Snoqualmie River
Game Fish Enhancement Plan

FINAL REPORT OF RESEARCH

Jamie N. Thompson, Jennifer L. Whitney, Robert E. Lamb

Washington Department of Fish and Wildlife

November 2011

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Snoqualmie River Game Fish Enhancement Plan:
Final Report of Research

Submitted to Puget Sound Energy in partial fulfillment of the
Snoqualmie River Game Fish Enhancement Plan

SNOQUALMIE FALLS HYDROELECTRIC PROJECT
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All photos throughout this document Courtesy of Washington Department of Fish and Wildlife.
Front Cover: Upper Middle Fork Snoqualmie River near Goldmyer Hot Springs
Back Cover: Coastal cutthroat trout, Upper Middle Fork Snoqualmie River

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1. Introduction

The Snoqualmie River Game Fish Enhancement Plan (Plan) is a comprehensive inventory and ecological study of the fishery resources in the upper Snoqualmie River watershed (USRW). The USRW consists of all waters draining the Snoqualmie River basin upstream of the Snoqualmie Falls Hydroelectric Project, which is owned and operated by Puget Sound Energy (PSE).

In 2004, the Federal Energy Regulatory Commission (FERC) issued a new license for the hydroelectric project. Article 413 of the license required PSE to file a Plan to the FERC for approval and to allocate funds to implement it. PSE developed the Plan in consultation with the Washington Department of Fish and Wildlife (WDFW) and submitted it to the FERC (Puget Sound Energy 2005).

The Plan was approved by the FERC in December 2006, and in 2007, PSE contracted WDFW to conduct the Plan. Ten primary study tasks related to game fish resources were identified for the Plan, including: 1) habitat surveys and mapping, 2) background environmental data monitoring, 3) trout reproductive life history, 4) age and growth studies, 5) density and relative abundance, 6) creel census, 7) species distribution, 8) trout movement, 9) habitat enhancement, and 10) public education.

These tasks are consistent with the mission of WDFW, which is to provide maximum recreational fishing opportunities compatible with healthy and diverse fish populations. Investigative results were intended to serve as a resource for management of the wild trout fishery. The goals of implementing Plan study tasks were to provide an updated assessment of the fishery resource and aquatic habitats, to identify potential fishery or habitat enhancement opportunities, and to expand public awareness of the resource.

The Plan was divided into three phases: 1) literature review and study design, 2) field studies, analysis, and interpretation, and 3) programmatic implementation. Phase 1 began in January 2008 and was completed in June 2008 as existing USRW fishery data were compiled in a literature review, and data gaps in Plan research tasks were identified (Overman 2008, Appendix 4). Phase 2 began in July 2008 with the initiation of pilot field studies. Fieldwork continued through November 2010, and Phase 2 concluded with analysis of data and interpretation of results. Phase 3 implementation began in September 2011 as results from field studies were used to guide habitat enhancement and public outreach.

2. Research Objectives

Phase 1:
Literature Review and Study Plan

The objectives for Phase 1 were to identify fishery data gaps for the USRW and define the scope of work for the Plan. The fulfillment of these objectives required a comprehensive review of current and historical scientific literature on the USRW fishery resources and the development of a study plan. The literature review revealed that there were data gaps for each of the ten study tasks identified in the Plan (Overman 2008, Appendix 4).

Phase 2:
Field Studies

The three overall research objectives outlined for Phase 2 fieldwork were: 1) improve the knowledge of game fish populations and fish habitat in the USRW; 2) collect useful information for management of the USRW fishery; and 3) identify fishery enhancement opportunities. To satisfy these objectives, Phase 2 study tasks were defined as follows (WDFW 2008):

1) *Habitat surveys and mapping*—Describe the quality and quantity of game fish habitat, assess man-made and natural barriers to fish passage, and help identify general limiting factors.
2) *Background environmental data monitoring*—Characterize environmental conditions and their effects on resident fish populations.
3) *Trout reproductive life history*—Determine spawning distribution, habitat use, quality/type of spawning habitat, spawning duration, egg/alevin incubation periods, and behavior of spawning adults and newly emerged fry.
4) *Age and growth studies*—Refine knowledge of population age structure, growth, mortality, and age at maturity.
5) *Density and relative abundance*—Develop estimates of trout abundance and size or age structure for various reaches in the basin.
6) *Creel census*—Assess angler effort, catch, harvest, and demographics as practical.
7) *Species distribution*—Determine presence and spatial distribution of native and non-native trout and other fishes (juvenile and adult), and assess alpine lake trout stocking influences on composition where practical.
8) *Movement*—Determine if trout exhibit extensive instream movements, including seasonal transitions to summer feeding stations, overwintering areas, and spawning sites.

Phase 3:
Programmatic Implementation

The primary objectives for Phase 3 were to identify habitat enhancement and public education or outreach opportunities in the USRW. Phase 2 field studies were designed in conjunction with Phase 3 to help identify habitat enhancement needs and increase the public's awareness of the fishery resources available in the USRW (WDFW 2008):

9) *Habitat enhancement*—Supplement existing habitat information useful for fishery management and identify habitat enhancement opportunities.
10) *Public outreach and education*—Help educate the public on the fishery opportunities available in the Snoqualmie River.

Study tasks were consolidated into five chapters to improve the organization and fluidity of this document: Chapter 4 Habitat and Water Quality, Chapter 5 Abundance, Distribution, and Age and Growth, Chapter 6 Movement and Life History, Chapter 7 Angler Use, and Chapter 8 Habitat Enhancement and Public Outreach.

