (Version 9.1, MyTopo; Billings, Montana; Meyer et al. 2003; Sindt et al. 2012). Elevation and gradient were estimated from USGS Topographic Maps at 1:24,000 scale using Terrain Navigator Pro. The distance (m) between the two contour lines that bounded the sampling reach was traced.

Gradient was calculated as the elevational increment (12.192 meters) between those two contour lines divided by the traced distance (Meyer et al. 2003). Road density was estimated using a raster layer in ArcMap and calculated as kilometers of roads per square kilometer surrounding a reach (km/km^2; Vadal and Quinn 2011). Dominant land use was determined in the field and categorized as timberland, land that had recently been or was currently being clear cut for timber; mineral, land that was managed and used for mineral extraction; private property, residential homes or summer camps; cattle-grazed, land where cattle grazing was occurring; forest, land that did not have noticeable effects from timber harvest; and thinned forest, forests that were not clear cut, but had some timber harvested.

Fine-scale habitat characteristics were quantified at the reach-level for each macrohabitat. Water temperature (°C) and conductivity (µS/cm) were taken prior to electrofishing using a handheld probe (DiST, Hanna; Woonsocket, Rhode Island). Total length of each macrohabitat was measured along the thalweg. If the macrohabitat length was less than 30 m, two transects at 25% and 75% of the macrohabitat length were established (Quist et al. 2003). If the macrohabitat length was greater than 30 m, transects at 25%, 50%, and 75% of the macrohabitat length were established. At each transect, wetted stream width was measured. Depth, current velocity, and substrate particle size were measured at four equidistant points and at the midpoint of each transect (20%, 40%, 50%, 60%, and 80%; Platts et al. 1983). Benthic and mean current velocity were taken using a portable water velocity meter (Marsh McBirney Model 2000 Portable Flowmeter; Hach Company, Loveland, Colorado). Benthic current velocity was taken 0.03 m above the substrate. Mean current velocity was measured at 60% of the depth when depths were less than 0.75 m, and at 20% and 80% of the depth when depths were greater than 0.75 m (Buchanan and Somers 1969).

Substrate type was visually assessed and classified as wood, clay (< 0.004 mm), silt (0.004-0.063 mm), sand (0.064-2.000 mm), gravel (2-16 mm), coarse gravel (16-64 mm), cobble (64-256 mm), boulder (> 256 mm), or bedrock (Cummins 1962; Sindt et al. 2012). The percentage of substrate embeddedness was visually estimated (i.e., 25%, 50%, 75%, and 100%; Platts et al. 1983) for coarse gravel, cobble, and boulder substrate types (Eaglin and Hubert 1993). Canopy cover (%) was estimated at each transect using a concave densiometer while standing at the stream margin and facing each bank, and facing upstream and downstream at the midpoint of the channel (Quist et al. 2003). Bank characteristics were recorded for both banks at each transect. Bank characteristics were classified at each transect by the presence of woody vegetation, nonwoody vegetation, roots, boulders, rip-rap, eroding ground, and bare ground. All instream cover at least 0.3 m in length and in water 0.2 m deep or greater was quantified by taking one length measurement, three width measurements, and three depth measurements. Instream cover was classified as undercut bank, overhanging vegetation, branch complex, log complex, root wad, boulder, rip-rap, or aquatic vegetation (Quist et al. 2003).

For each macrohabitat, area was estimated using the thalweg length multiplied by the mean wetted width of all transects. Means were calculated for depth, current velocity, wetted width, substrate embeddedness, and canopy cover for each macrohabitat unit. Additionally, the mean coefficient of variation (CV) in depth, width, current velocity, and canopy cover was calculated ($CV = 100 \times [SD/mean]$) as an estimate of habitat heterogeneity. The proportions of each substrate type, bank characteristics, and instream cover type were calculated for each macrohabitat unit. All habitat characteristics, except instream cover, were then averaged across macrohabitat units in a reach. Averaged values were weighted by the proportion of the total stream reach area that was represented by the macrohabitat. Weighted values were summed to quantify habitat characteristics for the entire stream reach. Instream cover type was quantified as the proportion of reach area. Additional variables were created by combining two or more habitat variables (e.g., proportion of nonwoody cover, proportion of large substrate).

Data analysis

Abundance and distribution related to habitat characteristics for different life stages were investigated by separating WCT into two groups: age-0 fish and age-1 and older fish (Mcgrath et al. 2008; Meyer et al. 2010). Ages of WCT were estimated on a subsample of collected fish (see chapter 3). The TL of age-0 fish (≤ 61 mm) was used to discriminate age-0 from age-1 and older WCT. Species-specific habitat relationships with presence-absence and abundance data were investigated using a hurdle regression modeling approach (Welsh et al. 1996; Martin et al. 2005; Wenger and Freeman 2008; Smith et al. 2016). Hurdle regression models consisted of two submodels. One submodel used logistic regression under a binomial distribution to predict the presence of WCT in relation to habitat characteristics across all reaches. The other submodel evaluated the relationship between the abundance of WCT in relation to habitat characteristics under a negative binomial distribution for reaches where at least one WCT was present. The abundance of WCT was standardized to 100 m of linear stream length (Meyer et al. 2006a). Presence-absence and abundance of age-0 and age-1 and older WCT were modeled separately to investigate whether habitat characteristics varied between life stages. Furthermore, analyses for each age group were conducted at multiple spatial scales (i.e., basin-level, reach-level).

Hurdle models were constructed using the “glm” (R Development Core Team 2008) and the “glm.nb” functions (Venables and Ripley 2002) using R Statistical Software. Models were assessed for overdispersion by visually examining diagnostic plots and estimating the dispersion parameter ($\hat{c}$). The dispersion parameter was calculated by dividing Pearson’s residual deviance by the residual degrees of freedom. Models were considered overdispersed when $\hat{c}$ was greater than one (Burnham and Andersen 2002). Overdispersed models had an additional parameter added to adjust for the estimation of dispersion (Lawless 1987; Venables and Ripley 2002). McFadden’s pseudo-R^2 was used to assess model fit (McFadden 1974; Hosmer and Lemeshow 1989). McFadden’s pseudo R^2 was calculated as one minus the difference in the log likelihood of a model with an intercept and explanatory variables, and the log likelihood of an intercept-only model (McFadden 1974). McFadden’s pseudo R^2 values vary from 0.0 to 1.0 with values greater than 0.20 indicating good fit (Hox 2010); however, models with pseudo R^2 values as low as 0.10 have also been shown to exhibit good model fit (Hosmer and Lemeshow 1989).

To avoid multicollinearity, Spearman’s correlation coefficient (r_s) was used to further investigate relationships among habitat characteristics. Variables with an r_s greater than or equal to |0.70| were considered highly correlated. When two variables were highly correlated, the most ecologically relevant and interpretable variable was retained for consideration in candidate models (Meyer et al. 2010; Sindt et al. 2012; Smith et al. 2016). For example, the sum of all instream cover in a reach was highly correlated with the sum of all nonwoody cover and the sum of all woody cover ($r_s \geq 0.70$). The sum of all instream cover was deemed the most ecologically important variable and was retained in candidate models; the other variables were removed. Habitat variables that were used to develop hurdle models included four large-scale variables and seventeen small-scale variables (Table 2.1). The relationships between WCT presence-absence and abundance related to large-scale habitat characteristics were assessed with fourteen candidate models created a priori for each submodel. Small-scale habitat characteristics were assessed with thirty-nine candidate models that were created a priori for each submodel. Competing multiple regression models were evaluated using an information theoretic approach to rank submodels using Akaike's Information Criterion adjusted for small sample size (AIC_c; Burnham and Anderson 2002). The top model was the model that had the lowest AIC_c value. Models that had an AIC_c score within 2.0 AIC_c values of the top model were also considered top models and retained for interpretation (Burnham and Anderson 2002). Additionally, the sum of Akaike weights (*w*) for all models in which a variable was present was used to assess the relative importance of independent variables (Burnham and Anderson 2002; Quist et al. 2005; Meyer and High 2011).

Results

Westslope Cutthroat Trout were distributed throughout the St. Maries River basin at multiple spatial scales. In tributaries of the St. Maries River basin, 5,690 individual fish representing 15 different species were sampled from 35 different tributaries. Westslope Cutthroat Trout occurred at the most sites (76%), followed by Shorthead Sculpin *Cottus confusus* (69%), Torrent Sculpin *Cottus rhotheus* (56%), and Speckled Dace *Rhinichthys osculus* (32%; Figure 2.2). A total of 652 WCT was sampled from 52 of 68 reaches (76%). Total length of WCT varied from 23 mm to 406 mm and the average TL was 110 mm (SD = 57 mm; Figure 2.3). Age-0 WCT occurred at 28 reaches (41%) and were sampled as early as June 7 in 2017 and June 19 in 2018.

The relationship between age-0 WCT and habitat characteristics were investigated at multiple scales (i.e., basin-level, reach-level). Logistic regression models evaluating large-scale habitat characteristics indicated that the presence of age-0 WCT was positively related to gradient and elevation, but negatively related to road density (Table 2.2). The second component of the hurdle regression models (i.e., abundance) indicated that gradient and road density were positively related to the abundance of age-0 WCT, but negatively related to elevation. At the reach-level, mean depth, fine substrate, and the presence of Brook Trout were negatively related to the presence of age-0 WCT. Furthermore, catch rates of age-0 WCT were positively related to water temperature and the proportion of instream cover in a reach, but negatively related to depth and canopy cover.

I further investigated the relationship between habitat characteristics and age-1 and older WCT. Logistic regression models predicting the presence of age-1 and older WCT followed a similar pattern to models predicting the presence of age-0 WCT. The presence of age-1 and older WCT was positively related to stream gradient and elevation, and negatively related to road density (Table 2.3). Regarding relative abundance, gradient and road density were positively related to the abundance of age-1 and older WCT, but elevation was negatively correlated with abundance. At the reach-level, logistic regression models indicated that the proportion of instream cover, percentage of canopy cover, and mean current velocity were positively related to the presence of age-1 and older WCT. The presence of age-1 and older WCT was inversely related to the proportion of fine substrate (i.e., silt, sand), the presence of Brook Trout, mean depth, and the ratio of pools to riffles. The relative abundance of age-1 and older WCT was inversely related to mean depth, and positively related to water temperature and the proportion of instream cover in a reach.

The sum of Akaike weights for all top models in which an independent variable occurred provided additional evidence related to the importance of each variable (Table 2.4). Fine substrate and the presence of Brook Trout were equally weighted in the top models predicting presence-absence of age-0 WCT followed by gradient and depth. Temperature was the highest weighted independent variable predicting the relative abundance of age-0 WCT (Figure 2.4). The sum of Akaike weights for gradient and road density were highest for predicting the presence-absence of age-1 and older WCT followed by canopy cover, proportion of instream cover, and fine substrate (i.e., silt, sand). Gradient also had the highest sum of Akaike weights for predicting the relative abundance of age-1 and older WCT.

Discussion

The primary goals of this research were to evaluate the distribution and abundance of WCT in tributaries of the St. Maries River, and to evaluate how the distribution and abundance of WCT in tributaries of the St. Maries River were related to habitat characteristics. Headwater streams and tributaries are vital habitat for Cutthroat Trout at multiple life stages (Schlosser 1991; Northcote 1997; Fausch et al. 2002; Uthe et al. 2016). Headwater streams are critical for reproductive success (Rieman and Apperson 1989; Behnke 1992; Magee et al. 1996; Northcote 1997; Shepard 2005), natal rearing (Northcote 1997; Rosenfeld et al. 2002), and thermal refuge (Kaeding 1996; Baird and Krueger 2003; D’Angelo and Muhlfeld 2013). Distribution and length frequencies of WCT in tributaries of the St. Maries River were consistent with what was observed by IDFG in the 1980s (Horton and Mahan 1988; Apperson et al. 1988). Apperson et al. (1988) estimated that WCT caught in tributaries were dominated by age-2 fish, suggesting that tributaries of the St. Maries River were important natal and juvenile rearing areas. The majority of WCT that I caught in tributaries of the St. Maries River were less than 170 mm with the highest frequencies of lengths at 30–39 mm and 140–149 mm. The high abundance of age-0 fish (TL $\leq$ 61 mm) supports the idea that tributaries of the St. Maries River are important natal rearing areas for WCT in the watershed.

The current study supports existing research that WCT populations appear robust and broadly distributed in headwaters (Shepard et al. 2005; D'Angelo and Muhlfeld 2013) and tributaries (Sloat et al. 2005; McGrath et al. 2008) throughout their current distribution. Previous research has indicated that certain habitat characteristics such as gradient (Brown and Mackay 1995; D'Angelo and Muhlfeld 2013), road density (Eaglin and Hubert 1993; Valdal and Quinn 2011), stream temperature (Shepard 2004; Sloat et al. 2005; D'Angelo and Muhlfeld 2013; Dobos et al. 2016), instream cover (Schmetterling 2001; DuPont et al. 2004; D'Angelo and Muhlfeld 2013), and canopy cover (Platts and Nelson 1989) are important for the occurrence of WCT. My findings corroborate previous research regarding instream cover, canopy cover, and temperature as important habitat characteristics for the occurrence of WCT. More specifically, multiple large-scale (e.g., gradient, road density, elevation) and small-scale (e.g., temperature, instream cover, canopy cover) habitat characteristics were important for predicting the occurrence of age-0 and age-1 and older WCT in tributaries of the St. Maries River. This pattern follows similar findings in streams of Glacier National Park, Montana, where WCT were most commonly found in high-elevation headwater streams with steep gradients (D'Angelo and Muhlfeld 2013). Kozel and Hubert (1989) observed that gradient had a substantial influence on stream habitat when predicting trout standing stock in Wyoming streams. My observations in the St. Maries River basin corroborate these studies;

gradient of a reach had a positive correlation with the presence of WCT. Moreover, gradient was also positively related to the relative abundance of age-1 and older WCT. The sum of Akaike weights for gradient were high (≥ 0.50), suggesting that gradient was an important covariate for predicting those responses. The effect of elevation on the abundance of WCT was negative. This pattern suggests that WCT are common at higher elevations, but most abundant at lower elevation reaches. Lower reaches of streams may have more abundant resources (e.g., prey availability) throughout the year and are able to support greater abundances of WCT (Berger and Gresswell 2009). Migration to lower elevations has been observed when salmonids seek overwintering habitat (Bjornn and Mallet 1964; Lewynsky 1986; Brown and Mackay 1995; Uthe et al. 2016), which is the likely pattern that WCT follow in the St. Maries River basin.

Westslope Cutthroat Trout in St. Maries River tributaries were closely associated with stream depths <0.4 m deep, which is contrary to research in the Coeur d'Alene River basin (DuPont et al. 2004; Stevens and DuPont 2011). DuPont et al. (2004) and Stevens and DuPont (2011) observed that adult WCT in the Coeur d'Alene River basin preferred water >1.0 m deep. However, the current study predominantly sampled juvenile WCT, suggesting that stream depth of habitat used by WCT likely varies with age class and (or) length. Westslope Cutthroat Trout are widely distributed in the U. S. within lands that have stringent habitat protections (Shepard et al. 2005), suggesting that land use can effect spatial distributions of WCT. For example, timber harvest, roads, and cattle grazing have been implicated to fragment habitat, destabilize streambanks, and increase sedimentation (Meehan 1991). Although fine sediments can support prey for age-0 salmonids (Moore and Gregory

1988; Hubert and Joyce 2005), tributary sites where fine substrate (i.e., silt, sand) was the dominant substrate type were negatively related to the presence of WCT.

Timber harvest and associated roads often influence stream habitat by accelerating sediment delivery to stream channels (Chamberlain et al. 1991; Eaglin and Hubert 1993; Furniss et al. 1993; Weaver and Fraley 1993). Seasonal roads for timber harvest in the St. Maries River watershed are abundant due to the long history of logging in the basin (Schott 1950; IDEQ 2003). Road density was inversely related to the occurrence of WCT, but positively related to the abundance of WCT. A positive relationship between the abundance of WCT and road density is contrary to many studies (Furniss et al. 1991; Eaglin and Hubert 1993; Valdal and Quinn 2011). The sum of Akaike weights for road density were much greater (0.90) when inversely related to presence-absence models than in other models (i.e., $\leq$ 0.28) containing the covariate. In other words, road density carried more weight when inversely related to the response than when it was positively related, which indicates that road density may have a greater negative effect on the occurrence of WCT than a positive effect on the abundance of WCT. Furthermore, the positive relationship between the abundance of WCT and road density is explained by the highest density of roads that occurred at mid to low elevation sites, which were also the elevations where WCT were most abundant. In addition, Akaike weights for gradient (0.64–0.90) were greater than road density (0.17–0.28), implicating that gradient was a more important covariate. Roads have been linked to increasing sediment delivery to stream channels (Chamberlain et al. 1991; Eaglin and Hubert 1993; Furniss et al. 1993; Weaver and Fraley 1993) and increased sedimentation can affect spawning gravel embeddedness and fry emergence (Chamberlain et al. 1991; Weaver and Fraley 1993; Magee et al. 1996). Westslope Cutthroat Trout were sampled in tributaries (n =

18) that are 303(d) listed for sediment (Idaho DEQ 2003) and regression models indicated a negative relationship between the occurrence of WCT and fine substrates (i.e., silt, sand). A negative relationship between WCT occurrence and fine substrates, but a positive relationship to gradient indicates that WCT were found in streams with increased stream velocity and less fine substrates.

Research on the relationship between Cutthroat Trout and Brook Trout is well documented. Brook Trout compete with Cutthroat Trout and often displace native Cutthroat Trout (Griffith 1988; Behnke 1992; Dunham 2002; Shepard 2004; Quist and Hubert 2005). The presence of Brook Trout was negatively related to the presence of WCT in the St. Maries River basin. Brook Trout likely displaced WCT from Alder and Crystal creeks, where WCT were once the dominant salmonid species (Apperson et al. 1988). Shepard (2004) suggested that certain habitat characteristics may influence Brook Trout invasion and their displacement of WCT. Shepard (2004) found that Brook Trout invasion and displacement of WCT was influenced by water temperature, pool frequency, and erosion and deposition of fine sediments. Support for Shepard’s (2004) findings were observed in the St. Maries River basin. The presence of WCT in the St. Maries River basin were negatively related to the presence of Brook Trout, but also fine sediments and the pool to riffle ratio.

Westslope Cutthroat Trout appeared to be thriving in most tributaries that had suitable habitat, even though the St. Maries River basin has been negatively altered by land use practices. Westslope Cutthroat Trout abundances were low, or they were absent in some tributaries due to poor habitat conditions and (or) interactions with nonnative Brook Trout. On the contrary, the abundance of WCT in the St. Maries River basin was positively correlated with gradient, instream cover, and stream temperature, which are habitat characteristics that have been shown to be critical for the distribution and abundance of WCT in other portions of their distribution. The current study suggests that it is essential for streams to encompass habitat for all life stages of WCT. Positive relationships between WCT abundance and certain habitat characteristics (i.e., gradient, instream cover, temperature) indicate that suitable habitat exists in the watershed and more suitable habitat could be created and protected if land easements and restoration projects are implemented. Even though land use practices like forest clearcutting and agricultural use occur in the St. Maries River watershed, the effects can be mitigated by maintaining and protecting habitat that promotes the occurrence and abundance of WCT.

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Table 2.1. Large-scale and small-scale habitat variables for 68 stream reaches in 35 different tributaries of the St. Maries River. Variables were used as independent variables in candidate models (SD = standard deviation; min = minimum; max = maximum).

Variable	**Description**	**Mean**	**SD**	**Min**	**Max**
	Large-scale variables				
Elevation	Elevation (m) of the upstream end of the stream reach	891.10	94.34	671.00	1302.00
Gradient	Reach length divided by the elevation change (%)	1.75	1.38	0.14	7.30
Road Density	Kilometers of roads per square kilometer (km/km^2)	1.49	0.58	0.42	2.51
Land use	Cattle grazing, timberland, forest, thinned forest, private property, mineral extraction				
	Small-scale variables				
Runs	Proportion of reach area as run	0.30	0.17	0.00	0.73
Pool:Riffle	Mean pool to riffle ratio	1.73	2.79	0.00	12.65
Depth	Mean water depth (m)	0.26	0.13	0.06	0.62
CV.Depth	Mean CV of depth	25.58	13.85	4.48	68.26
Current Velocity	Mean current velocity (m/s)	0.26	0.17	0.02	0.89
CV.Velocity	Mean CV of current velocity	28.84	14.16	3.47	70.71
Canopy Cover	Mean canopy cover (%)	65.41	19.56	17.18	98.10
CV.Canopy Cover	Mean CV of canopy cover	25.06	14.16	4.29	70.71
Substrate$_{Fine}$	Proportion of substrate that is silt or sand	0.22	0.24	0.00	1.00
Substrate$_{Gravel}$	Proportion of substrate that is gravel or coarse gravel	0.66	0.40	0.02	1.00
Substrate$_{Large}$	Proportion of substrate that is cobble or boulder	0.90	0.40	0.00	1.00
Embeddedness	Proportion of substrate that is covered in silt or sand	0.31	0.17	0.00	0.73
Total Cover Area	Mean sum of the area of all instream cover in a reach (m^2)	50.06	43.79	0.00	203.03
Temperature	Mean stream temperature at time of sampling (°C)	13.72	3.20	7.03	23.50
Distance to Road	Distance to the nearest road (m)	316.06	532.83	3.58	3096.42
BKT Presence	Percentage of reaches where Brook Trout occurred	29.00	46.00	0.00	100.00
Proportion Cover	Proportion of reach with instream cover	0.16	0.13	0.00	0.51

Table 2.2. The top logistic regression models investigating the presence-absence and relative abundance catch-per-unit-effort ([CPUE] = fish/minute of electrofishing) of age-0 Westslope Cutthroat Trout at multiple spatial scales based on habitat assessments. Habitat assessments were conducted in reaches (n = 68) of 35 different tributaries in the St. Maries River basin in 2017 and 2018 (variables are defined in Table 2.1). Akaike's Information Criterion adjusted for small sample size (AIC_c) was used to rank the candidate models. Delta AIC_c was the difference between given model and the top model. Only candidate models within 2.00 AIC_c values were considered as a top model (Burnham and Anderson 2002). The total number of parameters (K) and model weight (w_i) are included. McFadden's pseudo-R^2 was used to evaluate model fit, and the direction of effect for each covariate is indicated ([+] positive, [–] negative).