3. Study Area

Upper Snoqualmie River Watershed

The USRW is composed of the headwater portions of the Snoqualmie River above Snoqualmie Falls, an 82 m vertical barrier that limits anadromous fish distribution to the lower watershed. The Snoqualmie River below Snoqualmie Falls converges with the Skykomish River near the city of Monroe to form the Snohomish River, the second largest river system flowing into Puget Sound (Figure 1). Major river basins in the USRW are the North, Middle, and South forks, and the Mainstem of the Snoqualmie River above Snoqualmie Falls. The Snoqualmie forks originate on the west slopes of the Cascade Mountains, flowing in a general westerly direction through varied landscapes, and converge as the Mainstem Snoqualmie near the cities of Snoqualmie and North Bend (Figure 2). The Mainstem Snoqualmie continues downstream for about 6 km before plunging over Snoqualmie Falls.

The headwater portions of each fork originate high on the Cascade Crest in the Alpine Lakes Wilderness. In a landscape sculpted by alpine glaciers (c. 20,000 years before

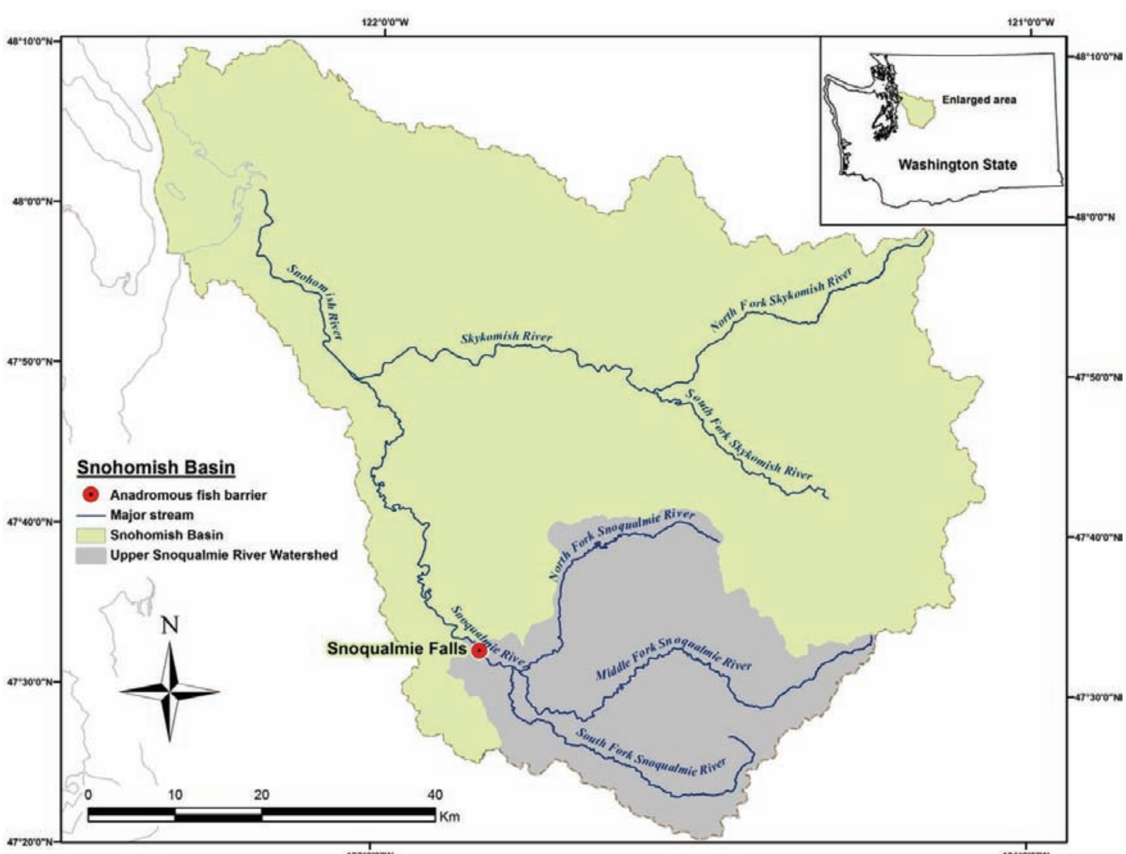


Figure 1. Map of the Snohomish River basin, which is composed of the Snoqualmie and Skykomish watersheds. The upper Snoqualmie River watershed (highlighted in gray) is isolated by Snoqualmie Falls.

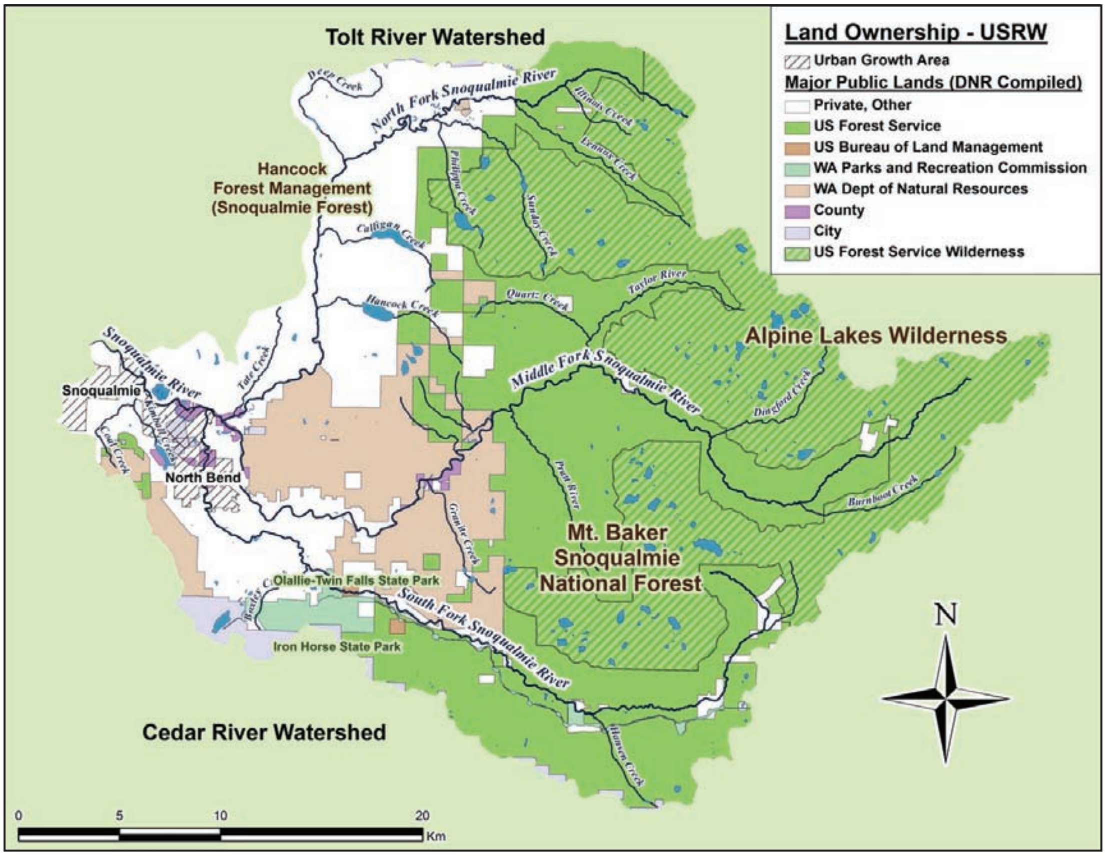


Figure 2. Land ownership, land management and urban growth areas in the upper Snoqualmie River watershed.

present [ybp]), headwaters consist of confined, turbulent, high gradient habitats with geologic barriers that isolate fish into sub-populations (Figure 3). Downstream of headwaters, the steep stream channels give way to more moderate gradient terraced u-shaped montane valley bottoms. Gradient is heterogeneous along montane valley bottoms as low gradient segments yield to steeper exposed bedrock or boulder-cascade reaches that isolate fish (e.g., Big Creek Falls in the North Fork and Weeks Falls in the South Fork). Each fork is low to moderate gradient downstream of the largest geologic barriers (Black Canyon in the North Fork, Twin Falls in the South Fork, and Dingford Canyon in the Middle Fork).

Natural history

Prior to the most recent continental glaciation (c. 14,000 ybp), the upper Cedar River basin drained directly into the Snoqualmie basin. However, the Cedar River was diverted south and the major geologic barriers in each fork of the Snoqualmie were formed after the encroachment and retreat of the Vashon Lobe of the Cordilleran Ice Sheet, as glacial moraines (e.g., Grouse Ridge) were formed, creating lakes behind large earthen dams, and bedrock outcroppings (e.g., Twin Falls) were exposed. The Vashon Lobe of the ice sheet blocked the pathway of the Snoqualmie River, and a large ice-marginal lake occupied the lower portion of the basin just upstream of Snoqualmie Falls as the ice sheet slowly retreated. This lake received streamflow from most, if not all, northern and central Puget Sound basins (Skagit, Stilliguamish, Skykomish, etc.) as they converged with and flowed south along the eastern border of the ice sheet. The original outlet for the ice marginal lake was through the Cedar Channel near Rattlesnake Lake, but as the Vashon Lobe retreated, the lake level dropped and the Snoqualmie carved a new channel that flowed over Snoqualmie Falls (Figure 3). More detailed descriptions of the geomorphologic and glacial processes that have influenced the landscape of the USRW are the subjects of other studies, but were used in this study to gain a broader understanding of the watershed on a geologic timeline (MacKin 1941, Booth 1990, Bethel 2004, Fenner 2008).