Response variable	**Model parameters**	**AIC_c**	**ΔAIC_c**	**K**	**w_i**	**R^2**
	Large-scale models					
Presence-absence	+ Gradient	92.10	0.00	2	0.31	0.76
	+ Gradient – Road Density	93.20	1.06	3	0.18	0.76
	+ Gradient + Elevation	93.60	1.44	3	0.15	0.76
	Small-scale models					
	– BKT Presence – Depth – $Substrate_{Fine}$	83.40	0.00	4	0.58	0.79
	– BKT Presence – $Substrate_{Fine}$	84.90	0.38	3	0.28	0.78
	Large-scale models					
Relative abundance	+ Road Density	199.20	0.00	3	0.28	0.01
	– Elevation	199.20	0.01	3	0.28	0.01
	+ Gradient	200.70	1.54	3	0.13	0.00
	Small-scale models					
	– Depth + Temperature	193.20	0.00	4	0.20	0.05
	+ Temperature	193.20	0.05	3	0.19	0.04
	– Depth + Temperature + Proportion Cover	194.70	1.53	5	0.09	0.06
	+ Temperature + Proportion Cover	194.80	1.57	4	0.09	0.05
	– Canopy Cover + Temperature	195.10	1.89	4	0.08	0.05
	– Depth	195.20	1.97	3	0.08	0.03

Table 2.3. The top logistic regression models investigating the presence-absence and relative abundance catch-per-unit-effort ([CPUE] = fish/minute of electrofishing) of age-1 and older Westslope Cutthroat Trout at multiple spatial scales based on habitat assessments. Habitat assessments were conducted in reaches (*n* = 68) of 35 different tributaries in the St. Maries River basin in 2017 and 2018 (variables are defined in Table 2.1). Akaike's Information Criterion adjusted for small sample size (AIC_c) was used to rank the candidate models. Delta AIC_c was the difference between given model and the top model. Only candidate models within 2.00 AIC_c values were considered as a top model (Burnham and Anderson 2002). The total number of parameters (*K*) and model weight (w_i) are included. McFadden's pseudo-R^2 was used to evaluate model fit, and the direction of effect for each covariate is indicated ([+] positive, [–] negative).

Response variable	**Model parameters**	**AIC_c**	**ΔAIC_c**	***K***	**w_i**	**R^2**
	Large-scale models					
Presence-absence	+ Gradient – Road Density	52.00	0.00	3	0.60	0.39
	+ Elevation + Gradient – Road Density	53.40	1.39	4	0.30	0.40
	Small-scale models					
	+ Proportion Cover + Canopy Cover – $Substrate_{Fine}$	60.30	0.00	4	0.30	0.30
	+ Proportion Cover + Canopy Cover + Current Velocity	60.30	0.03	4	0.30	0.30
	– BKT Presence – Depth – $Substrate_{Fine}$	62.00	1.67	4	0.13	0.28
	+ Canopy Cover – Pool:Riffle – $Substrate_{Fine}$	62.00	1.70	4	0.13	0.28
	Large-scale models					
Relative abundance	+ Gradient	350.70	0.00	3	0.43	0.05
	+ Gradient – Elevation	351.80	1.09	4	0.25	0.05
	+ Gradient + Road Density	352.50	1.83	4	0.17	0.05
	Small-scale models					
	– Depth + Temperature + Proportion cover	355.20	0.00	5	0.29	0.05
	– Depth	357.00	1.80	3	0.12	0.03

Table 2.4. Sum of AIC weights and direction of relationship for each independent variable in the top logistic regression models. High values (e.g., ≥ 0.50) suggest that a variable is important to that life stage.

Response variable	**Independent variable**	***w***
Age-0 presence-absence	$Substrate_{Fine}$	(–) **0.86**
	BKT presence	(–) **0.86**
	Gradient	(+) **0.64**
	Depth	(–) **0.58**
	Road density	(–) 0.18
	Elevation	(+) 0.15
Age-0 relative abundance	Temperature	(+) **0.65**
	Depth	(–) 0.37
	Road density	(+) 0.28
	Elevation	(–) 0.28
	Proportion cover	(+) 0.18
	Gradient	(+) 0.13
	Canopy cover	(–) 0.08
Age-1 and older presence-absence	Gradient	(+) **0.90**
	Road density	(–) **0.90**
	Canopy cover	(+) **0.73**
	Proportion cover	(+) **0.60**
	$Substrate_{Fine}$	(–) **0.56**
	Current velocity	(+) 0.30
	BKT presence	(–) 0.13
	Depth	(–) 0.13
	Pool: riffle	(–) 0.13
Age-1 and older relative abundance	Gradient	(+) **0.85**
	Depth	(–) 0.41
	Proportion cover	(+) 0.29
	Temperature	(+) 0.29
	Elevation	(–) 0.25
	Road density	(+) 0.17

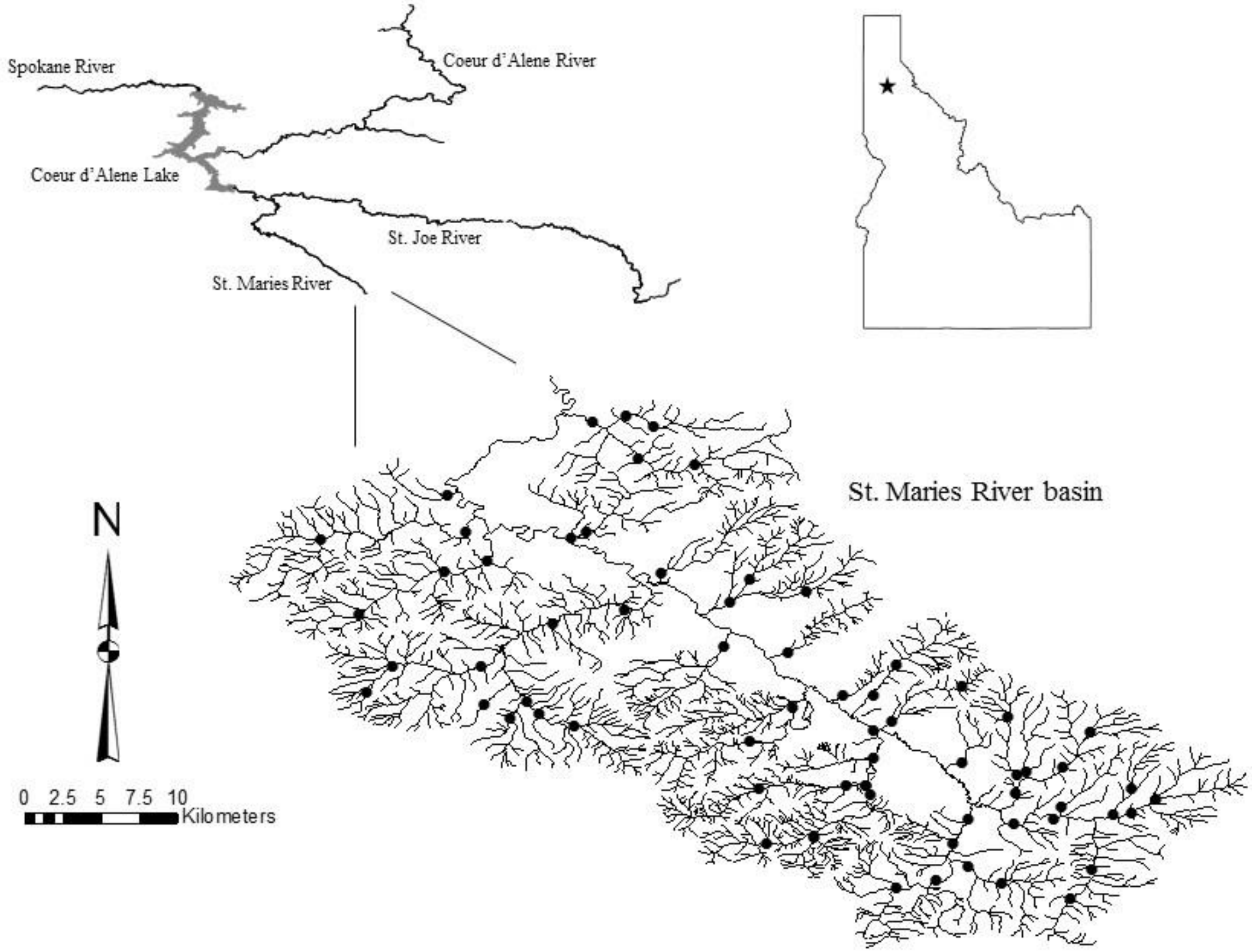

Figure 2.1. Tributary sites where habitat assessments were conducted in 2017 and 2018 in the St. Maries River basin, Idaho, are symbolized by black circles.

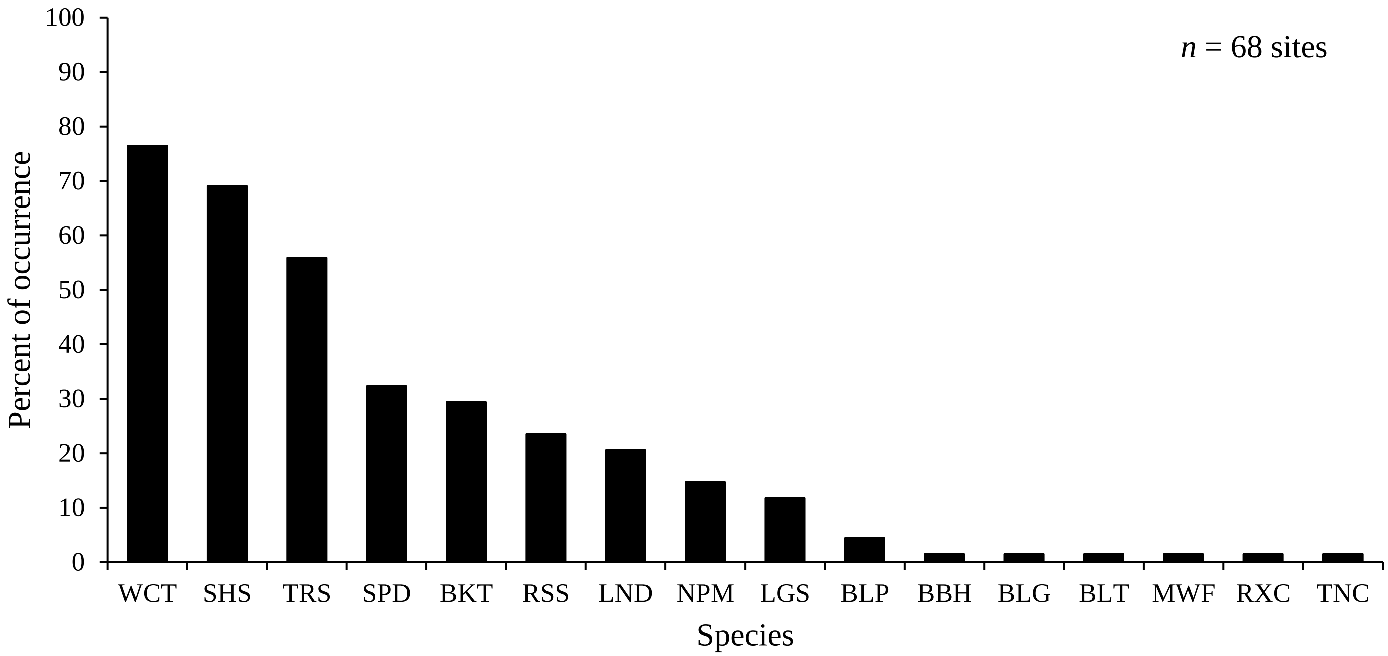

Figure 2.2. The percentage of species occurrence in tributary reaches of the St. Maries River. Species codes represent Westslope Cutthroat Trout (WCT), Shorthead Sculpin (SHS), Torrent Sculpin (TRS), Speckled Dace (SPD), Brook Trout (BKT), Redside Shiner (RSS), Longnose Dace (LND), Northern Pikeminnow (NPM), Largescale Sucker (LGS), Bridgelip Sucker (BLP), Brown Bullhead Catfish (BBH), Bluegill (BLG), Bull Trout (BLT), Mountain Whitefish (MWF), Rainbow Trout/Cutthroat Trout hybrid (RXC), and Tench (TNC).

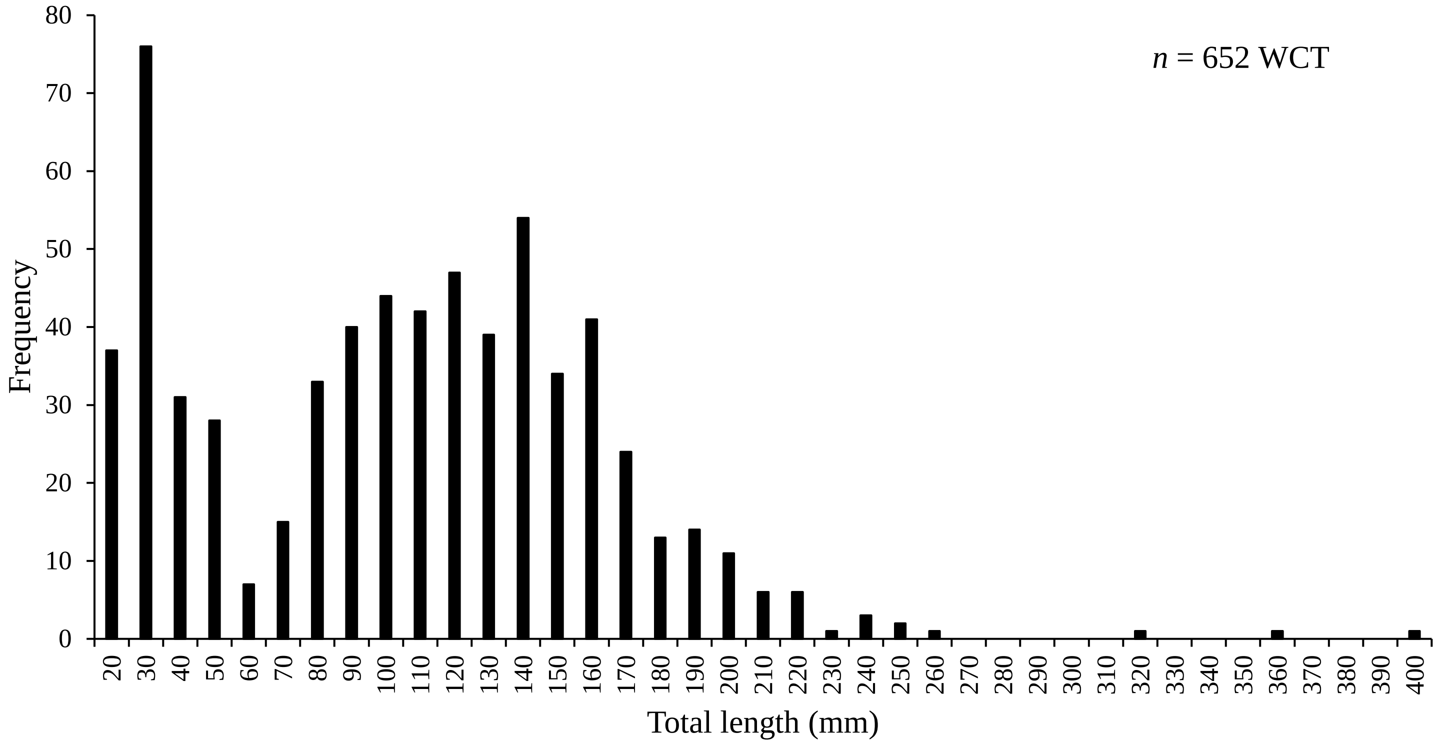

Figure 2.3. Length frequency distribution of Westslope Cutthroat Trout caught in tributaries of the St. Maries River, 2017–2018.

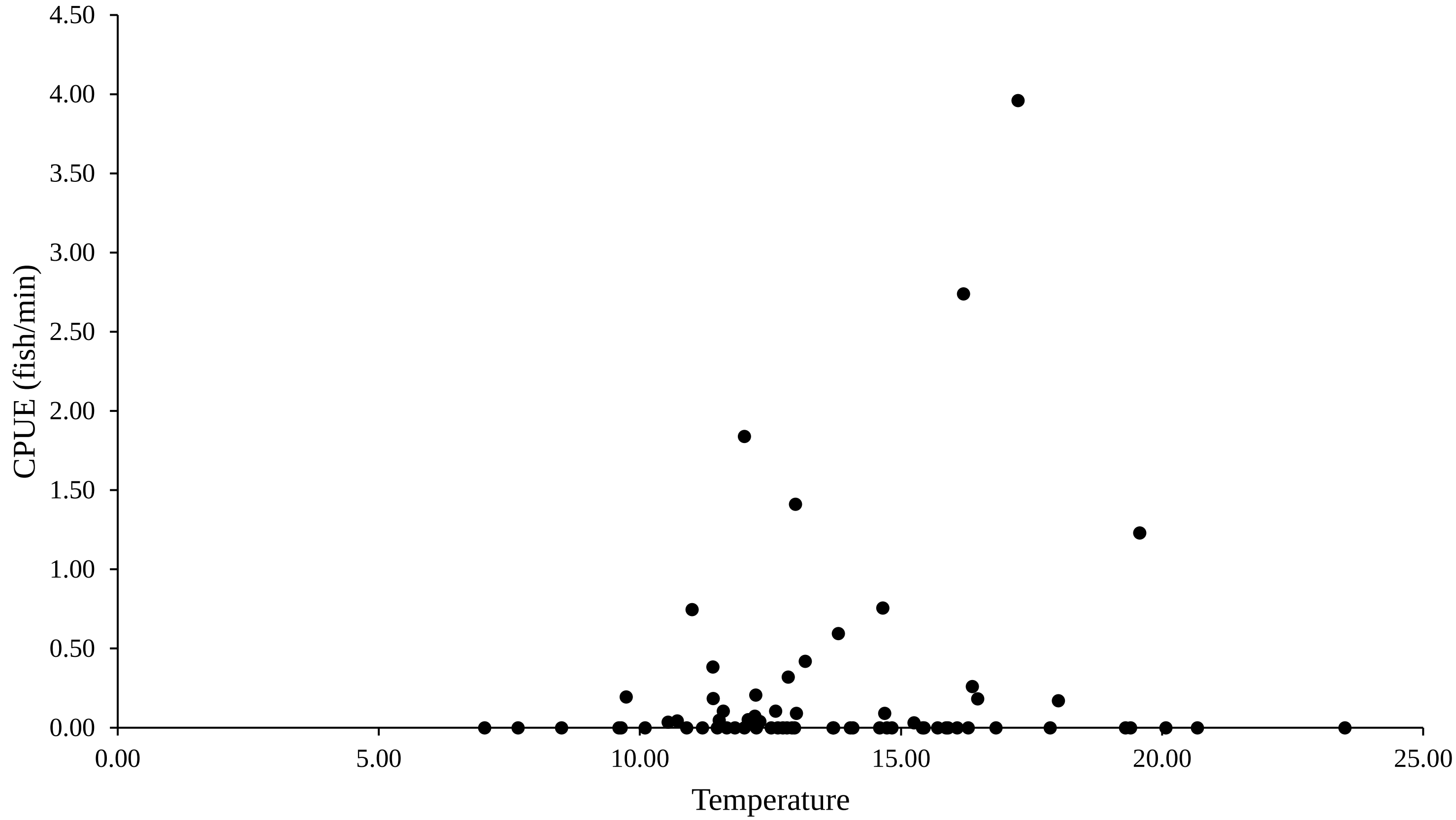

Figure 2.4. The relationship between water temperature (°C) point estimates taken prior to electrofishing to catch rates ([CPUE] = fish/minute of electrofishing) of age-0 Westslope Cutthroat Trout.

Chapter 3: Life History Structure of Westslope Cutthroat Trout in the St. Maries River Basin: Inferences from Otolith Microchemistry

Abstract

Migratory and nonmigratory life history forms of Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) have been observed in the St. Joe, Coeur d'Alene, and St. Maries river watersheds of Idaho, and in direct tributaries of Coeur d'Alene Lake. However, the population structure of WCT in the St. Maries River basin, and whether adfluvial WCT use the St. Maries River basin and contribute to the Coeur d'Alene Lake WCT population is unknown. Otolith microchemistry has emerged as a powerful tool for evaluating the life histories of fishes and the subsequent life history diversity in fish populations. The goals of this research were to use strontium isotopes (i.e., $^{87}Sr/^{86}Sr$) derived from ambient water and sagittal otoliths to assess spatial variability throughout the Coeur d'Alene Lake watershed and its sub-basins, and describe the life history structure of WCT in the St. Maries River basin using otolith microchemistry. Water samples (n = 49) were collected throughout the Coeur d'Alene Lake basin and analyzed for Sr isotopes. Westslope Cutthroat Trout (n = 525) were collected from the St. Maries River basin and Coeur d'Alene Lake (n = 46) and analyzed for Sr isotopes. Kruskal-Wallis tests were conducted to compare watersheds in the Coeur d'Alene Lake basin and to compare tributaries in the St. Maries River watershed. Strontium isotope ratios differed significantly among watersheds (P < 0.01) in the Coeur d'Alene Lake basin and among tributaries (P < 0.01) in the St. Maries River watershed. Model-based discriminant function analysis was used to assign WCT to natal tributaries (81% accuracy) in the St. Maries River basin and to infer maternal origins (73% accuracy) from WCT caught in

tributaries of the St. Maries River basin. Life history structure was inferred from maternal signatures and indicated that fluvial (68% of all fish), resident (27%), and adfluvial (5%) life history strategies were present in the St. Maries River basin. The current study demonstrates that it is possible to assess the population structure of WCT in the St. Maries River basin using otolith microchemistry. The life history diversity of WCT in the St. Maries River basin supports a broad distribution of the species and further suggests that there is connectivity from tributaries to the St. Maries River, to Coeur d'Alene Lake, and production of all life history strategies is occurring in the watershed.

Introduction

Linking fish movement patterns to landscape and aquatic habitat has long been an important challenge in fisheries science (Schlosser 1995; Fausch et al. 2002; Wells et al. 2003). Cutthroat Trout *Oncorhynchus clarkii* spp. are known to exhibit life history strategies involving migration (Bjornn and Mallet 1964; Liknes and Graham 1988; Varley and Gresswell 1988; Behnke 1992). Uncovering the migration history and movement patterns of Cutthroat Trout to understand the mechanisms responsible for migration has been studied for decades (Bjornn and Mallet 1964; Brown and Mackay 1995; Knight et al. 1999; Schmetterling 2001; Schoby and Keeley 2011; Young 2011; Muhlfeld et al. 2012). However, research that relied on radiotelemetry, tagging, trapping, and genetic markers lacked the ability to trace the life history of fishes over long time periods (i.e., the life of a fish). Otolith microchemistry has emerged as a powerful tool for evaluating the life histories of fishes and the subsequent life history diversity in fish populations (Campana and Thorrold 2001;

Kennedy et al. 2002; Wells et al. 2003; Barnett-Johnson et al. 2008; Muhlfeld et al. 2012; Benjamin et al. 2014).