Fish species

Predominant game fish in the USRW are the Pacific trout

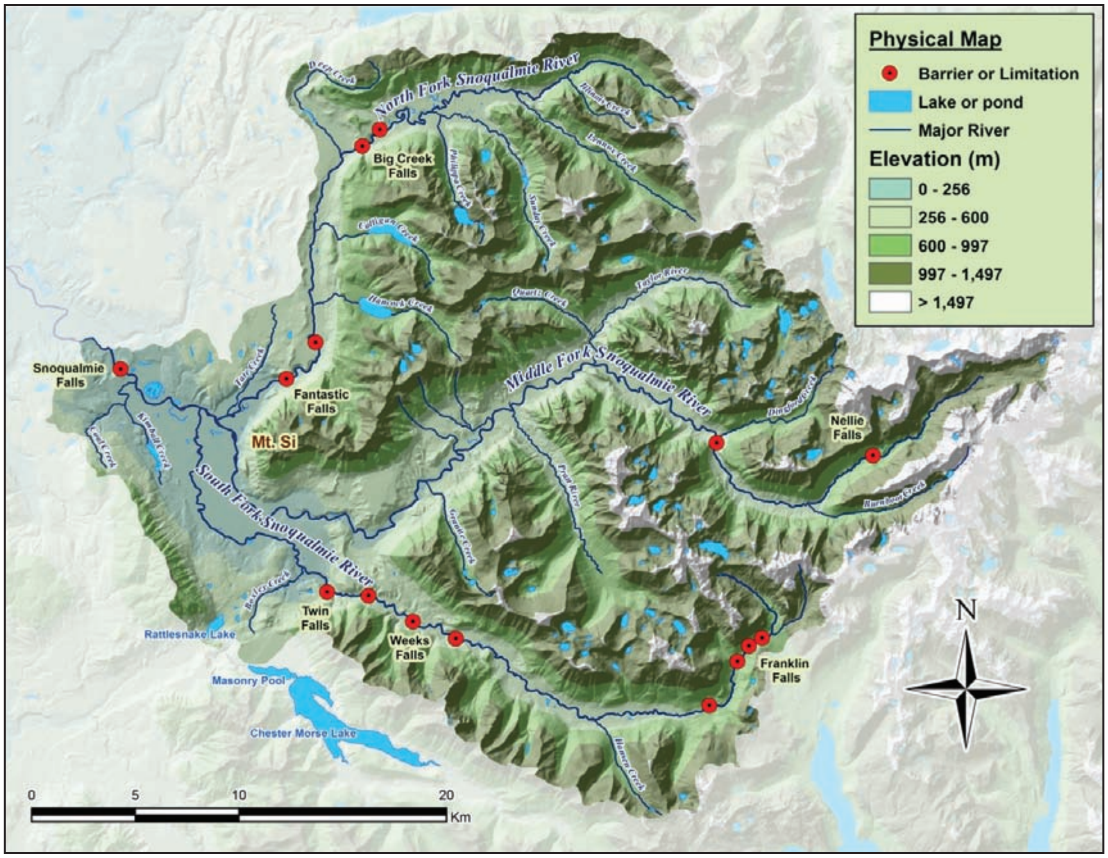


Figure 3. Physical map of the upper Snoqualmie River watershed showing the locations of known geologic barriers. Chester Morse Lake and Masonry Pool (upper Cedar River Municipal watershed) are shown because they are linked to the South Fork Snoqualmie River through a glacial moraine near the headwaters of Boxley Creek.

species, including coastal cutthroat trout *Oncorhynchus clarki clarki* (CCT), rainbow trout *O. mykiss* (RBT), westslope cutthroat trout *O. clarki lewisi* (WCT), and hybrid or unidentified Pacific trout *Oncorhynchus* species (Onxx). Less abundant game fishes include eastern brook trout *Salvelinus fontinalis* (EBT) and mountain whitefish *Prosopium williamsoni* (MWF). Other fish species include largescale sucker *Catostomus macrocheilus* (SUCKER), longnose dace *Rhinichthys cataractae*, and western brook lamprey *Lampetra richardsoni*. Sculpin species include shorthead *Cottus confusus*, mottled *C. bairdi*, torrent *C. rhotheus*, Pauite *C. beldingii*, and reticulate *C. perplexus,* (Overman 2008, Appendix 4), but were not differentiated in this portion of the study. Other species known to inhabit or that have been stocked in water bodies of the USRW include threespine stickleback (*Gasterosteus aculeatus*), golden trout (*O. aguabonita*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), and pumpkinseed (*Lepomis gibbosus*). Bull trout (*Salvelinus confluentus*) is the only known char species endemic to the inland Central Puget Sound region, but none were found during this study. Over the years, anglers have reported sightings of bull trout in the USRW; however, none were observed during a previous study designed specifically to detect their presence in the USRW (Berge and Mavros 2001).

Study design

Each fork and the Mainstem Snoqualmie were organized into units at large, medium, and fine scales (Table 1). Use of multiple scales helped to categorize patterns in biological and physical factors during analysis to enable meaningful syntheses and comparisons within and between the forks and Mainstem Snoqualmie. Units in the large-scale category (river sections) were delineated by locations of the major geologic barriers or transitions in gradient. Each of the forks was divided into upper, middle, and lower river sections, and the Mainstem Snoqualmie was divided into upper and lower river sections (Figure 4). Units in the medium-scale category (river segments) were delineated by localized transitions in gradient, geologic barriers, geo-

Table 1. Spatial range and defining characteristics of the three scales used to investigate physical and biological patterns in the upper Snoqualmie River watershed (*sensu* Frissell et al. 1986, Naiman et al. 1992, Kocik and Ferreri 1998, and Montgomery and Buffington 1998).

Scale	System level	Linear spatial scale	Environmental characteristics that distinguish each level
Large	River Section	5–20 (km)	Watershed scale gradient transitions, migratory barriers
Medium	River Segment	1–10 (km)	Segment-scale gradient transitions, migratory barriers or limitations, reach morphology, fish abundance or species composition
Fine	Habitat Unit	1–1,000 (m)	Gradient, depth, hydrologic characteristics such as sheerness and velocity of flow

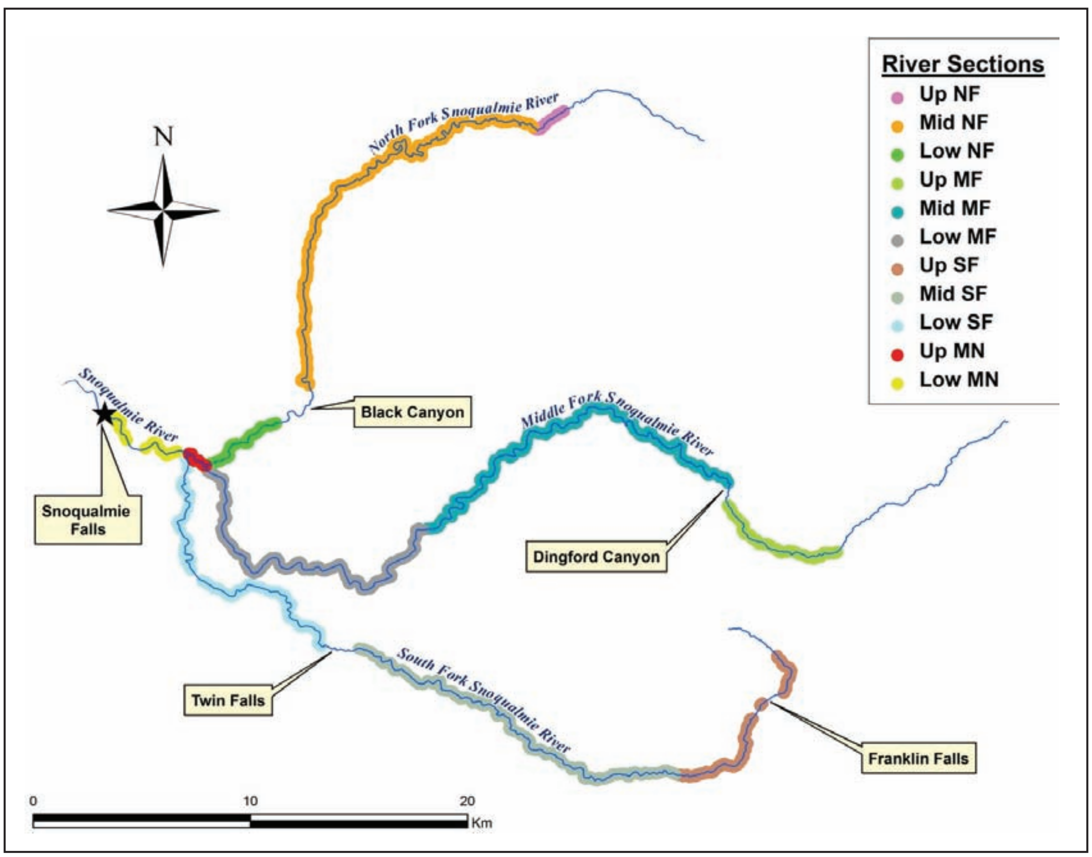


Figure 4. River section divisions and non-surveyed areas in captions. Color codes delineate river sections and show the extent of the snorkel/habitat survey range in each fork and the Mainstem Snoqualmie River.

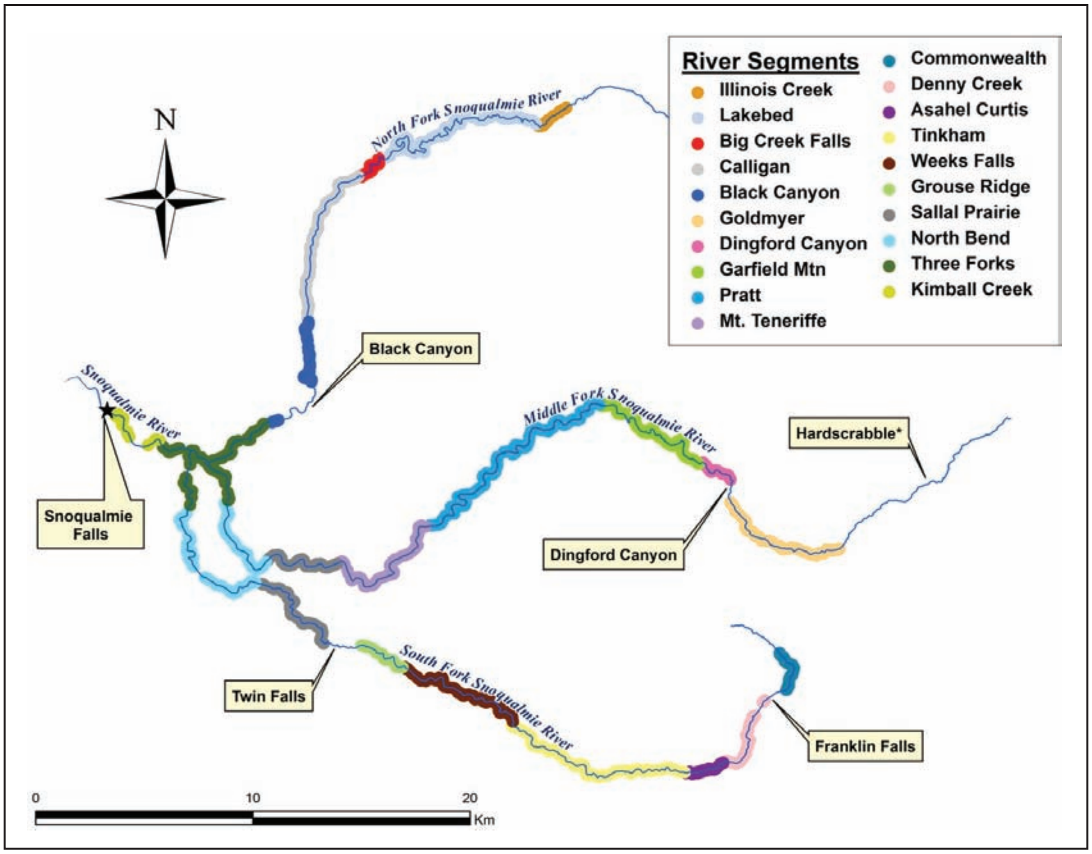


Figure 5. River segment divisions and non-surveyed areas in captions. Color codes delineate river segments and show the snorkel/habitat survey range in each fork and the Mainstem Snoqualmie River. *The Hardscrabble reach (Up MF) was explored and trout genetic samples were opportunistically obtained, but the area was not within the snorkel/habitat survey range.