Analyzing otoliths for trace elemental signatures has been used for inferring migration history, life history variation, maternal origins, stock assessment, and natal origins of freshwater and marine fishes (Campana 1999; Volk et al. 2000; Kennedy et al. 2002; Bacon et al. 2004; Barnett-Johnson et al. 2008; Muhlfeld et al. 2012; Paracheil et al. 2014). Isostructural to Ca, Sr replaces Ca in geological and biological structures. Therefore, relatively high concentrations of Sr, that reflect the geology of a drainage, are incorporated into the calcified otoliths of fish. In female fishes, ions are transferred from their blood plasma into eggs that are developing in their ovaries and are consequently inherited into the fluid of a yolk sac (Kalish 1990; Campana 1999; Volk et al. 2000; Campana and Thorrold 2001; Barnett-Johnson et al. 2008). Therefore, as otoliths develop prior to hatching they reflect the chemical signatures of the mother (Kalish 1990; Volk et a. 2000; Zimmerman et al. 2002; Munro et al. 2009; Zitek et al. 2013). Larval fish absorb the yolk sac and subsequently inherit the chemical signatures from its mother in its otoliths. If the mother lived in a different water chemistry than where the eggs hatch, then the larvae will retain the chemical signature of her previous location (Volk et al. 2000; Bacon et al. 2004). Accordingly, if the mother migrated from a location with a different chemical composition, then her offspring will inherit the chemical signatures of where she was prior to spawning. The transgenerational inheritance of stable isotopes is well established such that it has been used as a mass-marking tool for the offspring of female fishes (Thorrold et al. 2006; Zitek et al. 2013; Starrs et al. 2014). Chemical signatures from otoliths can then be used to assess the variability among and within watersheds, to evaluate maternal origins, natal origins, migration history, and assess life history structure of a population (Wells et al. 2003; Bacon et al. 2004; Pangle et al. 2010; Muhlfeld et al. 2012; Paracheil et al. 2014; Chase et al. 2015).

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) is a coldwater salmonid native to western North America (Behnke 2002; Shepard et al. 2005). In the Spokane River basin of northern Idaho, WCT are native upstream of Spokane Falls in Coeur d'Alene Lake and its tributaries (Behnke 1992). Westslope Cutthroat Trout occupy a variety of coldwater habitats varying from high-elevation, low-productivity, headwater streams to highly productive, large rivers (Rieman and Apperson 1989; Behnke 1992; Shepard et al. 2005; Sloat et al. 2005). Two major life history forms characterize the WCT subspecies: migratory (i.e., fluvial, adfluvial) and nonmigratory (i.e., resident; Behnke 1992; Northcote 1997; Schmetterling 2001; Muhlfeld et al. 2009). All life history strategies contain mobile life stages at some spatial and temporal scale. Furthermore, multiple life history strategies are often demonstrated in the same watershed (Bjornn and Mallet 1964; Behnke 1992; Gresswell et al. 1994). Because WCT can demonstrate multiple life history strategies in a single lotic-lentic system (Bjornn and Mallet 1964; Behnke 1992; Northcote 1997; Shepard et al. 2005; Muhlfeld et al. 2009), it is important to understand the population structure so that conservation and management actions are effective and efficient.

Life history strategies of WCT have been studied in the Coeur d'Alene Lake basin since 1961 when Averett (1962) investigated the age, growth, and behavior of migratory and nonmigratory WCT. Migratory and nonmigratory life history forms of WCT were further observed in the St. Joe, Coeur d'Alene, and St. Maries river watersheds, and in direct tributaries of Coeur d'Alene Lake (Averett 1962; Rankel 1971; Lukens 1978; Thurow and Bjornn 1978; Rieman and Apperson 1989; DuPont et al. 2004; Wells et al. 2004; Parametrix

2006). Additional Coeur d'Alene Lake tributaries were surveyed for adfluvial WCT presence; migratory and resident life history forms were observed in Wolf Lodge Creek (Lukens 1978) and in Benewah and Lake creeks on the Coeur d'Alene Indian Reservation (Firehammer 2012). Thurow and Bjornn (1978) concluded that there were both migratory and resident stocks of WCT in St. Joe River tributaries. Previous research that investigated the life history structure of WCT in the Coeur d'Alene Lake basin used tagging (Lukens 1978; Horton and Mahan 1987), radio telemetry (DuPont et al. 2004; Parametrix 2006; Firehammer et al. 2012), passive integrated transponder (PIT) tagging (Firehammer et al. 2012), netting (Averett 1962), and trapping (Lukens 1978; Horton and Mahan 1987; Apperson et al. 1988; Firehammer et al. 2012). Interestingly, one study investigated the validity of using hard-part chemistry to describe movements of WCT in the Coeur d'Alene River basin (Wells et al. 2003). Wells et al. (2003) found that otoliths could be used to describe movements of WCT through the Coeur d'Alene River basin due to heterogeneous geology and the stability of the water chemistry.

Although the St. Maries River has not been the focus of extensive research, nor is it annually monitored by the Idaho Department of Fish and Game (IDFG), there has been investigation into WCT migratory behavior in the St. Maries River basin. Distribution studies (Apperson et al. 1988; Horton and Mahan 1988) and radio telemetry (Parametrix 2006) have been used to evaluate WCT in the St. Maries River basin. Sample sizes in the radio telemetry study were small (n = 17 fish tagged in the lower St. Maries River) and tracking was limited, but migratory movement patterns were observed (Parametrix 2006). Notably, a higher proportion of fish tagged in the St. Maries River moved downstream and out of the system than fish tagged in the Coeur d'Alene and St. Joe rivers. Downstream movement patterns are an exhibition of fluvial and adfluvial migration behavior (Bjornn and Mallet 1964; Thurow and Bjornn 1978; Knight et al. 1999; Muhlfeld et al. 2009; Firehammer 2012; Campbell et al. 2018).

Previous research on WCT in the Coeur d'Alene Lake basin suggests that movement among lotic systems and between lotic-lentic environments contributed to a broad distribution and to the persistence of WCT populations. Where population linkages exist and the extent to which WCT use the Coeur d'Alene Lake basin at-large is mostly unknown. Furthermore, there is a knowledge gap pertaining to the WCT population structure in the St. Maries River basin, and whether adfluvial WCT use the St. Maries River basin and contribute to the population. Identifying locations that promote life history diversity in WCT populations is imperative for management decision making. The objectives of this research were to use strontium isotope ratios (i.e., $^{87}Sr/^{86}Sr$) derived from ambient water and sagittal otoliths to assess spatial variability throughout the Coeur d'Alene Lake watershed and its sub-basins, and describe the population structure of WCT in the St. Maries River basin.

Study Area

The Coeur d'Alene Lake basin is located in the panhandle of Idaho and drains an area of approximately 9,946 km^2 (Figure 3.1; Northwest Power 2005). The basin extends from the Bitterroot Divide along the Montana-Idaho border in the east to the outlet (i.e., Spokane River) of Coeur d'Alene Lake in the west. Elevations vary from 646 m at the lake to over 2,134 m along the Bitterroot Divide. Coeur d'Alene Lake is a glacially-formed, natural lake. The only outflow is the Spokane River, which is dammed at Post Falls, Idaho. Post Falls Dam is privately owned and operated by Avista Corporation. Approximately 27 tributaries flow into Coeur d'Alene Lake; the two principle tributaries are the Coeur d'Alene River and the St. Joe River. The Coeur d'Alene River drains an area of approximately 3,900 km^2 with around 75 major tributaries. The St. Joe River drains approximately 4,500 km^2 with about 75 tributaries. The St. Maries River is a sixth-order tributary of the St. Joe River that joins the St. Joe River about 25 km upstream from Coeur d'Alene Lake. The St. Maries River basin drains an area of approximately 1,800 km^2, extends into four counties (Benewah, Clearwater, Latah, and Shoshone), and is characterized by alluvial sedimentary deposits resulting from the formation of ancient Lake Clarkia (Ladderud et al. 2015). The St. Maries River contains around 26 major drainages. Elevations in the St. Maries River basin vary from approximately 670 m to 1,600 m, and the mainstem St. Maries River has a longitudinal elevation difference of 207 m. The Coeur d'Alene and St. Joe rivers support popular recreational fisheries for WCT, whereas the St. Maries River does not receive as much effort from anglers. A variety of native fishes occupy the St. Maries River basin, including Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi*, Mountain Whitefish *Prosopium williamsoni*, Northern Pikeminnow *Ptychocheilus oregonensis*, Longnose Dace *Rhinichthys cataractae,* Speckled Dace, *Rhinichthys osculus*, Redside Shiner *Richardsonius balteatus*, Bridgelip Sucker *Catostomus columbianus*, Largescale Sucker *Catostomus macrocheilus,* Shorthead Sculpin *Cottus confusus*, and Torrent Sculpin *Cottus rhotheus*. Additionally, nonnative fishes occupy the watershed, including Brook Trout *Salvelinus fontinalis*, Brown Bullhead *Ictalurus nebulosus*, Pumpkinseed *Lepomis gibbosus*, and Tench *Tinca tinca*.

Methods

Water sampling

In 2016 and 2017, water samples were collected throughout the Coeur d'Alene Lake basin and its sub-basins (i.e., Coeur d'Alene, St. Joe, St. Maries river basins; Figure 3.1) to characterize isotopic (i.e., $^{87}Sr/^{86}Sr$) variability within and among watersheds. Water samples were taken during baseflow periods at the downstream end of a sampling reach to characterize the interaction between water and geology. Vials (50 ml polypropylene), lids, and syringes (10 ml polypropylene) used for water sampling were acid-washed, rinsed with ultrapure water, air dried, and then stored in sterile Whirl Paks (Nasco, Fort Atkinson, Wisconsin). Water was filtered through 25 mm diameter, 2 µm nylon syringe filters (GE, Pittsburgh, Pennsylvania). Water samples were analyzed for $^{87}Sr/^{86}Sr$ isotope ratios using inductively coupled plasma mass spectrometry (ICP-MS) at the University of California-Davis Interdisciplinary Center for Plasma Mass Spectrometry (UC-Davis), and using thermal ionization mass spectrometry (TIMS) at the University of Idaho Kennedy LIFE Lab – TIMS Laboratory. Replicate analysis of the National Institute of Standards and Technology standard reference material (SRM-987) was used to standardize analytical equipment and estimate error.

Fish sampling

In 2016, backpack electrofishing was used to collect WCT from streams throughout the Coeur d'Alene Lake watershed and its sub-basins. Sites (n = 43) were predetermined and selected based on where previous research sampled WCT (Figure 3.1; Apperson et al. 1988; Wells et al. 2004; Ryan et al. 2013). An emphasis on collecting age-0 WCT and water samples were the focus in 2016 to assess isotopic variability and evaluate if otolith microchemistry could be used to infer life history structure of WCT caught in the Coeur d'Alene Lake watershed. Fishes were sampled in each reach using single-pass pulsed direct current (PDC) electrofishing (Model LR-24 Backpack Electrofisher; Smith Root, Inc., Vancouver, Washington; Simonson and Lyons 1995). For all backpack electrofishing, two netters each used a 6.4 mm mesh dip net to collect fishes. Seconds of electrofishing were recorded for each macrohabitat. Electrofishing continued in each stream until 10 age-0 WCT were caught. Westslope Cutthroat Trout were sacrificed, frozen, sagittal otoliths were extracted and prepared for microchemistry analysis in the lab, and age was estimated. In addition to collecting WCT, hook-and-line sampling was conducted on Coeur d'Alene Lake in 2016 (n = 4 sites) to collect kokanee *Oncorhynchus nerka*, which served as a surrogate when water samples were compared to otoliths.

Gill netting was conducted on Coeur d'Alene Lake in October 2017 to collect WCT from the lake and obtain a lake signature from WCT otoliths. Floating gill nets were 45 m long and 1.8 m deep. Each net consisted of 6 panels; each panel was 7.6 m long and designed from smallest to largest mesh size (i.e., 1.9, 2.5, 3.2, 3.8, 5.1, 6.4 cm bar-measure). Nets were set for a total of 134 net nights. All WCT caught were sacrificed, measured for total length (TL; mm), and weight was measured to the nearest tenth of a gram. Sagittal otoliths were extracted and transferred to the laboratory where they were prepared for microchemistry analysis, and age was estimated.

In 2017 and 2018, sampling was focused in the St. Maries River basin from March through August. The St. Maries River was sampled using drift boat electrofishing from March through May in 2017 and 2018. Electrofishing was conducted to collect WCT from the mainstem river, which were used to infer natal origins. Discharge data were obtained from the USGS gaging station (station number 12414900) on the St. Maries River near Santa, Idaho. Previous research suggests that WCT in the Coeur d'Alene Lake basin begin adfluvial spawning migrations in late March, peak in April, and conclude in May (Averett 1962; Lukens 1978; Apperson et al. 1988; Firehammer et al. 2012). The St. Maries River is approximately 76 km long from the mouth to the town of Clarkia where the Middle Fork St. Maries River and Merry Creek join. The St. Maries River was divided into three large sections based on access limitations. River sections were defined as the lower river, extending from the mouth upstream to the confluence with Santa Creek; the middle river, from the confluence with Santa Creek upstream to the town of Fernwood; and the upper river, from the town of Fernwood upstream to the confluence with Merry Creek.

The St. Maries River was further subdivided into 1 km reaches (n = 76) and sampling occurred in a 1-in-2 systematic design. A 1 km sampling reach was randomly selected from the first two 1 km reaches and sampling began at the upstream boundary of the respective reach. Each subsequent 1 km sampling reach was 1 km downstream from the previous reach, such that every other river kilometer was sampled in a section. Starting and ending points of sampling reaches were flagged and georeferenced with a handheld global positioning system (GPS; GPSMAP 64st; Garmin, Olathe, Kansas). Some reaches were sampled more than once in a field season. One section of river, approximately 22 km long, was not sampled due to unsafe whitewater conditions. In 2017, 58 reaches were sampled. In 2018, 34 reaches were sampled. Fewer reaches were sampled in 2018 due to large, woody obstructions that blocked the entire river and prevented boat passage.

Sampling the St. Maries River was accomplished by using a 4 m long, low-sided drift boat (Koffler Boats, Eugene, Oregon). Water temperature (°C) and conductivity (µS/cm) were taken prior to active electrofishing using a handheld probe (DiST, Hanna; Woonsocket, Rhode Island). Pulsed direct current power was provided by a 5000 W generator and standardized to 2,750-3,250 W based on water conductivity (Miranda 2009). Electricity was applied to the water using an Infinity model electrofisher (Midwest Lake Management, Inc., Polo, Missouri). Electrofishing began at the uppermost point of the sampling reach and proceeded in a downstream direction. One netter was positioned at the bow of the boat and used a 2.4 m long dip net with 6 mm bar knotless mesh. Although the focus was to collect WCT, all fishes were netted and placed into an aerated live well until the entire reach was sampled. All fishes were identified to species and measured for TL to the nearest mm. Up to 10 WCT per 10-mm length-group were sacrificed, sagittal otoliths were extracted and prepared for microchemistry analysis, and age was estimated. Weight was measured from sacrificed WCT to the nearest tenth of a gram. Minutes of active electrofishing were recorded for each reach and were used to calculate catch-per-unit-effort ([CPUE] = fish/minute of electrofishing).

Fishes were sampled from tributaries in the St. Maries River basin in 2017 and 2018 in conjunction with habitat assessments (Figure 3.2). A stratified sampling design was used to select the locations of sampling reaches. Tributaries of the St. Maries River were considered strata and reaches were randomly selected in each stratum. Reaches varied in length based on the average wetted stream width (Lyons 1992; Simonson 1995) and were selected using a random point generator in ArcMap version 10.5.1 (Esri, Redlands, California). In 2017, sampling was conducted from May–August on 44 reaches in 33 different tributaries. In 2018, sampling was conducted from June–August on 24 reaches in 20 different tributaries. Water temperature (°C) and conductivity (µS/cm) were taken prior to electrofishing using a handheld probe (DiST, Hanna; Woonsocket, RI). Fishes were sampled in each reach using single-pass PDC electrofishing (Model LR-24 Backpack Electrofisher; Smith Root, Inc., Vancouver, Washington; Simonson and Lyons 1995). For all backpack electrofishing, two netters each used a 6.4 mm mesh dip net to collect fishes. Seconds of electrofishing were recorded for each macrohabitat and were used to calculate catch-per-unit-effort ([CPUE] = fish/minute of electrofishing). All fishes were identified to species and measured for TL to the nearest mm. The abundance of WCT was variable among reaches, therefore a subsample between 5 and 10 WCT per reach were sacrificed, sagittal otoliths were extracted and prepared for microchemistry analysis, and age was estimated. Weight was measured on sacrificed WCT to the nearest tenth of a gram.

Large-scale habitat characteristics (i.e., gradient, elevation, road density, stream order, land use, geology) were estimated at the basin-level using ArcMap and Terrain Navigator Pro (Version 9.1, MyTopo; Billings, Montana; Meyer et al. 2003; Sindt et al. 2012). Elevation, gradient, and stream order were estimated from USGS Topographic Maps at 1:24,000 scale using Terrain Navigator Pro. The distance (m) between the two contour lines that bounded the sampling reach was traced. Gradient was calculated as the elevational increment (12.192 meters) between those two contour lines divided by the traced distance (Meyer et al. 2003). Distance to road (m), road density, and geology were estimated using ArcMap. Road density was calculated as kilometers of roads per square kilometer (km/km^2; Vadal and Quinn 2011). Geology was determined from the USGS mineral resources Idaho geologic map geospatial dataset (ArcMap 10.5.1, Redlands, California). Dominant land use was determined in the field and categorized as timberland, land that had recently been or was currently being clear cut for timber; mineral, land that was managed and used for mineral extraction; private property, residential homes or summer camps; cattle-grazed, land where cattle grazing was occurring; forest, land that did not have noticeable effects from timber harvest; and thinned forest, forests that were not clear cut, but had some timber harvested. All instream cover at least 0.3 m in length and in water 0.2 m deep or greater was quantified by taking one length measurement, three width measurements, and three depth measurements. Instream cover was classified as undercut bank, overhanging vegetation, branch complex, log complex, root wad, boulder, rip-rap, or aquatic vegetation (Quist et al. 2003).

Otolith preparation and analysis

After sagittal otoliths were extracted from WCT, otoliths were wiped clean of any tissue and stored dry in 1.5 mL polypropylene vials. One otolith per fish was mounted with the sulcus acusticus side facing up onto a microscope slide using Crystalbond 509-3 (Aremco, Valley Vintage, New York). Mounted otoliths were wet-sanded using ultrapure water on a Buehler MetaServ 250 (Buehler, Lake Bluff, Illinois) with 600-1200 grit silicon carbide sandpaper. Otoliths were sanded until daily growth increments from the primordium (i.e., prehatch region) to the dorsal and ventral edges were exposed (Thorrold et al. 1998; Hobbs et al. 2010; Chase et al. 2015). A compound microscope was used in conjunction while sanding to assess progress. Otoliths were then mounted onto petrographic slides with Crystalbond for laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICP-MS).

Otoliths were analyzed for Sr isotopes using LA-MC-ICP-MS at UC-Davis using a New Wave Research UP213 (Fremont, California) laser ablation system coupled with a Nu Plasma HR (Nu032; North Wales, United Kingdom) multiple-collection, high-resolution, double-focusing plasma mass spectrometer system. Line scans were ablated from the ventral edge, through the primordium, to the dorsal edge to generate a $^{87}Sr/^{86}Sr$ profile throughout the life of each fish. Lines scans were programmed from edge to edge because it provided more data per sample and isotopic shifts at the primordium were more distinguishable compared to programming scans from either the primordium to the edge or programming spot scans. The line scan distance (μm) from otolith edge to the primordium and total line scan distance were recorded. The measurement from otolith edge to the primordium was also used to estimate the location of the maternal signature at the primordium during data analysis (Kalish 1990; Volk et al. 2000; Zimmerman et al. 2002; Bacon et al. 2004). Settings for line scans included a scanning speed of 5 μm/s, beam width of 40 μm, laser pulse frequency of 10 Hz, and 60% laser power were used. Values for the $^{87}Sr/^{86}Sr$ isotope ratio were normalized for instrumental mass discrimination by monitoring the $^{86}Sr/^{88}Sr$ isotope ratio (assumed $^{86}Sr/^{88}Sr = 0.1194$). The interference of rubidium (^{87}Rb) on the $^{87}Sr/^{86}Sr$ isotope ratio was corrected by monitoring the ^{85}Rb signal. Instrumental accuracy and precision were evaluated by analyzing a White Seabass *Atractoscion nobilis* otolith before and after each sample slide of WCT otoliths. To compare analysis days, values for $^{87}Sr/^{86}Sr$ derived from WCT otoliths were normalized in each session based on the correction factor of the White Seabass otolith (mean $^{87}Sr/^{86}Sr$ = 0.709098, SD = 0.000075, n = 89) to the modern seawater value of $^{87}Sr/^{86}Sr$ (0.70918; McArthur et al. 2001).

Data analysis

Data reduction and analysis of WCT otoliths were conducted using the IsoFishR app in R Statistical Software (Willmes et al. 2018; R Core Development Team 2018). Data were reduced at an integration time of 0.2 s, blank time of 30 s, minimum ^{88}Sr value set to 0.2 V, and maximum ^{88}Sr set to 9.95 V. Data were smoothed to a ten-point moving average for visual inspection and outliers > 2 SD were removed (Chase et al. 2015). Data were further analyzed by manually selecting visible differences in heterogeneous samples (Figure 3.3) then summary statistics (i.e., mean, standard deviation) were calculated for each region (Willmes et al. 2018). Plots of reduced data were used to visually inspect each otolith and identify regions of maternal, natal, and stream signatures. The mean for two different regions (i.e., maternal, stream) were calculated for each otolith of WCT caught in St. Maries River tributaries. Means for three different regions (i.e., maternal, natal, stream) were calculated for each otolith of WCT caught in the St. Maries River. The maternal signature was estimated visually by referring to plots of reduced data in IsoFishR. To confirm that the maternal signature was at the primordium, the measurement that was recorded when line scans were programmed was referenced. Maternal signatures were derived from the area within the hatchmark at the primordium (Volk et al. 2000; Bacon et al. 2004). Natal signatures were estimated from the area immediately adjacent to the maternal signature where stable $^{87}Sr/^{86}Sr$ isotope ratios occurred (Barnett-Johnson et al. 2005). Due to variability in the ages of WCT and subsequently the sizes of otoliths, a standard distance from the primordium to where natal regions were derived was unavailable. Stream signatures were estimated from the dorsal and ventral edges of each otolith from regions that were stable in $^{87}Sr/^{86}Sr$ (Brennan et al. 2015). Otolith edges contained the area of most recent otolith growth and were assumed to represent the stream of capture. In addition to using $^{87}Sr/^{86}Sr$ isotope ratios, ^{88}Sr values (measured in volts) were also derived from the same regions of each otolith to further discriminate among locations. Therefore, each WCT otolith had unique values of $^{87}Sr/^{86}Sr$ and ^{88}Sr for each life stage.