morphic reach type (Montgomery and Buffington 1998), and fish abundance or species composition. River segments were similar to functional habitat units described by Kocik and Ferreri 1998, which incorporate the spatial arrangement of channel types and coincide with variation in fish production and distribution (Figure 5). River section and segment names and abbreviations used throughout this document, and total lengths of each of these two unit types are listed in Table 2. The fine-scale units (habitat units) were delineated based on smaller scale hydrologic characteristics commonly described in other studies of riverine fishes and aquatic habitat (e.g., Bisson et al. 1982). All fish counts and habitat measurements were made at the habitat unit scale (Table 3). Tributaries were systematically surveyed, and for reference, unnamed tributaries were given aliases. Tributary aliases are shown in text, tables, and figures with an asterisk throughout the remainder of this document and may differ with popular or unofficial names.

North Fork Snoqualmie River

The North Fork Snoqualmie River sub-basin encompasses 268.1 km² and begins near Lake Kanim in the Alpine Lakes Wilderness. The upper North Fork Snoqualmie river section (Up NF) begins approximately 1 km upstream of the confluence with Lennox Creek and continues upstream for approximately 2 km. Habitat consists of bedrock cascades at the upper end (Figure 6a), but transitions to alluvial plane-bed with large woody debris (LWD) accumulations toward the confluence with Lennox Creek. The middle section of the North Fork Snoqualmie (Mid NF) begins approximately 1 km upstream of the confluence with Lennox Creek and continues downstream to the non-surveyed Black Canyon area. A large portion of this river section flows through an ancient glacial lakebed that contains exposed lacustrine clay deposits, where erosion has led to bank failures, and large amounts of LWD recruit into the channel. Habitat in this river segment (Lakebed

Table 2. River section names, river section abbreviations, river segment names, and total surveyed length of each of these two unit types.

River Section	River Section (abbreviations)	River Segment	Unit length (km)
Upper North Fork	Up NF		**1.84**
		Illinois Creek	1.84
Middle North Fork	Mid NF		**25.32**
		Lakebed	12.27
		Big Creek Falls	1.64
		Calligan	8.30
		Black Canyon	3.11
Lower North Fork	Low NF		**4.39**
		Black Canyon	0.32
		Three Forks	4.06
Upper Middle Fork	Up MF		**6.83**
		Goldmyer	6.83
Middle Middle Fork	Mid MF		**22.44**
		Dingford Canyon	1.89
		Garfield Mtn.	7.04
		Pratt	13.51
Lower Middle Fork	Low MF		**18.42**
		Mt. Teneriffe	7.22
		Sallal Prairie	4.18
		North Bend	4.57
		Three Forks	2.45
Upper South Fork	Up SF		**8.06**
		Commonwealth	2.22
		Denny Creek	4.41
		Asahel Curtis	2.37
Middle South Fork	Mid SF		**19.28**
		Tinkham	9.84
		Weeks Falls	6.43
		Grouse Ridge	3.01
Lower South Fork	Low SF		**15.49**
		Sallal Prairie	5.13
		North Bend	7.33
		Three Forks	3.04
Upper Mainstem	Up MN		**1.70**
		Three Forks	1.70
Lower Mainstem	Low MN		**4.45**
		Three Forks	1.31
		Kimball Creek	3.14
Total			**128.21**

Table 3. Criteria for delineating habitat unit types in the upper Snoqualmie River watershed (*sensu* Bisson et al. 1982; Frissell et al. 1986; and Montgomery and Buffington 1998).

Habitat unit type	Typical gradient % slope	General description of habitat type
Pool	0–0.10	Residual depth, low velocity flow throughout middle and base, eddies on either side, non-uniform cross section, base of unit shallower than head, major substrate deposition at base
Glide	0.10–1.0	Sheer flow, but can be interrupted by structure (pocket water), uniform cross section and depth, minor deposition or scour
Riffle	1.0–3.0	Shallow depth, broken surface, often with significant turbulence, high velocity flow, uniform cross section but may have deeper pockets
Cascade	≥ 3.0	Moderately shallow but with deeper pockets, large substrates, turbulence and higher velocity flow than found in riffles

Figure 6a. Boulder cascades in the Illinois Creek segment of the Up NF.

Figure 6b. Erosion, LWD recruitment, and pool habitat in the Lakebed segment of the Mid NF.

segment) can be characterized as alluvial dune-ripple and pool-riffle (Figure 6b). The Big Creek Falls segment begins where the valley confines, the gradient steepens, and a large slope failure caused a boulder cascade limitation near the outlet of the ancient lake. As gradient increases downstream, the Mid NF plunges over a series of bedrock cascade barriers near the confluence with Big Creek (Figure 6c). Beginning at the base of Big Creek Falls, the Calligan segment is characterized as alluvial pool-riffle. The Mid NF throughout the Calligan segment is naturally channelized and off-channel habitat availability and diversity are limited (Figure 6d). The Black Canyon segment begins at the Spur 10 Bridge as the Mid NF becomes increasingly steeper and incised before entering the non-surveyed portion of the Black Canyon. The Black Canyon contains at least one barrier cascade (Fantastic Falls) as the Mid NF flows steeply over bedrock with numerous cascades and falls. The Mid NF drops about 150 m in elevation through the Black Canyon, and the deeper canyon reach was not surveyed due to logistical and safety constraints. The lower section of the North Fork Snoqualmie (Low NF) begins at the base of the Black Canyon (Figure 6e) and continues downstream to the confluence with the Middle Fork Snoqualmie. A

Figure 6d. Constrained pool-riffle habitat in the Calligan segment of the Mid NF.

Figure 6c. Big Creek Falls, a short series of bedrock cascade barriers in the Big Creek Falls segment of the Mid NF.

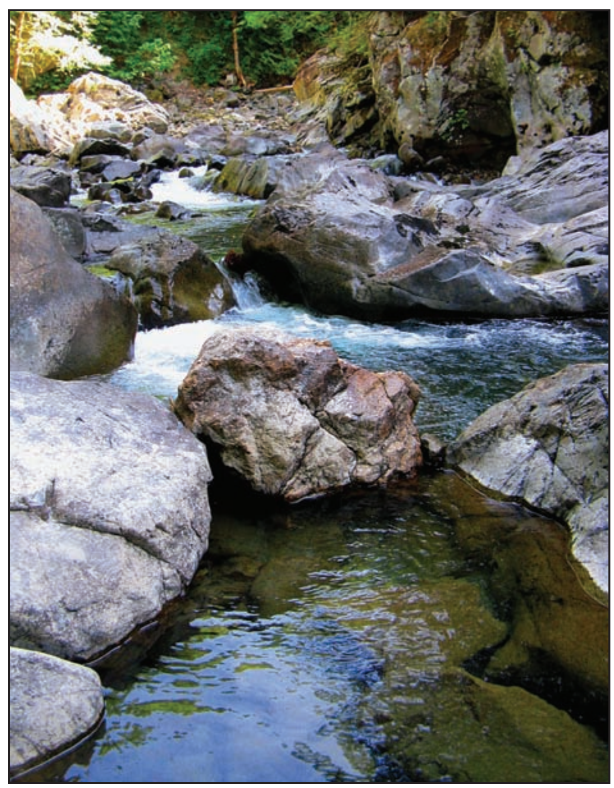


Figure 6e. Bedrock cascades in the lower Black Canyon segment of the Low NF.

small portion of the Low NF flows through the lower Black Canyon segment, but a majority flows through the alluvial pool-riffle Three Forks segment where some bank armoring has caused excessive channelization.

Middle Fork Snoqualmie River

The Middle Fork Snoqualmie River encompasses 440.3 km² and begins near La Bohn Gap in the Alpine Lakes Wilderness. The upper Middle Fork Snoqualmie river section (Up MF) begins at the Middle Fork Snoqualmie River Trail footbridge near Goldmyer Hot Springs Resort and continues downstream to Dingford Canyon. The Up MF can be characterized mainly as alluvial pool-riffle with gravel and cobble substrates and some particularly extensive LWD accumulations (Figure 7a), but a short stretch near Dingford Creek consists of boulder and bedrock cascades and pools. At its steepest point, Dingford Canyon contains at least one barrier cascade. The Up MF drops about 100 m in elevation through Dingford Canyon, and this area was not surveyed due to logistical and safety constraints. The middle section of the Middle Fork Snoqualmie River (Mid MF) begins at the base of Dingford Canyon (Figure 7b) and continues downstream to the confluence with Granite Creek. Habitat in the Garfield Mtn. and Pratt segments of the Mid MF consists of alluvial plane-bed and pool-riffle channel types (Figure 7c). Medium and large cobbles are the main substrates in the Mid MF, and prominent lacustrine clay deposits intersect with the channel causing increased turbidity downstream. The Granite Creek confluence marks the beginning of the lower Middle Fork Snoqualmie (Low MF), which continues downstream to the confluence with the North Fork Snoqualmie River. Habitat in the Low MF is characterized by boulder cascades and step-pools throughout the Mt. Teneriffe and Sallal Prairie segments (Figure 7d), but transitions to alluvial pool-riffle or plane-bed morphology as it reaches the North Bend segment (Figure 7e). Large cobbles are the predominant substrate type throughout much of the Low MF, but substrates transition to gravel near the Three Forks river segment. Bank armor and dikes channelize the Low MF as it flows through the city of North Bend.

Figure 7a. Broad, active valley with pool-riffle alluvial habitat and expansive accumulations of LWD in the Goldmyer segment of the Up MF.

Figure 7b. Boulder cascades at the base of Dingford Canyon in the Garfield Mtn. segment of the Mid MF.

Figure 7c. Alluvial pool-riffle habitat in the Garfield Mtn. segment of the Mid MF.