Stream signatures derived from otoliths of all WCT collected per stream were pooled and summary statistics (i.e., mean, standard deviation, standard error) were calculated. Each stream was assigned a stream signature based on $^{87}Sr/^{86}Sr$ values from otoliths and was then compared to $^{87}Sr/^{86}Sr$ values from water samples. Linear regression was conducted to evaluate the relationship between ambient water and stream signatures derived from otoliths (Bath et al. 2000; Kennedy et al. 2000; Barnett-Johnson et al. 2008; Muhlfeld et al. 2012; Brennan et al. 2015). Normality tests were conducted to assess the variance structure of $^{87}Sr/^{86}Sr$ from water samples and showed that assumptions of normality were violated. Therefore, nonparametric Kruskal-Wallis and post-hoc pairwise comparisons tests ($\alpha = 0.05$) were conducted to compare $^{87}Sr/^{86}Sr$ from water samples among watersheds of the Coeur d'Alene Lake basin (Dunn 1964). The {dunn.test} package in R was used to conduct post hoc pairwise comparisons and *P*-values were adjusted for multiple comparisons by controlling the false discovery rate using the Benjamini-Hochberg (1995) adjustment. Model-based discriminant function analysis (DFA) was conducted using the {Mclust} package in R (Fraley and Raftery 2002; Scrucca et al. 2016) to determine whether $^{87}Sr/^{86}Sr$ and ^{88}Sr values from otoliths could assign WCT from the St. Maries River to natal streams and to infer the maternal origins of WCT caught in St. Maries River tributaries. The {Mclust} package provides alternatives to traditional linear discriminant function that assumed observations to be multivariate normal (Fraley and Raftery 2002). Discriminant analysis was based on Gaussian finite mixture modeling fitted by the expectation maximization (EM) algorithm that allowed for different covariance structures and different numbers of mixture components within groups. Stream signatures (i.e., $^{87}Sr/^{86}Sr$, ^{88}Sr) from known capture locations were used as the training data set, then natal and maternal signatures were used as test data to classify the unknown locations of maternal and natal signatures (Thorrold et al. 1998; Barnett-Johnson et al. 2008). The proportion of each life history strategy was estimated in tributaries. Maternal signatures were used to infer the population structure of WCT in St. Maries River tributaries and evaluate where production from adfluvial fish was occurring. Discriminant function models were further tested using K-folds cross validation to investigate classification accuracy (Fraley and Raftery 2002; Scrucca et al. 2016). Logistic regression was conducted to investigate the relationship between habitat characteristics (Table 3.2) and life history strategy (Hosmer and Lemeshow 1989). Life history strategy (i.e., resident, fluvial, adfluvial) was the categorical dependent variable and habitat characteristics served as independent variables. For all covariates that had a significant effect ($\alpha = 0.05$) on life history strategy, the predicted probabilities were plotted to further evaluate the covariate.

Results

Water sample ($n = 49$) $^{87}Sr/^{86}Sr$ signatures varied significantly among the basins of Coeur d’Alene Lake ($\chi^2 = 29.97$, df = 4, $P < 0.01$; Figure 3.5). Post-hoc pairwise comparisons indicated that water sample $^{87}Sr/^{86}Sr$ signatures from the St. Maries River basin were significantly different from the St. Joe River ($P < 0.01$) and Coeur d’Alene Lake ($P = 0.02$), but not from Coeur d’Alene Lake tributaries ($P = 0.58$) or tributaries in the Coeur d’Alene River basin ($P = 0.96$). In the St. Maries River basin, there was no significant difference in water sample $^{87}Sr/^{86}Sr$ signatures among reaches ($\chi^2 = 17$, df = 17, $P = 0.45$). The relationship between water sample $^{87}Sr/^{86}Sr$ signatures and otolith $^{87}Sr/^{86}Sr$ signatures were highly correlated ($r^2 = 0.98$; Figure 3.6; Table 3.1).

A total of 46 WCT ($n = 46$ for microchemistry analysis) was caught in Coeur d'Alene Lake and varied in TL from 190 to 480 mm and the average TL was 308 ± 73 mm (mean ± standard deviation [SD]). Ages of WCT caught in Coeur d'Alene Lake varied from 1 to 12 years. Westslope Cutthroat Trout were distributed throughout the St. Maries River basin at multiple spatial scales. In the mainstem of the St. Maries River, 92 reaches were sampled in 2017 and 2018. In total, 125 WCT ($n = 99$ for microchemistry analysis) were sampled from 55 reaches (60%) in the mainstem of the St. Maries River. Average TL of WCT caught in the St. Maries River was 297 ± 74 mm. The minimum TL of WCT caught in the St. Maries River was 151 mm and the maximum TL was 477 mm (Figure 3.4). Ages of WCT caught in the St. Maries River varied from 1 to 12 years. In tributaries of the St. Maries River basin, 652 WCT ($n = 418$ for microchemistry analysis) were sampled from 52 reaches (76%) out of 68 reaches in 35 different tributaries and ages varied from 0 to 5 years. Total length of WCT varied from 23 to 406 mm and averaged 110 ± 57 mm. Similar to water samples, $^{87}Sr/^{86}Sr$ stream signatures derived from otoliths were significantly different ($\chi^2 = 401.76$, df = 24, $P < 0.01$) among St. Maries River tributaries. Additionally, the isotope ^{88}Sr provided further discriminatory power among St. Maries River tributaries (Figure 3.7).

The training set of $^{87}Sr/^{86}Sr$ stream signatures from otoliths correctly assigned known origin WCT with 81% accuracy. Westslope Cutthroat Trout caught in the St. Maries River were assigned to a natal tributary in the St. Maries River basin (Figure 3.8). Although WCT were caught in all sections of the St. Maries River, most natal signatures (69%) were assigned to tributaries in the upper St. Maries River basin (i.e., upstream of Clarkia). A second set of training data that included the Coeur d'Alene Lake $^{87}Sr/^{86}Sr$ and ^{88}Sr signatures was used to estimate the maternal origins of WCT that were caught in tributaries and infer population structure. The DFA for estimating maternal origins was 73% accurate at correctly classifying known origin fish (Figure 3.9). Most (68%) maternal origins were estimated to originate in the St. Maries River basin from locations other than the tributary where the sampled fish was caught. Fish that did not assign to the stream where they were captured, or Coeur d'Alene Lake, were deemed to have a fluvial mother. Fish that had a maternal signature estimated to originate from the stream where they were captured (27%) were deemed to have a resident mother. A portion (5%) of maternal origins were estimated to originate from Coeur d'Alene Lake and these fish were deemed to have an adfluvial mother. To infer population structure, the proportion of each life history strategy was estimated in St. Maries River tributaries (Figure 3.10). Although the adfluvial life history strategy was estimated to be the smallest proportion in the watershed, adfluvial signatures were most prevalent in tributaries located in the northeast portion of the basin.

The distance (km) of a drainage to the mouth of the St. Maries River, stream order, and gradient had significant effects on whether a fish was fluvial or resident (Table 3.3). For example, as the distance from the mouth of the St. Maries River to a drainage increased the probability of a fish having a fluvial maternal signature also increased. No covariates had a significant effect on predicting whether a fish was adfluvial.

Discussion

Previous studies have used trace elements in otoliths to reconstruct the life histories of anadromous fishes (Kennedy et al. 2002; Hobbs et al. 2007; Barnett-Johnson et al. 2008; Hegg et al. 2013; Brennan et al. 2017) and using the technique in freshwater systems has become more prevalent (Wells et al. 2003; Pangle et al. 2010; Muhlfeld et al. 2012; Chase et al. 2015). Two such studies (Wells et al. 2003; Muhlfeld et al. 2012) investigated using trace elements to evaluate the validity of using otolith microchemistry in freshwater systems to determine the migratory behavior of WCT. Both investigations were able to discriminate locations where fish were sampled at multiple spatial scales based on heterogeneity in geology and stream water chemistry. Furthermore, microchemistry analyses conducted on otoliths showed that otoliths consistently represented water chemistry where they lived and that fish movements in freshwater could be inferred from changes in chemical signatures in otoliths. The current study expanded on previous WCT microchemistry research by using a larger sample size, inferring population structure from Sr isotopes in otoliths, investigating where production of various life history strategies occurred, and related life history strategy to habitat characteristics. In addition, results from the current study were not only investigative, but the motivation behind a large sample size at this spatial scale was to inform management decisions.

The relationship between $^{87}Sr/^{86}Sr$ from water samples and WCT otoliths was representative of the relationship between water and otoliths reported in previous studies (Kennedy et al. 2000; Barnett-Johnson et al. 2008; Muhlfeld et al. 2012; Brennan et al. 2015). Due to the high correlation between Sr isotopes in water and otoliths, we could discriminate spatially within and among watersheds using water or otolith samples. However, because there were similarities in the underlying geology in the Coeur d'Alene Lake basin, some watersheds (i.e., Coeur d'Alene, St. Maries rivers) exhibited similar $^{87}Sr/^{86}Sr$ stream signatures. Therefore, using Sr isotopes alone to discriminate among watersheds in the Coeur d'Alene Lake basin for the purpose of assigning lake-caught WCT to their natal origins could lead to high rates of misclassification. Referring to other elemental ratios (e.g., Mg/Ca, Ba/Ca; Wells et al. 2003; Hobbs et al. 2007; Macdonald et al. 2008; Clarke et al. 2015) in addition to Sr isotopes could provide better classification accuracy in Coeur d'Alene Lake sub-basins that had similar Sr isotope signatures.

Referring to the primordium region of otoliths to make inferences about maternal origins has predominately focused on anadromous fishes (Kalish 1990; Volk et al. 2000; Donohoe et al. 2008; Miller and Kent 2009; Hegg et al. 2018). Additionally, it has been suggested that maternal signatures may have some influence from spawning streams based on the extent of migration to spawning tributaries and the duration of spawning (Hegg et al. 2018). In the current study, substantial heterogeneity in Sr isotopes among tributaries, the mainstem of the St. Maries River, and Coeur d'Alene Lake provided enough spatial variability to infer the maternal origins of juvenile WCT in a freshwater system and characterize population structure at the drainage and watershed scales. Line scans ablated across the sagittal plane of otoliths revealed migration histories or residency of WCT throughout a freshwater system. Furthermore, line scans in the current study encompassed otolith growth from dorsal to ventral edge including the primordium, which provided more data at the primordium where the maternal signature was derived compared to line scans measured from the otolith core to the edge. Owing to the migratory behavior of some WCT, the characteristics of transgenerational inheritance of Sr into eggs (Kalish 1990; Volk et al.

2000; Thorrold et al. 2006; Zitek et al. 2013; Starrs et al. 2014), and heterogeneity in geology, we were able to delineate differences between maternal, natal, and stream regions of otoliths. Although some maternal signatures were assigned to Coeur d'Alene Lake, the proportion of adfluvial WCT using the St. Maries River basin is likely underestimated in this study. However, results from the current study support that it is possible to infer life history structure using maternal signatures of a freshwater salmonid in a heterogeneous environment using Sr isotopes.

Westslope Cutthroat Trout are known to exhibit multiple life history strategies in a single watershed (Bjornn and Mallet 1964; Behnke 1992; Northcote 1997; Shepard et al. 2005; Muhlfeld et al. 2009). Although the DFA did not assign WCT with 100% accuracy, patterns in life history structure at multiple spatial scales emerged and WCT in the St. Maries River basin displayed substantial life history diversity. Westslope Cutthroat Trout populations are often robust in headwater streams and the upper portions of watersheds (Shepard et al. 2005). In the St. Joe River, Thurow and Bjornn (1978) hypothesized that fluvial and resident life history strategies were more dominant farther upstream from Coeur d'Alene Lake. Our results corroborate these assertions. For example, most natal and maternal signatures were assigned to the upper portion of the basin near Clarkia, Idaho. This pattern suggests that the upper watershed may have adequate habitat throughout the year and can support all life stages of WCT. Furthermore, the results from logistic regression models indicated that the fluvial life history strategy was more probable as the distance from the mouth of the St. Maries River to a drainage increased. An additional indication that suitable habitat is present in the St. Maries River basin is evident by similar length structures of WCT sampled in the St. Maries River to WCT sampled in Coeur d'Alene Lake. The similarity in length structures suggests that habitat and food resources in the St. Maries River basin are such that WCT can achieve large body size. However, the inability of WCT to achieve greater sizes in Coeur d'Alene Lake than in the St. Maries River may indicate that abiotic or biotic factors in the lake are affecting the growth of WCT.

Home range size has been shown to average about 65 km and vary from 7 to 235 km in a fluvial WCT population (Schoby and Keeley 2011). Results from the current study indicated that adfluvial WCT influence in the St. Maries River basin is slight even though the distance from the mouth of the St. Maries River to Coeur d'Alene Lake is about 25 km. The distance from the mouth of the St. Maries River upstream to the first tributary (i.e., Flat Creek) where an adfluvial signature was detected was 34 km from the river mouth, a total distance of approximately 59 km from Coeur d'Alene Lake. About 86 km upstream from Coeur d'Alene Lake is Childs Creek, which was where the highest proportion (32%) of adfluvial maternal signatures were observed. An additional caveat to the maternal signature assignments from Childs Creek to Coeur d'Alene Lake is that 6% of samples were misclassified to Coeur d'Alene Lake instead of Childs Creek. However, the pattern of adfluvial fish production occurring in the tributary is still evident. Considering the potential home range size of WCT, the distance from Coeur d'Alene Lake to St. Maries River spawning tributaries falls within the home range size of what has been described for the species. Tributaries that drained the northeast portion of the St. Maries River basin contained the greatest number (n = 16) of adfluvial maternal signatures compared to tributaries in the upper (n = 4) and southwest (n = 2) regions of the basin. Results from logistic regression models did not indicate that habitat characteristics had a significant effect on predicting whether a fish would be adfluvial. There were no obvious patterns in habitat that were observed in tributaries with adfluvial signatures.

Heterogeneity in water chemistry among tributaries made it possible to infer population structure and expand on previous research (Wells et al. 2003; Muhlfeld et al. 2012) that used otolith microchemistry on WCT. Life history structure of WCT was characterized at multiple spatial scales using Sr isotopes obtained from sagittal otoliths. Migratory and nonmigratory life histories were evident when sagittal otoliths were analyzed from dorsal to ventral edges due to spatial variability in Sr isotopes. The current study provided methodology for analyzing sagittal otoliths for the purpose of understanding the life history and population structure of WCT at multiple spatial scales to inform management decisions. Although the current study used a large sample size at a broad scale and there were similarities in Sr isotopes among tributaries, discriminatory power was retained by using multiple Sr isotopes as markers for each location and each otolith signature. However, there are limitations with using ^{88}Sr as an indicator for stream location. Environmental factors (i.e., water temperature, underlying geology) and unreplicable laboratory conditions (i.e., LA-MC-ICP-MS calibration) can influence how ^{88}Sr is incorporated and analyzed in otoliths. In the current study, there was low variability in ^{88}Sr among samples collected from the same tributaries, but using ^{88}Sr as a unique identifier for stream location should be done with caution.

Life history diversity is important for population stability and hinges on connectivity to habitat that supports all life stages and strategies for a species (Northcote 1997; Rieman and Dunham 2000; Moore et al. 2014). In response to environmental variability, plasticity in life history can help maintain a population. Resident, fluvial, and adfluvial life history strategies were observed in the St. Maries River basin, which illustrates the importance of maintaining connectivity to multiple types of habitat to support a diverse population. The St. Maries watershed is an example of the importance of maintaining connectivity to support population viability in response to altered habitat. For example, habitat fragmentation in St. Maries River tributaries resulted from thermal barriers (i.e., water temperature) in late summer, but WCT could move through these barriers during spring to successfully spawn in headwaters and contribute to genetic diversity. The observed diversity in life history structure throughout the St. Maries River basin illustrates that large-scale connectivity exists and promotes population viability. The WCT population in the St. Maries watershed has persisted in response to environmental change and land use activities because of life history diversity and connectivity to suitable habitat. Although biotic interactions (e.g., Brook Trout) and poor habitat have decreased the abundance of WCT in some tributaries, the longevity and wide distribution of WCT in the St. Maries watershed has buffered the population from disappearing in this system. Local adaptations of WCT in response to environmental change in the St. Maries River basin has prompted life history diversity and contributed to population stability.

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Table 3.1. Locations where water samples and Westslope Cutthroat Trout samples were collected in 2016–2018 to obtain $^{87}Sr/^{86}Sr$ isotope ratios. Sample size (*n*) and the mean of all samples from each location were used to estimate the stream signature from the edge of otoliths. The standard error (SE) of the mean is included and the corresponding water sample $^{87}Sr/^{86}Sr$ signature from locations where water samples were taken.

Basin	**Stream**	***n***	**Otolith edge mean**	**SE**	**ICP-MS water sample**	**SE**	**TIMS water sample**	**SE**
Coeur d'Alene River	Independence Creek	5	0.724564	0.000845	—	—	—	—
	Jordan Creek	5	0.719905	0.000061	—	—	0.720103	0.000001
	Latour Creek	6	0.725269	0.000095	0.725300	0.000007	—	—
	Little N. F. Coeur d'Alene	3	0.723402	0.000162	0.724726	0.000007	—	—
	N. F. Coeur d'Alene$_{middle}$	0	—	—	0.722883	0.000004	0.722770	0.000002
	N. F. Coeur d'Alene$_{upper}$	0	—	—	0.723769	0.000007	—	—
	Shsoshone Creek	8	0.719292	0.000111	0.719626	0.000006	—	—
	Tepee Creek	5	0.721089	0.000077	0.720562	0.000010	—	—
Coeur d'Alene Lake	Coeur d'Alene Lake$_{north}$	10	0.735315[a]	0.000210	0.735190	0.000005	—	—
	Coeur d'Alene Lake$_{midnorth}$	8	0.735684[a]	0.000154	0.736064	0.000005	—	—
	Coeur d'Alene Lake$_{midsouth}$	5	0.735786[a]	0.000228	0.737254	0.000007	—	—
	Coeur d'Alene Lake$_{south}$	4	0.735411[a]	0.000421	0.738722	0.000005	0.738131	0.000001
	Coeur d'Alene Lake$_{WCT}$	46	0.731417[b]	0.000405	0.736660[c]	0.000647	—	—
	Beauty Creek	11	0.727452	0.000098	0.727712	0.000006	—	—
	Benewah Creek	8	0.714723	0.001390	—	—	—	—
	Bozard Creek	5	0.713784	0.000049	—	—	—	—
	Carlin Creek	12	0.727282	0.000058	0.727395	0.000005	—	—
	Cougar Creek	10	0.717506	0.000033	0.717942	0.000005	—	—
	E. F. Bozard Creek	1	0.714325	0.000000	—	—	—	—
	Lake Creek	7	0.718548	0.000123	0.713564	0.000007	0.713564	0.000002
	N. F. Mica Creek	5	0.716399	0.000031	—	—	0.716622	0.000002
	S. F. Mica Creek	9	0.713393	0.000046	0.713692	0.000005	—	—
	Wolf Lodge Creek	8	0.720998	0.000155	0.721143	0.000004	—	—
Total		181						

a = signatures derived from kokanee otoliths
b = signatures derived from WCT otoliths
c = average of water samples from Coeur d'Alene Lake

Table 3.1 continued

Basin	Stream	*n*	Otolith edge mean	SE	ICP-MS water sample	SE	TIMS water sample	SE
St. Maries River	Alder Creek	4	0.714392	0.000368	0.717353	0.000006	0.717315	0.000002
	Beaver Creek	1	0.719673	0.000000	—	—	—	—
	Blair Creek	3	0.725045	0.000316	—	—	—	—
	Canyon Creek	40	0.708708	0.000093	0.709610	0.000005	—	—
	Carlin Creek	22	0.712493	0.000035	—	—	0.712642	0.000001
	Carpenter Creek	4	0.733041	0.000123	—	—	—	—
	Cat Spur Creek	25	0.720544	0.000218	—	—	0.720047	0.000005
	Charlie Creek	1	0.725980	0.000000	—	—	0.726402	0.000007
	Childs Creek	34	0.733907	0.000612	—	—	0.736991	0.000002
	Corbett Creek	11	0.728216	0.000441	—	—	—	—
	Crystal Creek	1	0.733190	0.000000	—	—	—	—
	Davis Creek	4	0.738873	0.000198	—	—	—	—
	E. F. Charlie Creek	2	0.729569	0.000260	—	—	0.730793	0.000002
	E. F. Emerald Creek	9	0.722910	0.001348	—	—	0.724074	0.000001
	Flat Creek	26	0.708836	0.000432	—	—	0.708490	0.000002
	Flewsie Creek	15	0.720479	0.000141	—	—	—	—
	Gold Center Creek	7	0.719549	0.000259	—	—	—	—
	Gramp Creek	5	0.728865	0.000789	—	—	—	—
	Hume Creek	14	0.720137	0.000541	—	—	0.723686	0.000002
	John Creek	2	0.712608	0.000029	—	—	—	—
	Little E. F. Emerald Creek	5	0.723929	0.000762	—	—	—	—
	Merry Creek	25	0.730248	0.000298	—	—	—	—
	Middle Fork St. Maries River	26	0.723253	0.000215	—	—	0.722219	0.000004
	Olson Creek	12	0.735347	0.000578	—	—	—	—
	Renfro Creek	15	0.742896	0.002008	—	—	0.753555	0.000002
	S. F. Santa Creek	17	0.713752	0.000043	—	—	0.714395	0.000002
	St. Maries River$_{lower}$	1	0.722388	0.000000	0.725588	0.000006	0.725653	0.000002
	St. Maries River$_{middle}$	22	0.725302	0.001049	0.727726	0.000005	—	—
	St. Maries River$_{upper}$	76	0.723402	0.000308	—	—	0.723966	0.000001

Table 3.1 continued

Basin	Stream	*n*	Otolith edge mean	SE	ICP-MS water sample	SE	TIMS water sample	SE
St. Maries River	Thorn Creek	34	0.709237	0.000047	0.709020	0.000005	—	—
	W. F. Emerald Creek	10	0.728447	0.000923	—	—	0.731750	0.000005
	W. F. Merry Creek	21	0.735754	0.000302	—	—	0.736095	0.000002
	W. F. St. Maries River	31	0.714128	0.000241	—	—	0.715369	0.000001
St. Joe River	Big Creek	5	0.733402	0.000158	0.727195	0.000009	—	—
	Bluff Creek	5	0.755894	0.001280	—	—	0.759718	0.000002
	Gold Creek	5	0.765027	0.001232	—	—	0.769090	0.000002
	Hugus Creek	4	0.738430	0.000231	0.738867	0.000006	—	—
	Marble Creek	10	0.728023	0.000193	0.728498	0.000005	—	—
	N. F. St. Joe River	7	0.743110	0.000428	0.745328	0.000006	—	—
	St. Joe River$_{lower}$	5	0.762304	0.000621	0.766226	0.000006	0.766495	0.000002
	St. Joe River$_{middle}$	5	0.760460	0.000489	0.766300	0.000012	—	—
	St. Joe River$_{upper}$	10	0.760288	0.000761	0.764536	0.000005	—	—
	St. Joe River$_{headwaters}$	11	0.758252	0.002008	0.757916	0.000007	—	—
Total		592						

Table 3.2. Habitat variables for 68 stream reaches in 35 different tributaries of the St. Maries River collected in 2017–2018. Variables were used as independent variables in logistic regression models to investigate the relationship between habitat characteristics and Westslope Cutthroat Trout life history strategy (SD = standard deviation; min = minimum; max = maximum).

Variable	**Description**	**Mean**	**SD**	**Min**	**Max**
Elevation	Elevation (m) of the upstream end of the stream reach	891.10	94.34	671.00	1302.00
Gradient	Reach length divided by the elevation change (%)	2.30	1.40	0.39	7.30
Road Density	Kilometers of roads per square kilometer (km/km^2)	1.42	0.56	0.42	2.51
Distance to road	Distance to the nearest road (m)	308.64	529.28	3.58	3096.42
Temperature	Mean stream temperature (°C)	13.45	2.52	7.03	19.58
Proportion Cover	Proportion of reach with instream cover	0.23	0.15	0.00	0.51
BKT Presence	Percentage of reaches where Brook Trout occurred	29.00	46.00	0.00	100.00
Stream order	Strahler (1964) stream order	4.00	1.12	1.00	5.00
Land use	Grazing, mineral, private, thinned forest, timberland				
Geology	Basalt, meta-argillite, mica-schist, siltstone				

Table 3.3. Habitat variables for 68 stream reaches in 35 different tributaries of the St. Maries River collected in 2017–2018 to investigate the relationship between habitat characteristics and Westslope Cutthroat Trout life history strategy. Variables that had a significant (α = 0.05) effect on life history strategy responses (SE = standard error). Coefficient estimates are the log odds of the response variable. For example, for a one-unit increase in river kilometer distance from the mouth of the St. Maries River, the log odds of a fish being resident decreases by 0.11.

Variable	**Coefficient estimate**	**SE**	***P* value**
	Resident response		
River km	-0.11	0.02	< 0.01
Stream order	-0.50	0.23	0.03
Gradient	-0.52	0.16	< 0.01
	Fluvial response		
River km	0.09	0.02	< 0.01
Stream order	0.52	0.20	0.01
Gradient	0.45	0.14	< 0.01

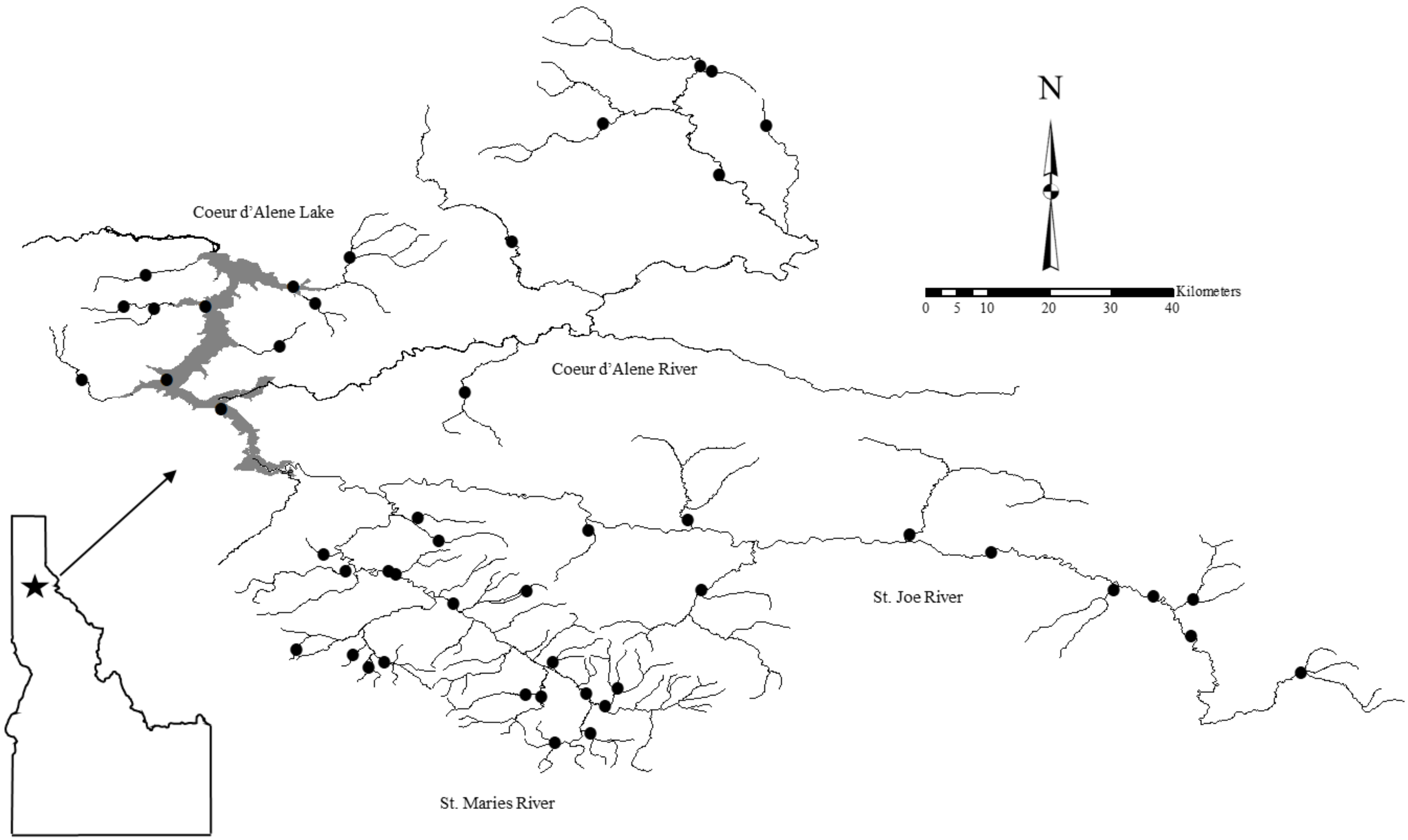

Figure 3.1. Locations where water samples and age-0 Westslope Cutthroat Trout were collected in 2016 and 2017 are symbolized by black circles.

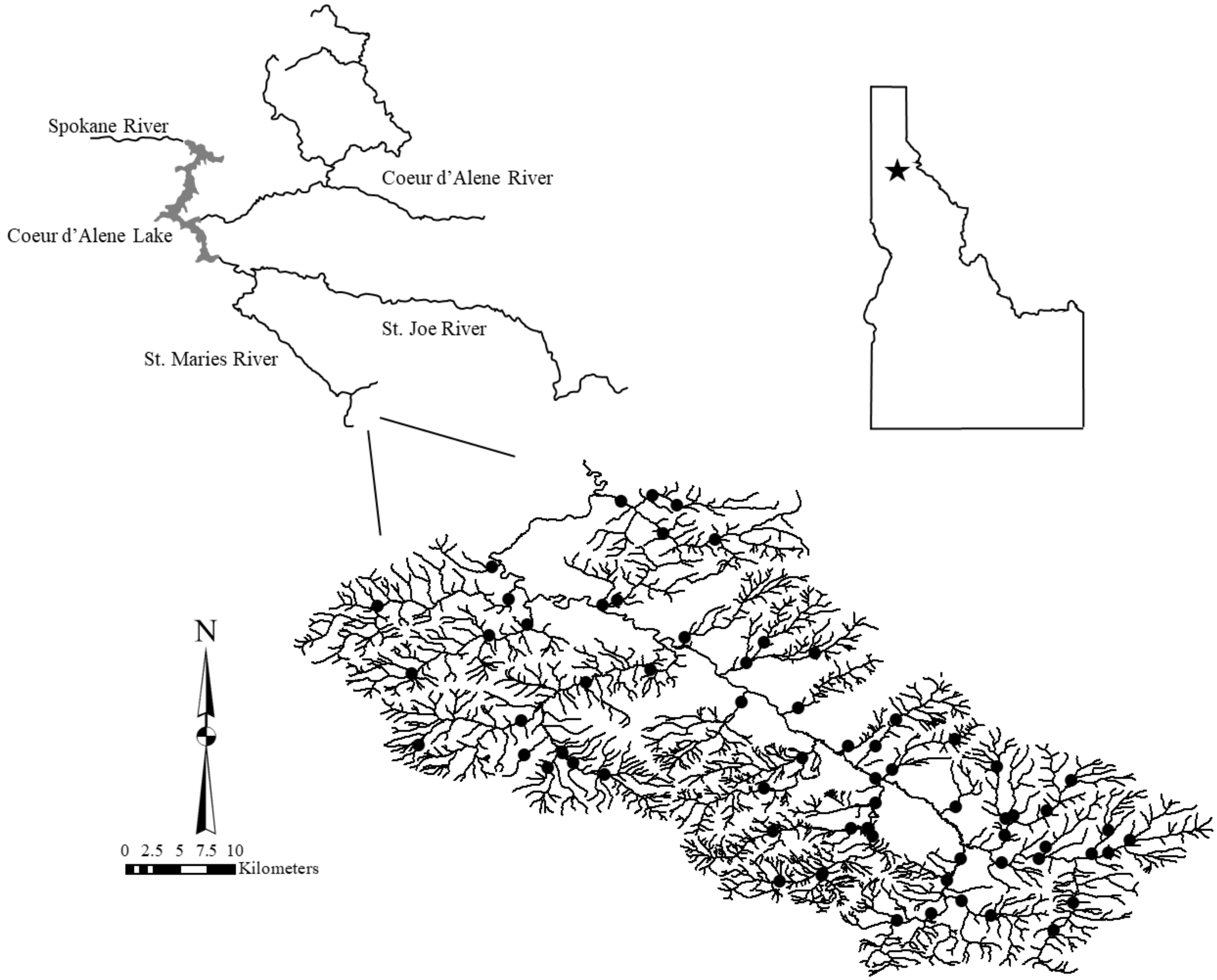

Figure 3.2. Tributary sites where sampling was conducted in 2017 and 2018 in the St. Maries River basin are symbolized by black circles.

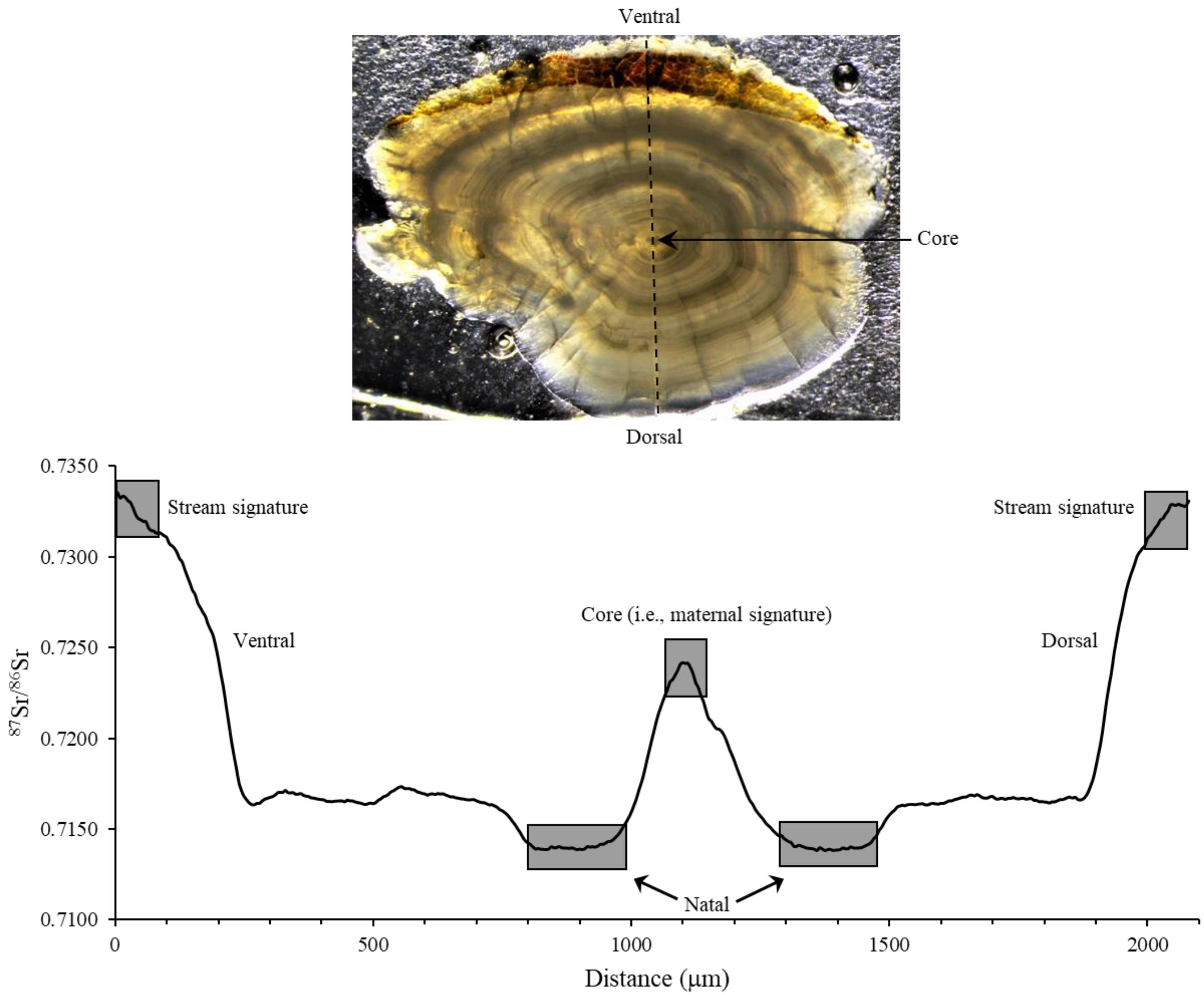

Figure 3.3. Digital image of a sagittal otolith from a Westslope Cutthroat Trout with line scan (dashed line) from laser ablation and the corresponding output of reduced data as a line plot. Regions of the reduced data that were used for maternal, natal, and stream signatures are highlighted in gray boxes.

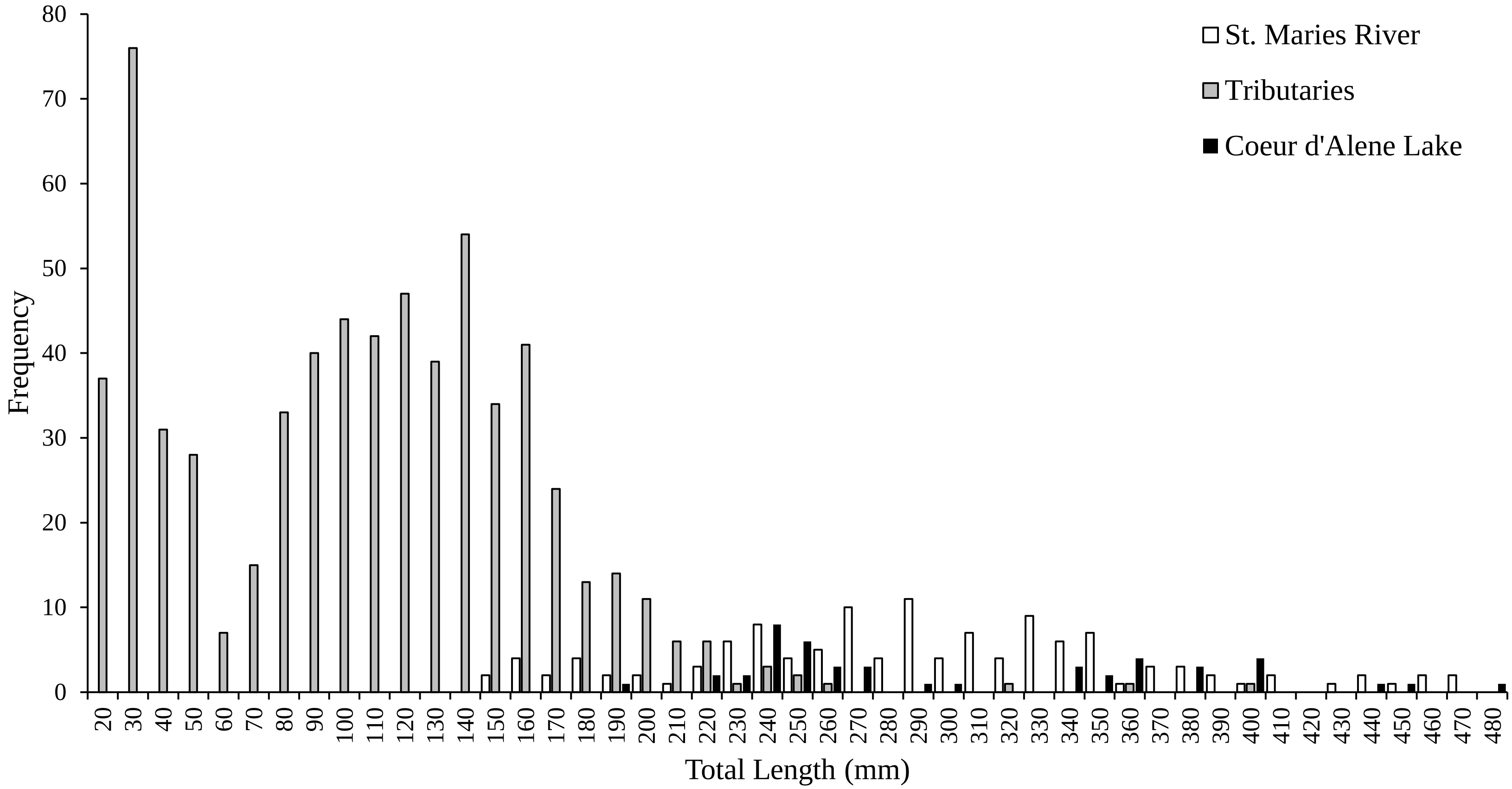

Figure 3.4. Comparison of the distribution of length frequencies of Westslope Cutthroat Trout sampled in the mainstem (n = 99) of the St. Maries River, tributaries (n = 418) of the St. Maries River, and Coeur d’Alene Lake (n = 46).

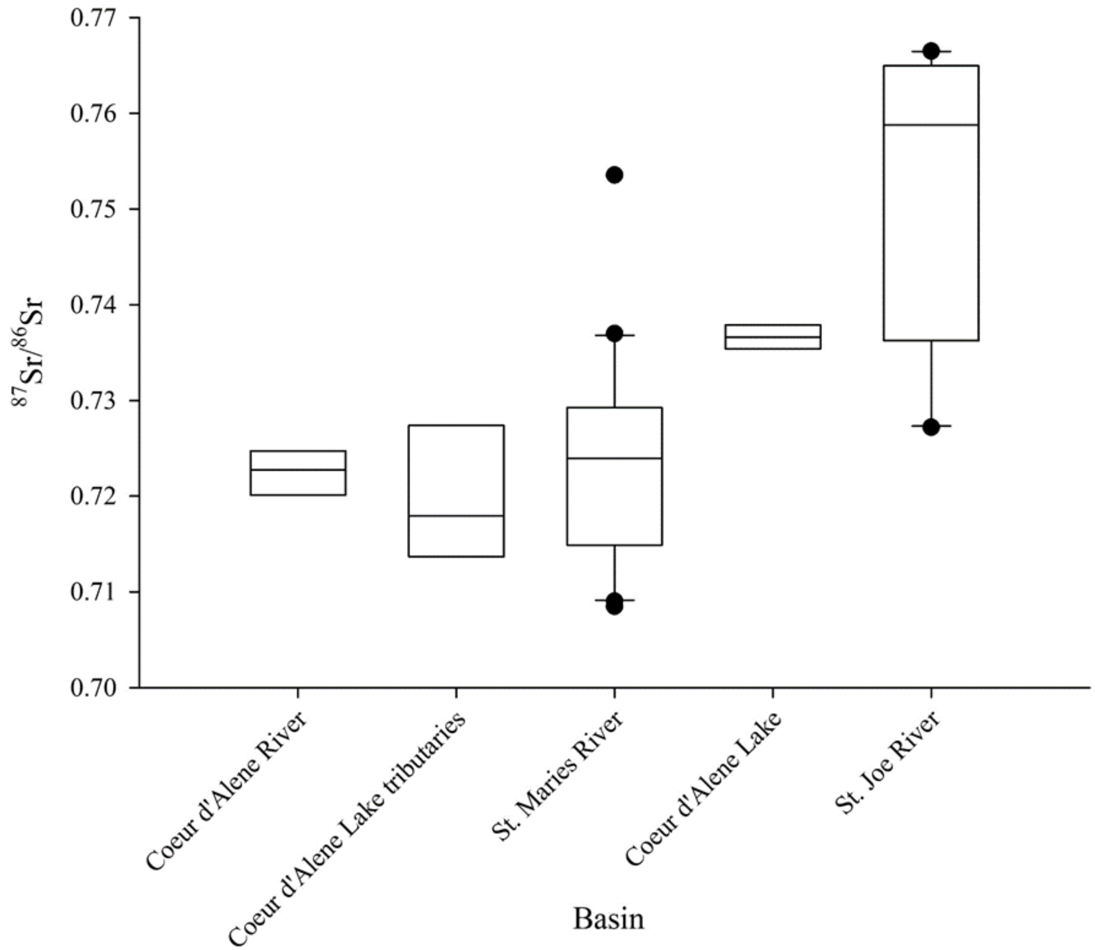

Figure 3.5. Spatial variability in $^{87}Sr/^{86}Sr$ values from water samples collected in 2016 and 2017 from the Coeur d'Alene River basin (n = 7), Coeur d'Alene Lake tributaries (n = 7), the St. Maries River basin (n = 20), Coeur d'Alene Lake (n = 4), and the St. Joe River basin (n = 10).

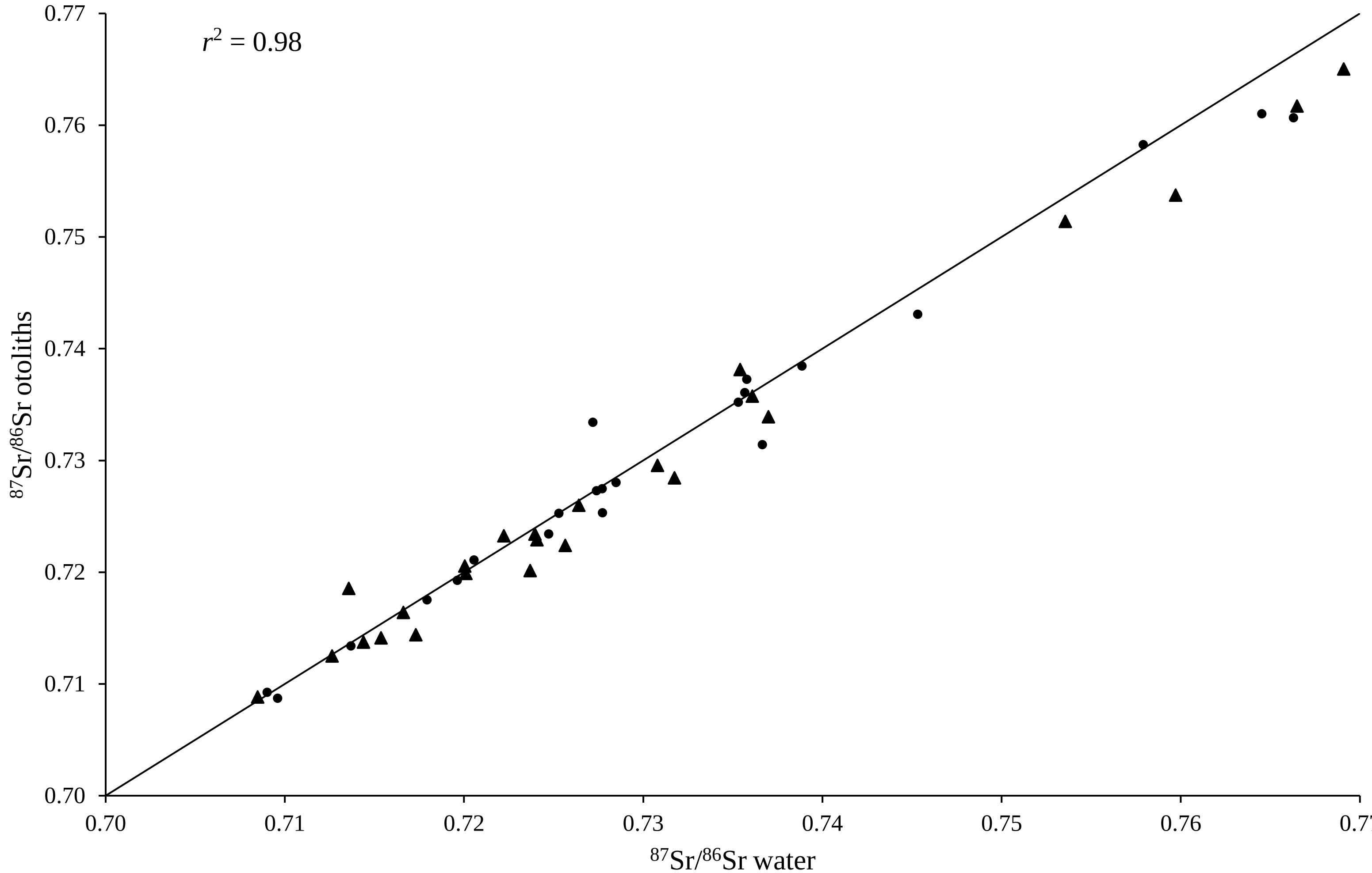

Figure 3.6. The linear relationship of $^{87}Sr/^{86}Sr$ ratios in water to otolith edge samples from Westslope Cutthroat Trout collected from 16 tributaries of the St. Maries River, 3 locations in the St. Maries River, 6 tributaries of the St. Joe River, 4 locations in the St. Joe River, 5 tributaries of the Coeur d'Alene River, 7 tributaries of Coeur d'Alene Lake, and from 4 locations in Coeur d'Alene Lake. The solid line represents a 1:1 relationship between water and otolith values. Solid circles (●) represent waters samples analyzed using MC-ICPMS and solid triangles (▲) represent waters samples analyzed using TIMS.

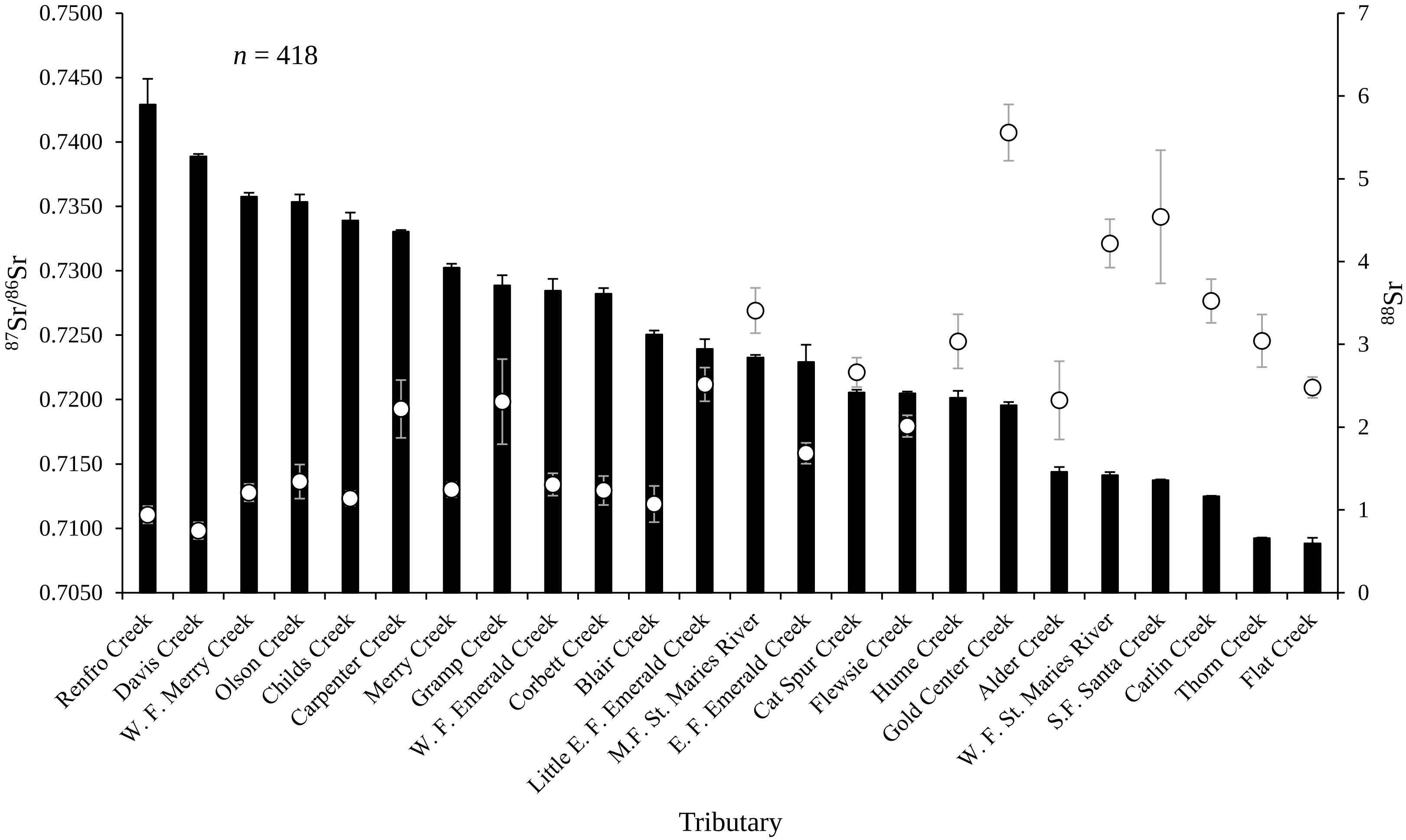

Figure 3.7. Values of $^{87}Sr/^{86}Sr$ (black bars) and ^{88}Sr (white circles) derived from Westslope Cutthroat Trout (WCT) sagittal otoliths that were caught in St. Maries River tributaries. Error bars represent one standard error of the mean.

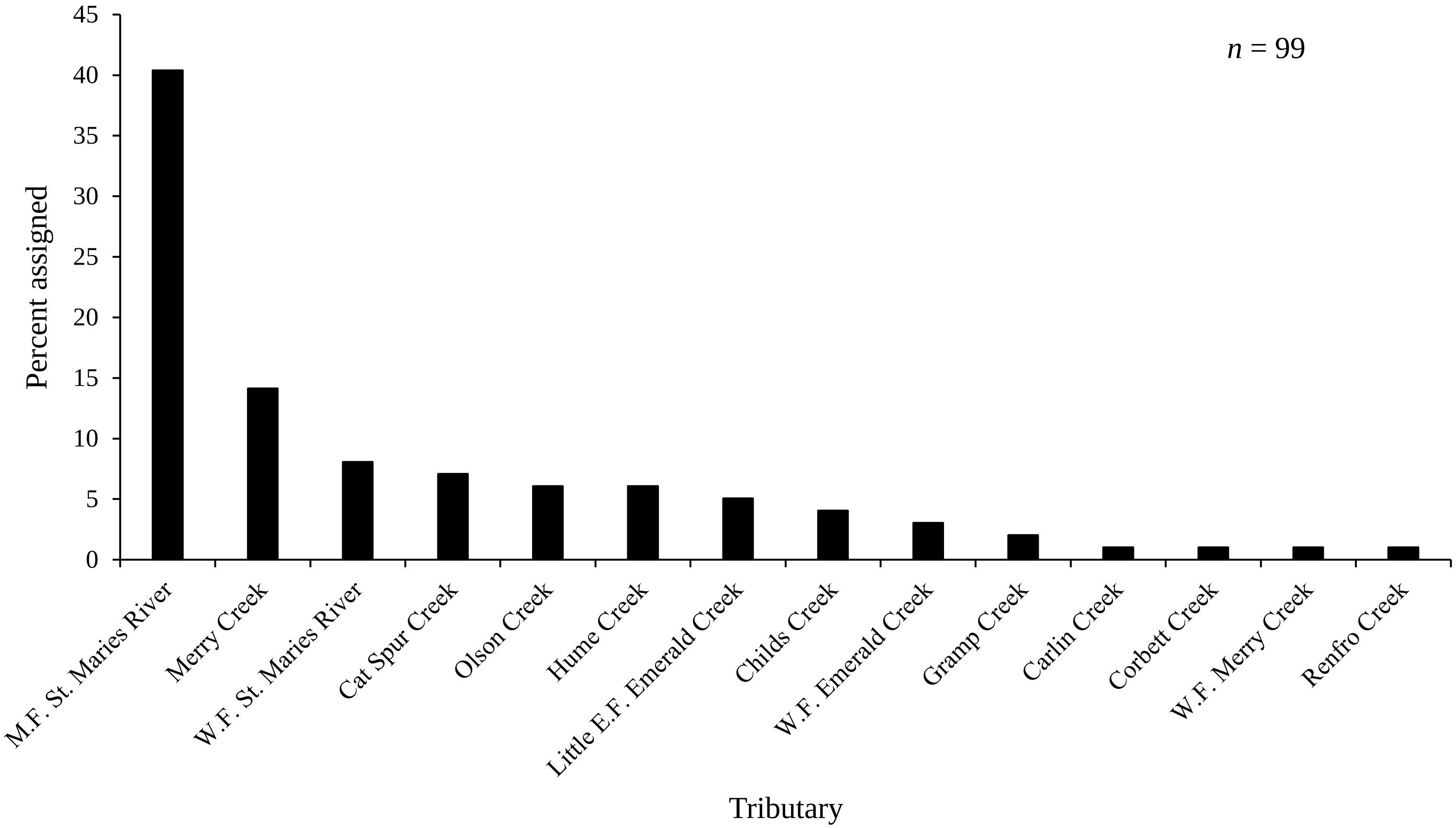

Figure 3.8. The percent of Westslope Cutthroat Trout assigned to each tributary based on natal signatures from fish caught in the St. Maries River. Discriminant function analysis was used to assign fish to natal tributaries.

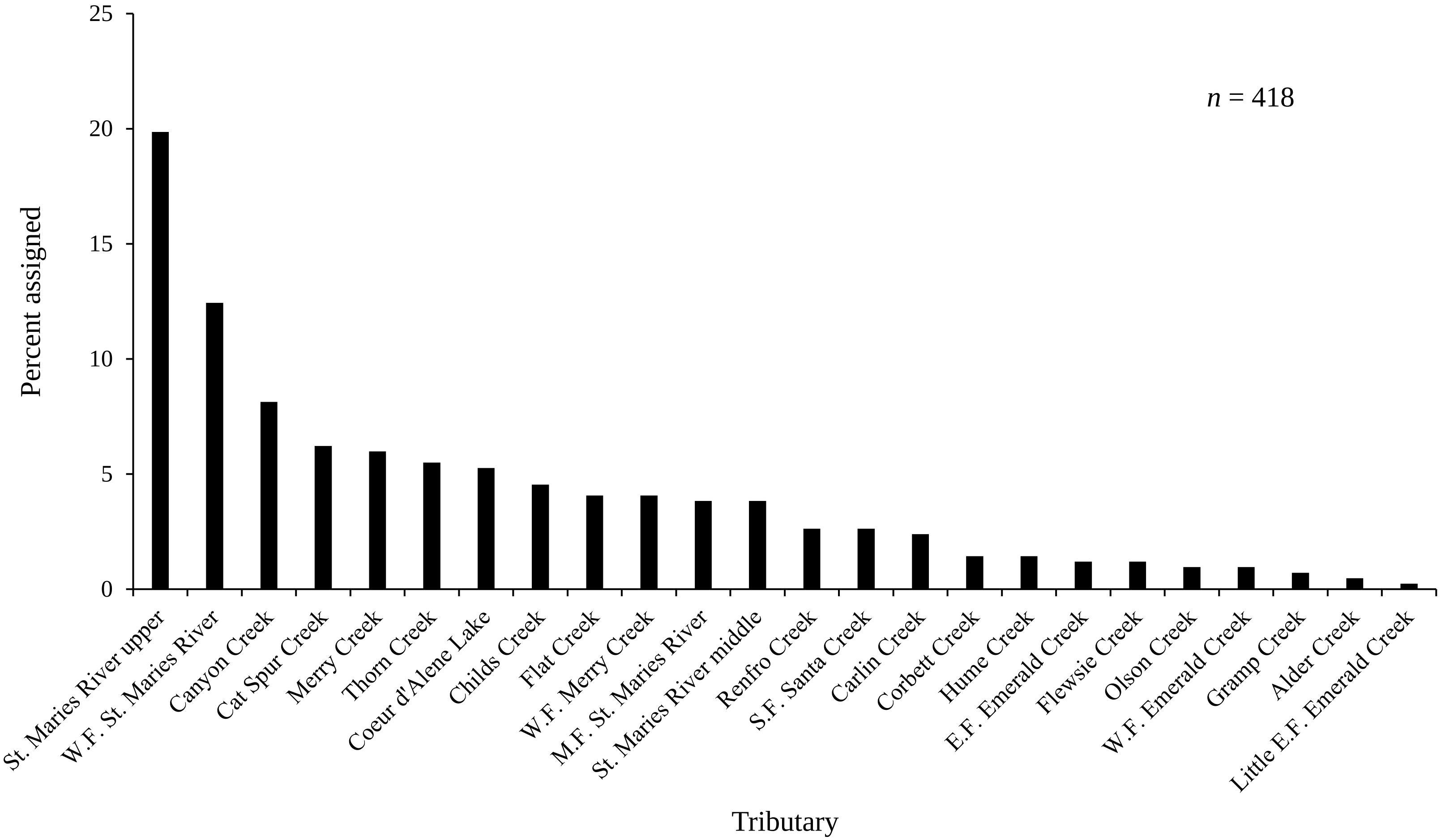

Figure 3.9. The percent of Westslope Cutthroat Trout assigned to each location based on maternal signatures from fish caught in St. Maries River tributaries. Discriminant function analysis was used to assign the maternal origins of Westslope Cutthroat Trout.

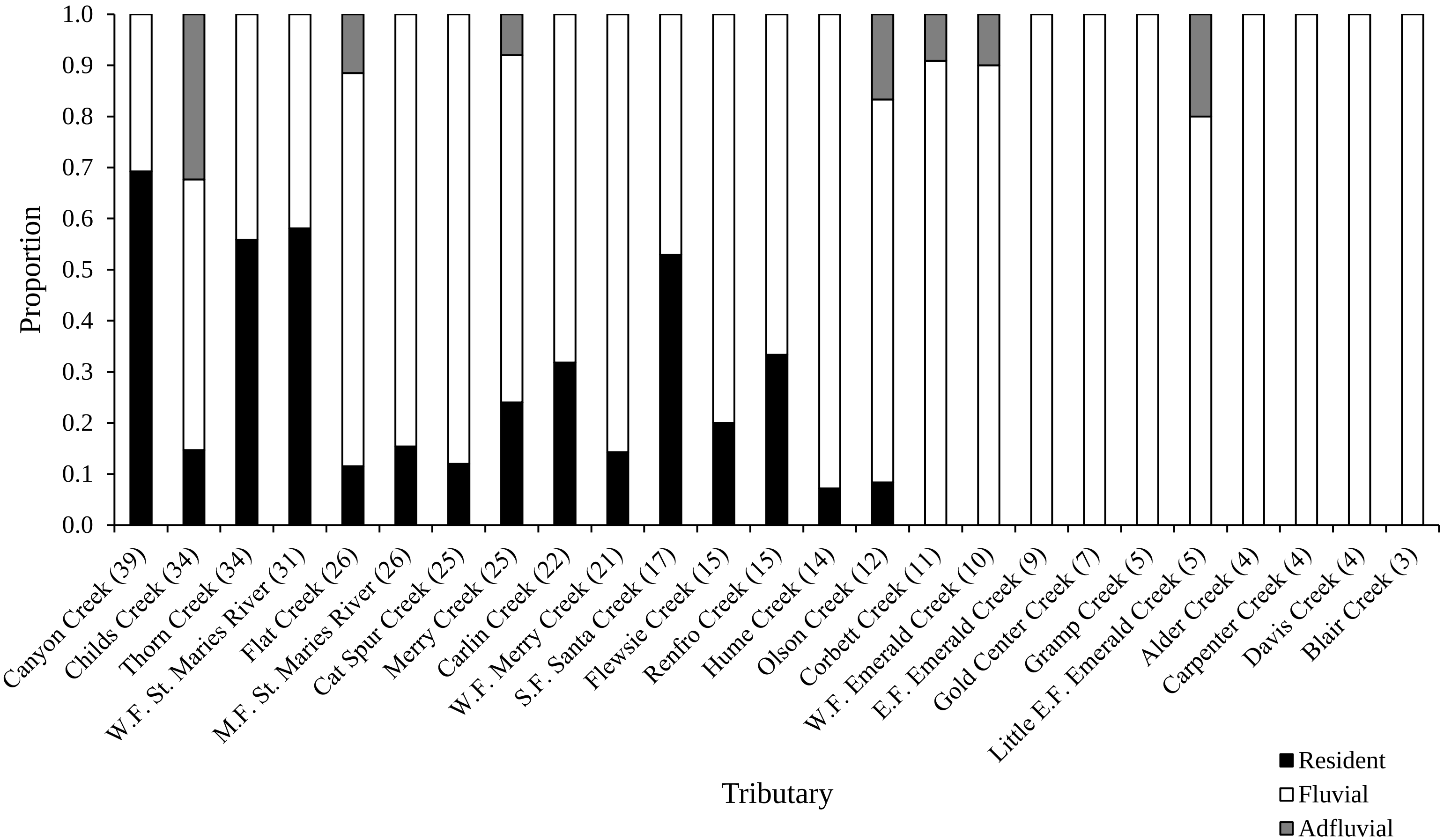

Figure 3.10. The life history structure of Westslope Cutthroat Trout (n = 418) in St. Maries River tributaries. Life history structure was estimated from maternal signatures from fish that were caught in tributaries. Tributaries are ranked by sample size (n) from greatest to smallest. For example, Canyon Creek had the greatest number of samples (n = 39) used for microchemistry analysis and the dominant life history strategy expressed was resident. About 70% of samples from Canyon Creek had a maternal signature assigned back to Canyon Creek.

Chapter 4: General Conclusions

This thesis contributes to the understanding of Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (WCT) life history structure, abundance, and distribution related to habitat characteristics in the St. Maries River basin of Idaho. The overarching goal of this thesis was to inform management decisions related to WCT in the St. Maries River basin and provide insight on whether there was a connection to Coeur d'Alene Lake. My findings implicate that there is connectivity and habitats throughout the St. Maries River basin such that the basin supports all life stages of WCT and a diversity of life history strategies. Tributaries appear to have a mixture of migratory juvenile WCT and resident WCT. In addition, the St. Maries River supports large, adult WCT and it serves as a migration corridor for fluvial and adfluvial WCT. Age-0 WCT were detected in most tributaries and had maternal origins representing all life history strategies, implicating that production is occurring and the basin is not an "ecological sink" for the adfluvial WCT population. Protecting current habitat where WCT are abundant should be a management priority. Moreover, habitat could be improved in riparian areas in upper portions (e.g., upstream of Fernwood) of the mainstem river where WCT were most abundant during boat electrofishing. This area was also where most natal and maternal origins were assigned, suggesting that the upper basin is driving the St. Maries River basin WCT population.

The last fisheries investigations in the basin occurred in the late 1980s. Anthropogenic alterations to the terrestrial landscape in the St. Maries River watershed have been extensive, but changes in land use practices have helped mitigate the effects to the aquatic ecosystem in the basin. The impetus of this project was to understand what the status of WCT was in the system. As a result of this research, we know that WCT are abundant in most tributaries, especially in headwaters, and use the mainstem of the St. Maries River in the spring as a migration corridor. In addition, there is connectivity to coldwater habitat in the upper portion of the watershed that large, adult WCT can use as a thermal refuge when warm water temperatures occur in downstream habitats. Expanding the amount of quality habitat in the mainstem river would benefit the WCT population and improve the fishery in the St. Maries River. Furthermore, the knowledge gained from this research could be used in other systems that WCT occupy to better understand factors affecting their distribution and abundance. Westslope Cutthroat Trout exhibit diverse life history strategies in dynamic habitat conditions, which has likely contributed to population viability in the St. Maries River basin.

Additional research and continued monitoring should be conducted in the St. Maries River basin. This thesis described where WCT were distributed related to habitat characteristics in tributaries of the St. Maries River. I recommend protecting tributaries where WCT are abundant, i.e., do no more harm. Tributaries in the upper portion of the watershed (i.e., upstream of Clarkia) and on the northeast portion of the watershed contained good habitat with cold water throughout the summer, high abundances of WCT, and connectivity to the St. Maries River. Most natal and maternal signatures assigned to the upper basin near Clarkia in the middle and west forks of the St. Maries River. However, poor habitat characterized by poor riparian stability, no canopy cover, and excessive cattle grazing was evident in lower reaches of those tributaries. Habitat improvement on the middle and west forks of the St. Maries River near Clarkia would benefit connectivity in the upper basin and consequently the WCT population. Monitoring the discharge and water temperature of larger tributaries draining the southwest portion of the watershed (e.g., Emerald Creek, Carpenter

Creek, Santa Creek, Alder Creek) should be conducted to gain an understanding of how much warm water those drainages are contributing to the St. Maries River. Drainages in the southwest portion of the basin contained the poorest habitat, which is where habitat enhancement could be focused. Large portions of these drainages were cattle grazed, had poor riparian stability, and contained warm water temperatures. In response, barriers to fish movement were formed between the St. Maries River and headwaters in those drainages. Therefore, understanding how those large drainages contribute to the St. Maries River is important in moving forward with habitat remediation projects in the mainstem river and in lower reaches of those tributaries.

Habitat may not be the only factor limiting WCT abundance in the St. Maries River basin. The harvest of two trout is allowed in the St. Maries River and tributaries from the Saturday of Memorial Day weekend through November 30. Therefore, it would be beneficial to investigate exploitation, compliance, angler use, and population estimates in the St. Maries River basin. Future monitoring could also include depletion estimates in tributaries and (or) snorkel surveys in tributaries where WCT were abundant in order to monitor recruitment and trends in abundance and density. Conducting snorkel surveys in the St. Maries River basin would provide data comparable to current annual monitoring that is conducted in the St. Joe and Coeur d'Alene basins. Furthermore, there are gaps in where adult WCT overwinter and where they migrate to in the summer. It is unclear if St. Maries River WCT residing in the mainstem migrate downstream to the St. Joe River for the winter, or Coeur d'Alene Lake, and whether there is suitable habitat in the summer. Additional research on summer and winter habitat use and movement in the mainstem would be beneficial in understanding movement patterns of various life stages of WCT in the system.

Appendix A

Site		Alder Creek 1	Alder Creek 2	Beaver Creek	Blair Creek	Canyon Creek 1
Date		8/8/2017	8/2/2018	7/26/2017	6/28/2017	7/19/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0529214	0521407	0539711	0556060	0537759
	Northing	5228348	5227680	5225085	5210397	5237479
Elevation (m)		721	874	816	940	782
Gradient (%)		7.30	0.90	1.41	3.96	3.01
Land use		timberland	timberland	timberland	forest	timberland
Road density (km/km^2)		2.38	2.30	1.50	1.10	1.66
Distance to road (m)		345.95	12.83	46.88	40.22	13.39
Temperature (°C)	At time of sampling	16.08	13.70	15.41	11.48	17.24
	Mean summer (SD)	–	–	14.84 (2.31)	12.33 (1.23)	14.90 (2.01)
	Max summer	–	–	20.23	14.71	19.57
Reach length (m)		104.60	66.00	74.40	54.20	64.90
Reach area (m^2)		284.49	185.62	132.90	69.08	98.59
Proportion of macrohabitat in reach	Runs	0.48	0.00	0.09	0.27	0.36
	Riffles	0.21	0.07	0.46	0.54	0.38
	Pools	0.31	0.93	0.45	0.20	0.26
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		1.46	12.65	0.98	0.37	0.67
Depth (m)		0.17	0.27	0.12	0.13	0.12
CV depth		15.08	67.12	29.62	5.01	20.84
Width (m)		2.83	2.99	1.88	1.33	1.54
CV width		16.69	66.47	24.06	17.67	1.66
Current velocity (m/s)		0.36	0.09	0.27	0.32	0.04
CV velocity		53.98	28.90	36.85	33.78	22.75
Canopy cover (%)		77.44	59.35	87.31	91.71	73.71
CV canopy cover		9.08	64.36	21.25	16.82	5.75
Substrate type	Fine	0.00	0.00	0.32	0.27	0.03
	Gravel	0.20	0.67	1.13	0.49	1.01
	Large	1.35	1.09	0.69	1.02	0.99
Substrate embeddedness		0.19	0.08	0.16	0.54	0.41
Instream cover	Total area (m^2)	15.01	22.63	13.94	31.43	18.84
	Proportion woody	0.00	0.05	0.09	0.36	0.11
	Proportion nonwoody	0.05	0.08	0.02	0.10	0.08
	Proportion of reach	0.05	0.12	0.10	0.46	0.19
Species CPUE (fish/min)	BKT	0.21	3.30	0.89	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.58	0.00	0.37	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.00	0.00	0.00	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	1.72	1.42	5.03	1.94	3.43
	SPD	0.00	0.00	1.52	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.56	0.00	0.64	0.00	0.00
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.00	0.00	3.96
	Age-0 density (fish/100m^2)	0.00	0.00	0.00	0.00	36.52
	Age-1+ CPUE	0.23	0.00	0.57	2.24	4.70
	Age-1+ density	1.41	0.00	1.50	5.79	30.43
Maternal influence	Resident	0.00	–	0.00	0.00	0.69
	Fluvial	1.00	–	1.00	1.00	0.31
	Adfluvial	0.00	–	0.00	0.00	0.00

Appendix A cont'd

Site		Canyon Creek 2	Carlin Creek	Carpenter Creek 1	Carpenter Creek 2	Cat Spur Creek 1
Date		6/20/2018	8/8/2017	7/11/2017	7/11/2017	6/21/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0539221	0528217	0546840	0544598	0556438
	Northing	5236630	5231135	5214597	5211841	5202183
Elevation (m)		826	715	830	873	885
Gradient (%)		3.92	5.23	0.37	0.84	0.68
Land use		timberland	private	private	timberland	grazing
Road density (km/km^2)		1.55	2.39	1.87	1.69	1.05
Distance to road (m)		10.70	204.16	85.64	35.03	420.82
Temperature (°C)	At time of sampling	12.84	16.20	15.87	18.02	12.91
	Mean summer (SD)	–	13.91 (1.40)	–	14.91 (2.38)	–
	Max summer	–	19.90	–	20.52	–
Reach length (m)		69.60	43.50	133.30	110.95	104.80
Reach area (m^2)		136.64	59.12	489.44	343.50	311.09
Proportion of macrohabitat in reach	Runs	0.14	0.73	0.14	0.56	0.27
	Riffles	0.46	0.16	0.16	0.37	0.42
	Pools	0.39	0.11	0.70	0.07	0.31
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.85	0.70	4.47	0.20	0.72
Depth (m)		0.18	0.09	0.55	0.18	0.38
CV depth		24.51	35.22	32.96	29.88	10.93
Width (m)		2.38	1.40	5.00	3.02	3.32
CV width		24.39	36.14	23.74	22.03	8.76
Current velocity (m/s)		0.11	0.09	0.16	0.34	0.30
CV velocity		35.17	49.11	10.67	25.91	25.18
Canopy cover (%)		87.43	90.78	83.05	54.58	72.39
CV canopy cover		15.96	33.72	22.70	22.82	8.75
Substrate type	Fine	0.00	0.11	0.81	0.06	0.38
	Gravel	0.26	0.56	2.00	0.98	1.02
	Large	1.05	1.10	1.21	1.19	0.39
Substrate embeddedness		0.30	0.22	0.35	0.36	0.22
Instream cover	Total area (m^2)	13.95	16.56	111.29	33.81	82.80
	Proportion woody	0.07	0.17	0.17	0.06	0.14
	Proportion nonwoody	0.04	0.11	0.06	0.04	0.12
	Proportion of reach	0.10	0.28	0.23	0.10	0.27
Species CPUE (fish/min)	BKT	0.00	0.00	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.00	0.15	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.11	0.00	0.00
	RSS	0.00	0.00	0.48	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.93	0.00	0.00	0.22	1.82
	SPD	0.00	0.00	0.26	0.22	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.00	0.00	0.41	1.53	0.48
Westslope Cutthroat Trout	Age-0 CPUE	0.32	2.74	0.00	0.17	0.00
	Age-0 density (fish/100m^2)	3.66	16.92	0.00	5.00	0.00
	Age-1+ CPUE	1.96	6.56	0.00	0.21	3.00
	Age-1+ density	21.96	40.60	0.00	6.00	2.00
Maternal influence	Resident	0.00	0.32	–	0.00	0.10
	Fluvial	1.00	0.68	–	1.00	0.90
	Adfluvial	0.00	0.00	–	0.00	0.00

Appendix A cont'd

Site		Cat Spur Creek 3	Charlie Creek 1	Charlie Creek 2	Childs Creek 1	Childs Creek 2
Date		7/26/2018	7/25/2017	6/15/2018	7/30/2018	7/18/2018
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0558239	0532485	0531619	0552192	0555941
	Northing	5200845	5214957	5213611	5213539	5216307
Elevation (m)		922	885	923	871	1302
Gradient (%)		1.44	0.88	1.73	3.79	4.35
Land use		timberland	grazing	forest	timberland	timberland
Road density (km/km^2)		0.90	2.33	2.48	1.35	0.96
Distance to road (m)		9.18	274.63	1658.40	67.22	1367.90
Temperature (°C)	At time of sampling	12.00	19.40	8.50	11.40	11.40
	Mean summer (SD)	–	–	–	11.50 (1.10)	–
	Max summer	–	–	–	13.94	–
Reach length (m)		105.10	101.20	65.10	98.00	57.00
Reach area (m^2)		241.00	272.34	101.30	247.49	118.91
Proportion of macrohabitat in reach	Runs	0.28	0.37	0.36	0.17	0.14
	Riffles	0.62	0.45	0.46	0.77	0.77
	Pools	0.09	0.19	0.18	0.06	0.09
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.15	0.42	0.39	0.07	0.11
Depth (m)		0.15	0.15	0.20	0.40	0.13
CV depth		15.22	8.32	6.13	21.69	25.93
Width (m)		2.49	2.61	1.68	3.88	1.90
CV width		29.49	14.36	9.92	20.17	39.51
Current velocity (m/s)		0.38	0.35	0.21	0.79	0.32
CV velocity		34.43	33.95	33.22	28.00	48.69
Canopy cover (%)		63.23	60.95	71.41	96.13	94.73
CV canopy cover		31.29	5.45	15.93	36.81	38.60
Substrate type	Fine	0.15	0.12	0.03	0.15	0.02
	Gravel	0.94	1.06	0.23	1.36	0.96
	Large	0.90	0.98	1.08	1.40	0.74
Substrate embeddedness		0.49	0.16	0.59	0.49	0.31
Instream cover	Total area (m^2)	30.16	27.55	15.91	111.02	25.04
	Proportion woody	0.07	0.06	0.13	0.35	0.20
	Proportion nonwoody	0.06	0.04	0.02	0.10	0.01
	Proportion of reach	0.13	0.10	0.16	0.45	0.21
Species CPUE (fish/min)	BKT	0.00	0.00	1.23	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.00	1.38	0.00	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	3.54	0.42	1.48	1.36	0.00
	SPD	0.00	1.61	0.00	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.48	1.99	0.00	0.00	0.00
Westslope Cutthroat Trout	Age-0 CPUE	1.84	0.00	0.00	0.19	0.38
	Age-0 density (fish/100m^2)	17.01	0.00	0.00	1.62	2.52
	Age-1+ CPUE	0.63	0.27	0.00	0.74	2.14
	Age-1+ density	2.49	0.73	0.00	6.46	13.46
Maternal influence	Resident	0.13	1.00	–	0.14	0.20
	Fluvial	0.87	0.00	–	0.48	0.80
	Adfluvial	0.00	0.00	–	0.38	0.00

Appendix A cont'd

Site		Corbett Creek	Crystal Creek	Davis Creek	E.F. Charlie Creek 1
Date		5/31/2017	7/13/2017	7/6/2017	7/12/2017
NAD 83 UTM	Zone	11T	11T	11T	11T
	Easting	0559458	0546557	0544481	0533113
	Northing	5209591	5218973	5224702	5214104
Elevation (m)		909	841	874	898
Gradient (%)		2.26	1.86	2.19	0.95
Land use		timberland	timberland	timberland	grazing
Road density (km/km^2)		0.89	1.36	1.33	2.42
Distance to road (m)		242.42	115.68	295.96	295.40
Temperature (°C)	At time of sampling	12.00	11.82	14.73	16.29
	Mean summer (SD)	12.70 (0.98)	13.13 (1.64)	12.92 (1.60)	–
	Max summer	15.28	17.28	17.86	–
Reach length (m)		120.70	101.05	74.96	104.70
Reach area (m^2)		313.12	271.70	142.00	284.73
Proportion of macrohabitat in reach	Runs	0.41	0.10	0.51	0.33
	Riffles	0.18	0.80	0.33	0.18
	Pools	0.41	0.10	0.17	0.50
	Off-channel	0.00	0.00	0.00	0.00
Pool:riffle		2.24	0.13	0.51	2.80
Depth (m)		0.44	0.17	0.18	0.31
CV depth		18.24	32.37	20.71	27.70
Width (m)		2.92	2.71	1.89	2.89
CV width		16.48	39.23	16.43	21.08
Current velocity (m/s)		0.21	0.47	0.24	0.15
CV velocity		12.12	48.73	17.35	3.47
Canopy cover (%)		44.96	66.19	65.42	41.79
CV canopy cover		13.64	38.33	16.00	20.83
Substrate type	Fine	0.29	0.07	0.13	0.40
	Gravel	0.39	0.58	1.04	1.09
	Large	0.25	1.30	0.87	0.72
Substrate embeddedness		0.10	0.32	0.31	0.47
Instream cover	Total area (m^2)	148.45	41.37	35.48	25.79
	Proportion woody	0.40	0.05	0.14	0.06
	Proportion nonwoody	0.08	0.11	0.11	0.03
	Proportion of reach	0.47	0.15	0.25	0.09
Species CPUE (fish/min)	BKT	0.00	1.07	0.67	0.50
	BLG	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00
	LND	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00
	RSS	0.00	0.00	0.00	0.60
	RXC	0.00	0.00	0.00	0.00
	SHS	1.38	3.19	7.69	0.64
	SPD	0.00	0.00	0.00	0.84
	TNC	0.00	0.00	0.00	0.00
	TRS	0.00	0.00	0.00	2.21
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.00	0.00
	Age-0 density (fish/100m^2)	0.00	0.00	0.00	0.00
	Age-1+ CPUE	0.28	0.25	0.73	0.00
	Age-1+ density	3.51	0.37	4.93	0.00
Maternal influence	Resident	0.00	0.00	0.00	–
	Fluvial	0.91	1.00	1.00	–
	Adfluvial	0.09	0.00	0.00	–

Appendix A cont'd

Site		E.F. Charlie Creek 2	E.F. Emerald Creek 1	E.F. Emerald Creek 2	E.F. Emerald Creek 3	E.F. Emerald Creek 4
Date		6/18/2018	5/25/2017	6/7/2017	6/28/2018	7/23/2018
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0535070	0550948	0548139	0550813	0545551
	Northing	5213040	5207702	5204416	5208475	5203815
Elevation (m)		936	859	893	850	938
Gradient (%)		1.41	0.81	0.72	0.31	1.74
Land use		forest	forest	forest	mineral	forest
Road density (km/km^2)		2.29	1.58	1.77	1.58	2.02
Distance to road (m)		58.96	77.04	3.58	101.96	45.81
Temperature (°C)	At time of sampling	9.60	9.64	12.08	15.70	11.20
	Mean summer (SD)	–	15.80 (1.80)	–	15.58 (2.11)	–
	Max summer	–	15.86	–	20.33	–
Reach length (m)		100.50	211.20	110.10	176.70	80.45
Reach area (m^2)		219.45	1280.08	487.28	805.38	152.66
Proportion of macrohabitat in reach	Runs	0.39	0.50	0.31	0.10	0.49
	Riffles	0.55	0.31	0.32	0.52	0.33
	Pools	0.06	0.19	0.37	0.38	0.18
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.11	0.61	1.19	0.74	0.54
Depth (m)		0.18	0.34	0.31	0.26	0.18
CV depth		17.48	19.17	16.76	22.57	16.28
Width (m)		2.11	5.04	4.75	4.86	2.13
CV width		21.91	12.97	12.92	22.07	12.41
Current velocity (m/s)		0.41	0.32	0.28	0.28	0.20
CV velocity		37.49	13.27	15.66	40.62	16.62
Canopy cover (%)		70.33	69.25	62.83	46.07	59.85
CV canopy cover		25.05	12.47	4.29	18.59	17.43
Substrate type	Fine	0.02	0.11	0.21	0.19	0.35
	Gravel	0.43	0.25	0.46	0.18	0.40
	Large	1.00	0.68	0.76	0.92	0.66
Substrate embeddedness		0.09	0.23	0.44	0.25	0.73
Instream cover	Total area (m^2)	15.23	98.02	55.02	36.64	28.56
	Proportion woody	0.05	0.05	0.05	0.03	0.19
	Proportion nonwoody	0.02	0.03	0.07	0.01	0.00
	Proportion of reach	0.07	0.08	0.11	0.05	0.19
Species CPUE (fish/min)	BKT	0.30	0.00	0.00	0.00	0.63
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.12	0.00	0.16	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.00	0.00	0.00	0.52	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	3.81	0.00	1.33	0.00	2.36
	SPD	0.00	0.15	0.00	0.44	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.26	0.36	0.57	0.51	0.32
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.05	0.00	0.00
	Age-0 density (fish/100m^2)	0.00	0.00	0.41	0.00	0.00
	Age-1+ CPUE	0.98	0.05	0.03	0.00	0.28
	Age-1+ density	6.38	0.31	0.21	0.00	3.28
Maternal influence	Resident	1.00	0.00	0.00	–	0.00
	Fluvial	0.00	1.00	1.00	–	1.00
	Adfluvial	0.00	0.00	0.00	–	0.00

Appendix A cont'd

Site		Emerald Creek 1	Emerald Creek 2	Emerald Creek 3	Flat Creek 1	Flat Creek 2
Date		8/1/2017	6/25/2018	7/2/2018	6/29/2018	7/31/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0551217	0551230	0550874	0534829	0535691
	Northing	5210697	5212824	5208473	5227850	5228303
Elevation (m)		842	833	850	780	799
Gradient (%)		0.29	0.29	0.31	1.67	1.71
Land use		grazing	grazing	grazing	thinned	thinned
Road density (km/km^2)		1.60	1.54	1.58	2.02	1.89
Distance to road (m)		309.38	17.11	49.50	1528.88	586.65
Temperature (°C)	At time of sampling	23.50	14.83	12.51	12.98	19.57
	Mean summer (SD)	–	17.66 (2.38)	15.63 (2.40)	–	–
	Max summer	–	22.53	20.52	–	–
Reach length (m)		77.10	310.80	206.00	72.20	51.00
Reach area (m^2)		395.31	2729.38	1224.39	153.30	70.23
Proportion of macrohabitat in reach	Runs	0.39	0.29	0.58	0.73	0.00
	Riffles	0.00	0.52	0.30	0.08	0.08
	Pools	0.61	0.19	0.12	0.19	0.92
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.00	0.38	0.42	2.28	11.19
Depth (m)		0.44	0.28	0.39	0.13	0.17
CV depth		12.88	4.48	28.55	32.14	68.26
Width (m)		5.24	8.68	5.87	2.13	1.46
CV width		5.08	14.30	24.93	36.52	63.57
Current velocity (m/s)		0.15	0.29	0.26	0.03	0.05
CV velocity		20.85	31.39	23.96	35.05	70.71
Canopy cover (%)		17.18	48.09	34.73	86.62	53.55
CV canopy cover		19.44	14.45	22.38	33.90	55.55
Substrate type	Fine	0.56	0.50	0.04	0.00	0.14
	Gravel	1.48	0.08	0.26	0.09	0.10
	Large	0.52	1.34	1.24	1.29	1.25
Substrate embeddedness		0.18	0.45	0.37	0.01	0.35
Instream cover	Total area (m^2)	30.44	13.08	29.43	0.00	8.58
	Proportion woody	0.06	0.00	0.02	0.00	0.03
	Proportion nonwoody	0.01	0.00	0.00	0.00	0.10
	Proportion of reach	0.08	0.00	0.02	0.00	0.12
Species CPUE (fish/min)	BKT	0.00	0.00	0.00	0.00	0.00
	BLG	0.00	0.02	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	4.27	0.04	0.11	0.00	0.00
	LND	0.00	0.07	0.21	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	1.90	0.15	0.00	0.00	0.00
	RSS	5.46	0.25	0.21	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.00	0.00	0.00	1.20	13.68
	SPD	5.69	0.35	0.24	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.00	0.15	0.59	1.37	0.23
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.00	1.41	1.23
	Age-0 density (fish/100m^2)	0.00	0.00	0.00	8.48	22.78
	Age-1+ CPUE	0.00	0.00	0.03	1.72	1.47
	Age-1+ density	0.00	0.00	0.08	10.44	27.05
Maternal influence	Resident	–	–	–	0.13	0.09
	Fluvial	–	–	–	0.87	0.64
	Adfluvial	–	–	–	0.00	0.27

Appendix A cont'd

Site		Flewsie Creek	Gold Center Creek 1	Gold Center Creek 4	Gramp Creek 1	Gramp Creek 2
Date		6/13/2017	7/21/2017	7/12/2018	6/14/2017	6/15/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0561342	0565081	0566479	0564230	0565172
	Northing	5206293	5206426	5207532	5206361	5208388
Elevation (m)		914	959	1019	948	1024
Gradient (%)		1.60	1.53	3.31	1.56	3.15
Land use		timberland	timberland	forest	timberland	forest
Road density (km/km2)		0.75	0.50	0.42	0.50	0.50
Distance to road (m)		615.75	156.25	1383.96	46.20	254.56
Temperature (°C)	At time of sampling	9.74	12.23	10.54	7.67	7.03
	Mean summer (SD)	–	12.83 (1.63)	–	–	–
	Max summer	–	17.00	–	–	–
Reach length (m)		94.20	166.40	110.90	114.70	105.95
Reach area (m2)		206.40	713.59	403.38	344.81	267.82
Proportion of macrohabitat in reach	Runs	0.48	0.25	0.31	0.18	0.26
	Riffles	0.25	0.69	0.69	0.74	0.74
	Pools	0.28	0.06	0.00	0.08	0.00
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		1.11	0.09	0.00	0.11	0.00
Depth (m)		0.21	0.20	0.17	0.28	0.21
CV depth		15.39	21.72	4.65	32.29	24.18
Width (m)		2.28	4.18	4.27	3.02	2.47
CV width		9.40	32.71	28.61	37.32	26.93
Current velocity (m/s)		0.13	0.89	0.46	0.46	0.51
CV velocity		23.09	37.16	51.53	37.03	41.57
Canopy cover (%)		73.05	62.04	80.52	38.81	68.20
CV canopy cover		17.08	29.17	22.16	44.96	34.85
Substrate type	Fine	0.18	0.25	0.12	0.04	0.09
	Gravel	0.86	0.69	0.33	0.42	0.52
	Large	0.60	0.93	1.28	1.19	0.93
Substrate embeddedness		0.31	0.27	0.15	0.53	0.53
Instream cover	Total area (m2)	90.69	91.65	54.99	35.74	69.68
	Proportion woody	0.38	0.10	0.13	0.06	0.24
	Proportion nonwoody	0.06	0.03	0.00	0.05	0.02
	Proportion of reach	0.44	0.13	0.14	0.10	0.26
Species CPUE (fish/min)	BKT	0.23	0.00	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.00	0.00	0.00	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	1.69	1.54	0.69	1.87	0.96
	SPD	0.00	0.00	0.00	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.00	0.29	0.00	0.00	0.00
Westslope Cutthroat Trout	Age-0 CPUE	0.19	0.00	0.04	0.00	0.00
	Age-0 density (fish/100m2)	3.88	0.00	0.25	0.00	0.00
	Age-1+ CPUE	0.24	0.14	0.21	0.13	0.12
	Age-1+ density	4.36	0.84	1.49	0.87	1.12
Maternal influence	Resident	0.13	0.00	0.00	0.00	0.00
	Fluvial	0.87	1.00	1.00	1.00	1.00
	Adfluvial	0.00	0.00	0.00	0.00	0.00

Appendix A cont'd

Site		Hatton Creek	Hume Creek	John Creek 1	John Creek 2	John Creek 4
Date		7/13/2017	7/12/2017	8/7/2017	6/14/2018	6/13/2018
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0549563	0530260	0530348	0523486	0528059
	Northing	5215586	5214740	5226118	5221805	5225124
Elevation (m)		842	926	787	878	818
Gradient (%)		2.72	3.35	1.38	1.65	0.87
Land use		timberland	forest	timberland	timberland	timberland
Road density (km/km^2)		1.44	2.39	2.18	2.28	2.24
Distance to road (m)		616.36	593.35	157.62	71.66	247.26
Temperature (°C)	At time of sampling	14.08	11.52	20.08	12.81	11.66
	Mean summer (SD)	–	12.94 (1.26)	17.24 (2.98)	–	–
	Max summer	–	15.66	25.13	–	–
Reach length (m)		53.00	40.20	114.50	66.30	158.69
Reach area (m^2)		54.47	49.03	386.94	120.66	707.42
Proportion of macrohabitat in reach	Runs	0.06	0.13	0.49	0.26	0.12
	Riffles	0.53	0.66	0.11	0.24	0.55
	Pools	0.42	0.21	0.39	0.51	0.34
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.79	0.32	3.43	2.15	0.62
Depth (m)		0.09	0.06	0.17	0.18	0.16
CV depth		32.28	16.78	29.47	26.03	22.59
Width (m)		1.04	1.18	3.64	1.87	4.42
CV width		26.16	29.67	25.00	16.71	20.06
Current velocity (m/s)		0.06	0.03	0.03	0.13	0.23
CV velocity		21.08	39.31	45.14	17.49	42.76
Canopy cover (%)		91.99	97.33	72.93	39.50	70.84
CV canopy cover		24.05	29.72	22.85	23.55	29.47
Substrate type	Fine	0.51	0.00	0.10	0.10	0.00
	Gravel	0.81	0.92	0.51	0.89	0.02
	Large	0.87	1.13	1.18	0.48	1.18
Substrate embeddedness		0.35	0.28	0.20	0.28	0.29
Instream cover	Total area (m^2)	8.68	5.91	35.30	20.78	25.08
	Proportion woody	0.07	0.06	0.07	0.13	0.01
	Proportion nonwoody	0.09	0.06	0.03	0.05	0.02
	Proportion of reach	0.16	0.12	0.09	0.17	0.04
Species CPUE (fish/min)	BKT	1.71	0.00	1.02	3.69	0.20
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.00	0.00	0.00	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.00	2.82	1.88	4.15	0.87
	SPD	0.00	0.00	0.00	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.00	0.00	0.00	0.00	0.00
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.05	0.00	0.00	0.00
	Age-0 density (fish/100m^2)	0.00	2.04	0.00	0.00	0.00
	Age-1+ CPUE	0.00	0.12	0.26	0.00	0.00
	Age-1+ density	0.00	4.08	1.29	0.00	0.00
Maternal influence	Resident	–	0.07	1.00	–	–
	Fluvial	–	0.93	0.00	–	–
	Adfluvial	–	0.00	0.00	–	–

Appendix A cont'd

Site		Little E.F. Emerald Creek	Merry Creek 1	Merry Creek 2	Merry Creek 3	Middle Fork St. Maries River 1
Date		7/10/2018	6/27/2017	7/30/2018	7/9/2018	8/3/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0548115	0558977	0561486	0562912	0558718
	Northing	5204335	5207907	5210081	5212781	5205345
Elevation (m)		900	884	947	1036	878
Gradient (%)		1.37	1.90	0.89	2.75	0.73
Land use		forest	timberland	timberland	timberland	grazing
Road density (km/km^2)		1.77	0.87	0.73	0.59	0.90
Distance to road (m)		42.25	52.64	120.67	19.05	216.39
Temperature (°C)	At time of sampling	11.60	14.59	12.60	12.64	16.47
	Mean summer (SD)	–	14.07 (1.96)	14.00 (1.86)	–	15.86 (2.62)
	Max summer	–	18.71	18.71	–	22.53
Reach length (m)		68.20	202.20	126.50	61.90	231.30
Reach area (m^2)		121.66	998.10	411.08	93.45	1512.47
Proportion of macrohabitat in reach	Runs	0.41	0.29	0.41	0.16	0.52
	Riffles	0.59	0.50	0.29	0.31	0.29
	Pools	0.00	0.22	0.07	0.53	0.19
	Off-channel	0.00	0.00	0.23	0.00	0.00
Pool:riffle		0.00	0.44	0.24	1.74	0.66
Depth (m)		0.13	0.25	0.40	0.23	0.28
CV depth		8.75	7.63	18.99	33.44	20.33
Width (m)		1.80	3.13	3.81	1.59	6.61
CV width		17.66	9.02	17.60	26.80	13.21
Current velocity (m/s)		0.21	0.38	0.48	0.13	0.34
CV velocity		35.98	21.38	22.41	19.72	18.67
Canopy cover (%)		76.76	73.42	58.56	76.67	46.22
CV canopy cover		7.69	13.16	13.87	20.27	10.14
Substrate type	Fine	0.19	0.20	0.27	0.26	0.01
	Gravel	0.66	0.79	0.39	0.95	1.04
	Large	0.70	1.08	0.54	0.29	1.18
Substrate embeddedness		0.39	0.60	0.37	0.15	0.35
Instream cover	Total area (m^2)	4.07	176.30	171.73	35.97	62.72
	Proportion woody	0.02	0.15	0.17	0.23	0.02
	Proportion nonwoody	0.01	0.03	0.25	0.16	0.02
	Proportion of reach	0.03	0.18	0.42	0.38	0.04
Species CPUE (fish/min)	BKT	0.00	0.00	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.00	0.09	0.00	0.00	0.23
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.15
	RSS	0.00	0.00	0.00	0.00	0.30
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	2.08	1.11	0.49	1.78	0.00
	SPD	0.00	0.00	0.00	0.00	0.30
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.31	0.14	0.07	0.00	0.35
Westslope Cutthroat Trout	Age-0 CPUE	0.11	0.00	0.11	0.00	0.18
	Age-0 density (fish/100m^2)	1.64	0.00	1.70	0.00	0.46
	Age-1+ CPUE	0.25	0.11	0.16	1.19	0.18
	Age-1+ density	4.11	0.60	1.95	11.77	0.46
Maternal influence	Resident	0.00	0.17	0.42	0.00	0.33
	Fluvial	0.80	0.67	0.50	0.83	0.67
	Adfluvial	0.20	0.16	0.08	0.17	0.00

Appendix A cont'd

Site		Middle Fork St. Maries River 2	Middle Fork St. Maries River 3	Middle Fork St. Maries River 4	Olson Creek 1	Olson Creek 2
Date		7/16/2018	8/1/2018	7/17/2018	8/2/2017	7/19/2018
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0561031	0563126	0561997	0550812	0552403
	Northing	5205889	5202039	5199669	5215288	5217968
Elevation (m)		899	1033	1102	880	1030
Gradient (%)		0.60	1.52	1.47	2.36	3.85
Land use		timberland	timberland	timberland	timberland	timberland
Road density (km/km^2)		0.75	0.65	0.75	1.44	1.26
Distance to road (m)		30.51	25.63	31.74	1593.30	3096.42
Temperature (°C)	At time of sampling	14.03	10.72	11.00	12.22	10.90
	Mean summer (SD)	–	–	–	–	–
	Max summer	–	–	–	–	–
Reach length (m)		217.90	141.94	110.40	112.40	126.40
Reach area (m^2)		1840.93	588.53	356.86	336.26	523.10
Proportion of macrohabitat in reach	Runs	0.22	0.20	0.20	0.21	0.17
	Riffles	0.55	0.70	0.53	0.67	0.83
	Pools	0.23	0.10	0.27	0.12	0.00
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		0.42	0.14	0.50	0.18	0.00
Depth (m)		0.33	0.27	0.21	0.20	0.18
CV depth		6.19	29.77	7.42	22.22	34.34
Width (m)		8.35	4.17	3.48	3.08	4.13
CV width		19.17	32.54	14.48	29.82	48.13
Current velocity (m/s)		0.42	0.55	0.36	0.36	0.43
CV velocity		35.93	33.85	40.94	39.17	53.72
Canopy cover (%)		35.47	41.66	33.29	74.23	94.18
CV canopy cover		13.83	41.66	19.75	29.86	45.19
Substrate type	Fine	0.26	0.09	0.27	0.08	0.12
	Gravel	0.08	0.43	1.14	0.27	0.76
	Large	1.46	0.80	0.57	1.37	1.10
Substrate embeddedness		0.25	0.36	0.34	0.24	0.71
Instream cover	Total area (m^2)	83.77	70.17	43.96	38.20	51.33
	Proportion woody	0.03	0.14	0.07	0.07	0.10
	Proportion nonwoody	0.02	0.06	0.05	0.04	0.00
	Proportion of reach	0.04	0.20	0.12	0.11	0.10
Species CPUE (fish/min)	BKT	0.00	0.00	0.00	0.22	0.14
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.10	0.00	0.00	0.19	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	0.00
	RSS	0.96	0.00	0.00	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.34	1.77	1.76	2.75	0.94
	SPD	0.05	0.00	0.00	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.33	0.00	0.00	0.00	0.00
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.04	0.75	0.21	0.00
	Age-0 density (fish/100m^2)	0.00	0.68	7.29	2.08	0.00
	Age-1+ CPUE	0.11	0.15	0.25	0.72	0.63
	Age-1+ density	0.65	1.02	2.52	7.14	4.78
Maternal influence	Resident	0.20	0.25	0.00	0.17	0.00
	Fluvial	0.80	0.75	1.00	0.50	1.00
	Adfluvial	0.00	0.00	0.00	0.33	0.00

Appendix A cont'd

Site		Renfro Creek 1	Renfro Creek 2	Santa Creek 2	Santa Creek 4	Santa Creek 5
Date		8/1/2018	8/1/2017	7/24/2017	6/21/2018	6/22/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0543428	0547534	0538203	0533870	0528573
	Northing	5222899	5223736	5222138	5221085	5217085
Elevation (m)		828	986	816	847	865
Gradient (%)		1.07	4.13	1.08	0.18	0.14
Land use		private	timberland	private	grazing	grazing
Road density (km/km^2)		1.33	1.19	1.71	1.99	2.28
Distance to road (m)		19.83	194.58	59.05	99.90	6.38
Temperature (°C)	At time of sampling	13.80	12.20	20.68	15.90	17.86
	Mean summer (SD)	–	–	19.94 (2.39)	–	–
	Max summer	–	–	26.10	–	–
Reach length (m)		94.40	102.40	161.50	259.50	100.60
Reach area (m^2)		232.60	235.98	760.47	2128.05	188.13
Proportion of macrohabitat in reach	Runs	0.33	0.40	0.10	0.21	0.24
	Riffles	0.33	0.50	0.20	0.17	0.00
	Pools	0.34	0.09	0.70	0.62	0.76
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		1.05	0.18	3.47	3.69	0.00
Depth (m)		0.29	0.13	0.45	0.56	0.62
CV depth		20.31	19.70	50.50	37.52	53.02
Width (m)		2.61	2.30	5.63	8.14	1.82
CV width		9.69	19.87	43.08	26.06	45.12
Current velocity (m/s)		0.35	0.30	0.13	0.14	0.16
CV velocity		31.24	29.69	31.39	17.32	16.22
Canopy cover (%)		58.54	98.10	29.16	51.77	21.08
CV canopy cover		11.90	21.48	38.30	25.26	68.00
Substrate type	Fine	0.34	0.18	0.55	0.00	1.05
	Gravel	0.47	0.41	0.24	0.33	0.55
	Large	1.09	1.08	0.94	1.14	0.00
Substrate embeddedness		0.67	0.22	0.21	0.01	0.08
Instream cover	Total area (m^2)	12.03	60.29	48.67	88.00	67.65
	Proportion woody	0.03	0.22	0.04	0.04	0.02
	Proportion nonwoody	0.02	0.04	0.02	0.00	0.34
	Proportion of reach	0.05	0.26	0.06	0.04	0.36
Species CPUE (fish/min)	BKT	0.35	0.00	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.14	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	1.33
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.38	0.14	0.14
	LND	0.28	0.00	0.49	0.00	0.00
	MWF	0.34	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.09	0.02	0.00
	RSS	0.00	0.00	0.41	0.94	3.22
	RXC	0.14	0.00	0.00	0.00	0.00
	SHS	3.80	2.67	0.00	0.00	0.00
	SPD	0.00	0.00	1.57	0.87	2.62
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.25	0.00	0.99	0.22	0.37
Westslope Cutthroat Trout	Age-0 CPUE	0.59	0.07	0.00	0.00	0.00
	Age-0 density (fish/100m^2)	5.59	2.00	0.00	0.00	0.00
	Age-1+ CPUE	0.08	0.81	0.00	0.00	0.00
	Age-1+ density	0.86	24.00	0.00	0.00	0.00
Maternal influence	Resident	0.20	0.40	–	–	–
	Fluvial	0.80	0.60	–	–	–
	Adfluvial	0.00	0.00	–	–	–

Appendix A cont'd

Site		S.F. Santa Creek	Thorn Creek 1	Thorn Creek 2	Thorn Creek 3	Tyson Creek
Date		7/24/2017	7/19/2017	7/20/2017	7/24/2018	7/10/2017
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0523840	0535900	0541482	0538391	543149
	Northing	5215458	5236948	5233640	5234147	5219398
Elevation (m)		974	671	858	829	827
Gradient (%)		3.21	2.60	0.99	1.78	1.06
Land use		forest	private	timberland	thinned	thinned
Road density (km/km^2)		2.51	1.71	1.50	1.73	1.56
Distance to road (m)		79.56	40.83	38.89	14.47	46.45
Temperature (°C)	At time of sampling	14.65	15.25	16.37	13.17	19.30
	Mean summer (SD)	13.07 (1.28)		–	–	16.60 (2.47)
	Max summer	15.95		–	–	23.10
Reach length (m)		51.90	104.00	62.50	109.45	102.95
Reach area (m^2)		51.62	285.08	131.43	373.12	264.42
Proportion of macrohabitat in reach	Runs	0.27	0.22	0.22	0.64	0.34
	Riffles	0.32	0.27	0.07	0.21	0.24
	Pools	0.42	0.51	0.71	0.15	0.42
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		1.32	1.92	10.61	0.71	1.73
Depth (m)		0.10	0.20	0.21	0.19	0.20
CV depth		27.82	31.65	46.86	16.65	28.54
Width (m)		1.06	3.11	2.26	3.38	2.75
CV width		10.20	30.32	39.64	35.25	18.60
Current velocity (m/s)		0.10	0.11	0.05	0.15	0.12
CV velocity		9.11	24.70	12.10	24.18	13.78
Canopy cover (%)		91.15	73.97	57.72	82.84	87.85
CV canopy cover		6.42	16.56	29.26	30.43	12.04
Substrate type	Fine	0.12	0.00	0.00	0.18	0.12
	Gravel	0.56	0.25	1.29	0.06	0.93
	Large	0.98	1.48	0.93	0.97	1.07
Substrate embeddedness		0.22	0.36	0.32	0.21	0.39
Instream cover	Total area (m^2)	26.13	19.44	18.90	5.58	30.12
	Proportion woody	0.12	0.02	0.06	0.01	0.10
	Proportion nonwoody	0.39	0.04	0.09	0.00	0.02
	Proportion of reach	0.51	0.07	0.14	0.01	0.11
Species CPUE (fish/min)	BKT	0.00	0.17	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.17	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.15
	LND	0.00	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.00	0.00	1.11
	RSS	0.00	0.00	0.00	0.00	1.24
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.00	1.95	0.00	1.42	0.00
	SPD	0.00	0.00	0.00	0.00	0.62
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	0.00	0.00	1.77	0.32	1.06
Westslope Cutthroat Trout	Age-0 CPUE	0.76	0.03	0.26	0.42	0.00
	Age-0 density (fish/100m^2)	27.12	0.35	3.80	2.41	0.00
	Age-1+ CPUE	0.28	0.42	0.52	0.53	0.20
	Age-1+ density	9.69	5.26	7.61	2.95	0.38
Maternal influence	Resident	0.53	0.00	0.60	0.83	–
	Fluvial	0.47	1.00	0.40	0.17	–
	Adfluvial	0.00	0.00	0.00	0.00	–

Appendix A cont'd

Site		W.F. Emerald Creek 1	W.F. Emerald Creek 2	W.F. Emerald Creek 3	W.F. Merry Creek 1	W.F. Merry Creek 2
Date		6/8/2017	7/7/2017	6/27/2018	7/18/2017	7/18/2018
NAD 83 UTM	Zone	11T	11T	11T	11T	11T
	Easting	0549826	0545834	0550812	0559114	0558485
	Northing	5208464	5208347	5208482	5209496	5213935
Elevation (m)		857	898	851	911	1083
Gradient (%)		0.57	1.60	0.33	1.56	2.22
Land use		mineral	forest	mineral	timberland	forest
Road density (km/km^2)		1.58	1.95	1.58	0.87	0.85
Distance to road (m)		157.78	679.83	100.45	137.49	587.59
Temperature (°C)	At time of sampling	12.74	13.71	10.10	12.96	12.30
	Mean summer (SD)	–	–	15.40 (2.88)	–	–
	Max summer	–	–	21.66	–	–
Reach length (m)		120.60	132.70	107.90	119.30	79.20
Reach area (m^2)		465.85	463.10	336.34	324.24	215.33
Proportion of macrohabitat in reach	Runs	0.31	0.46	0.56	0.41	0.00
	Riffles	0.25	0.28	0.13	0.15	0.90
	Pools	0.44	0.27	0.32	0.44	0.10
	Off-channel	0.00	0.00	0.00	0.00	0.00
Pool:riffle		1.79	0.96	2.51	2.91	0.11
Depth (m)		0.38	0.22	0.34	0.25	0.14
CV depth		23.73	17.90	24.78	22.64	43.06
Width (m)		3.86	3.61	3.16	2.84	2.75
CV width		11.68	7.42	22.34	18.07	50.73
Current velocity (m/s)		0.33	0.32	0.30	0.17	0.46
CV velocity		6.25	11.91	24.49	5.79	65.15
Canopy cover (%)		66.41	63.99	52.35	71.49	62.92
CV canopy cover		16.69	12.13	24.95	19.51	59.58
Substrate type	Fine	0.18	0.06	0.32	0.63	0.01
	Gravel	0.91	0.72	0.70	0.76	0.59
	Large	0.43	1.12	0.38	0.71	1.56
Substrate embeddedness		0.30	0.36	0.10	0.40	0.01
Instream cover	Total area (m^2)	50.40	40.94	47.22	140.60	16.47
	Proportion woody	0.07	0.05	0.14	0.40	0.01
	Proportion nonwoody	0.04	0.04	0.00	0.04	0.06
	Proportion of reach	0.11	0.09	0.14	0.43	0.08
Species CPUE (fish/min)	BKT	0.00	0.09	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00	0.00
	LGS	0.00	0.00	0.00	0.00	0.00
	LND	0.12	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00	0.00
	NPM	0.00	0.00	0.28	0.00	0.00
	RSS	0.00	0.00	0.40	0.00	0.00
	RXC	0.00	0.00	0.00	0.00	0.00
	SHS	0.00	2.32	0.00	1.71	3.91
	SPD	0.18	0.00	0.40	0.00	0.00
	TNC	0.00	0.00	0.00	0.00	0.00
	TRS	1.57	0.00	0.61	0.17	0.00
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.00	0.00	0.04
	Age-0 density (fish/100m^2)	0.00	0.00	0.00	0.00	0.46
	Age-1+ CPUE	0.11	0.20	0.00	0.55	0.43
	Age-1+ density	0.64	0.86	0.00	5.86	4.18
Maternal influence	Resident	0.00	0.00	–	0.13	0.20
	Fluvial	0.88	1.00	–	0.87	0.80
	Adfluvial	0.12	0.00	–	0.00	0.00

Appendix A cont'd

Site		W.F. St. Maries River 1	W.F. St. Maries River 2	W.F. St. Maries River 7	W.F. St. Maries River 9
Date		6/20/2017	7/27/2017	7//1/2018	6/29/2017
NAD 83 UTM	Zone	11T	11T	11T	11T
	Easting	0556384	0555552	0554675	552681
	Northing	5205878	5203442	5201020	5200460
Elevation (m)		858	871	889	901
Gradient (%)		0.20	0.23	0.39	0.51
Land use		grazing	grazing	thinned	timberland
Road density (km/km^2)		1.08	1.24	1.22	1.39
Distance to road (m)		42.33	356.34	1120.16	17.56
Temperature (°C)	At time of sampling	15.44	16.82	13.00	14.69
	Mean summer (SD)	–	17.10 (2.01)	–	13.28 (1.74)
	Max summer	–	21.76	–	17.76
Reach length (m)		189.90	164.60	126.50	111.60
Reach area (m^2)		1190.02	699.28	581.46	328.11
Proportion of macrohabitat in reach	Runs	0.23	0.27	0.11	0.22
	Riffles	0.11	0.08	0.00	0.07
	Pools	0.66	0.66	0.89	0.71
	Off-channel	0.00	0.00	0.00	0.00
Pool:riffle		5.85	8.59	0.00	9.60
Depth (m)		0.55	0.33	0.60	0.36
CV depth		32.62	40.75	58.65	42.37
Width (m)		5.42	4.18	4.67	3.27
CV width		33.16	34.72	59.36	37.60
Current velocity (m/s)		0.25	0.20	0.02	0.12
CV velocity		16.40	15.33	19.01	21.53
Canopy cover (%)		39.26	53.94	83.07	65.32
CV canopy cover		35.19	34.88	53.17	33.43
Substrate type	Fine	0.52	1.03	0.57	0.74
	Gravel	0.97	1.23	0.63	1.23
	Large	0.58	0.04	0.06	0.01
Substrate embeddedness		0.47	0.07	0.44	0.03
Instream cover	Total area (m^2)	203.03	97.03	35.47	83.33
	Proportion woody	0.05	0.05	0.06	0.08
	Proportion nonwoody	0.12	0.09	0.00	0.17
	Proportion of reach	0.17	0.14	0.06	0.25
Species CPUE (fish/min)	BKT	0.00	0.00	0.00	0.00
	BLG	0.00	0.00	0.00	0.00
	BLH	0.00	0.00	0.00	0.00
	BLP	0.00	0.00	0.00	0.00
	BLT	0.00	0.00	0.00	0.00
	LGS	0.19	0.26	0.00	0.00
	LND	0.00	0.00	0.00	0.00
	MWF	0.00	0.00	0.00	0.00
	NPM	0.26	0.28	0.00	0.00
	RSS	0.51	0.19	0.00	0.00
	RXC	0.00	0.00	0.00	0.00
	SHS	0.00	0.00	0.00	0.41
	SPD	0.64	1.18	0.04	0.32
	TNC	0.00	0.06	0.00	0.00
	TRS	0.25	0.28	1.21	0.60
Westslope Cutthroat Trout	Age-0 CPUE	0.00	0.00	0.09	0.09
	Age-0 density (fish/100m^2)	0.00	0.00	0.52	2.74
	Age-1+ CPUE	0.00	0.00	0.09	0.10
	Age-1+ density	0.00	0.00	0.52	2.44
Maternal influence	Resident	–	–	0.50	0.59
	Fluvial	–	–	0.50	0.41
	Adfluvial	–	–	0.00	0.00