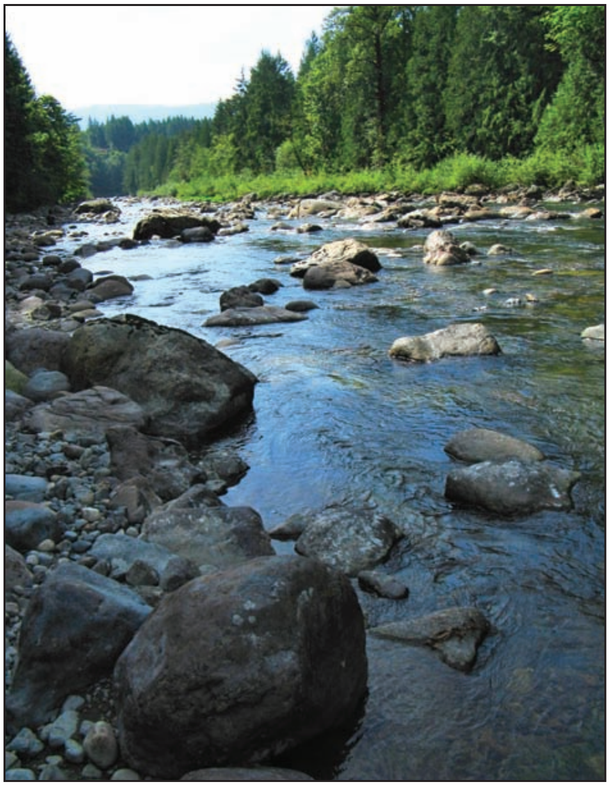


Figure 7d. Boulder riffles and cascade pocket water in the Mt. Teneriffe segment of the Low MF.

South Fork Snoqualmie River

The South Fork Snoqualmie River drainage encompasses 221.2 km² and begins in the Alpine Lakes Wilderness near Source Lake. Habitats in the upper South Fork Snoqualmie river section (Up SF) range from steep bedrock cascades with deep pools in the Denny Creek segment (Figure 8a) to gravel and cobble alluvial pool-riffle and plane-bed in the Asahel Curtis segment. At least four migratory barriers were identified in the Up SF, one of which is Franklin Falls, a series of bedrock waterfalls with a total drop of 41 m. Most of the Up SF near Franklin Falls was not surveyed due to logistical and safety constraints. At the downstream end of the Asahel Curtis segment, gradient lessens, finer sediments and LWD accumulate, and the river section changes to the middle South Fork Snoqualmie (Mid SF). The Tinkham segment of the Mid SF generally fits the description for alluvial pool-riffle or plane-bed as it contains gravel and cobble substrates and some accumulations of LWD throughout (Figure 8b), but is interspersed with short bedrock cascades. At least three bedrock migratory barriers were identified in the Weeks Falls segment of the Mid SF (Figure 8c), one of which is Weeks Falls (20 m drop), where a small hydroelectric project is maintained. The Twin Falls vicinity contains a number of barrier cascades and vertical drops in a steep bedrock canyon, and a

Figure 7e. Plane-bed and pool-riffle habitat in the North Bend segment of the Low MF. Note the width and shallowness of the channel.

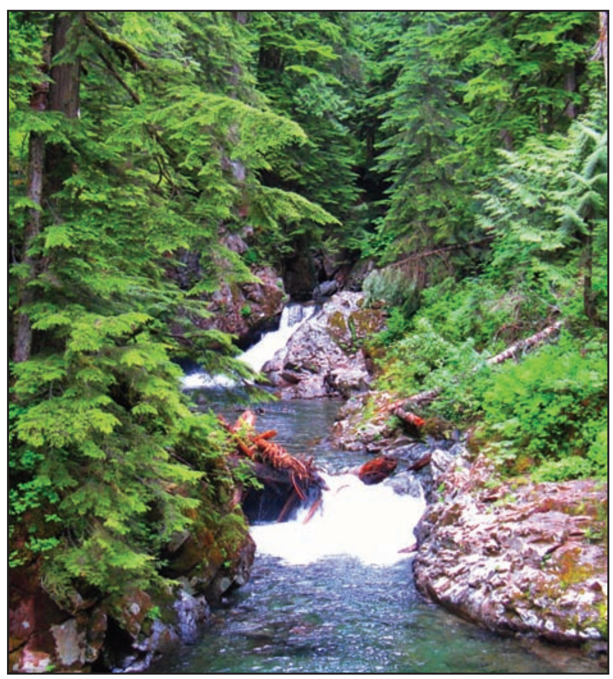


Figure 8a. Bedrock cascade and pool habitat in the Denny Creek segment of the Up SF.

small hydroelectric project is maintained just upstream of the first falls. At Twin Falls the Mid SF drops about 45 m in elevation and the area was not surveyed due to logistical and safety constraints. The lower South Fork Snoqualmie (Low SF) begins at the base of Twin Falls and continues downstream to the confluence with the lower Mainstem Snoqualmie (Low MN). Habitats in the Low SF range from moderate boulder cascades in the Sallal Prairie segment to alluvial pool-riffle in the North Bend segment (Figure 8d) and dune-ripple, with abundant LWD jams in the Three Forks segment. Bank armor and dikes channelize a large portion of the Low SF as it flows through the city of North Bend.

Figure 8b. Alluvial plane-bed habitat in the Tinkham segment of the Mid SF.

Mainstem Snoqualmie River

The Mainstem Snoqualmie River sub-basin begins at the confluence between the Middle Fork and North Fork of the Snoqualmie River, continues for abut 6 km, and ends about 200 m upstream of Snoqualmie Falls. Throughout this document, we refer to this body of water as the Mainstem Snoqualmie, whereas we use the terms “main-stem” or “main-stem channel” to differentiate main channel habitats from tributary habitats. The upper Mainstem Snoqualmie (Up MN) is located between the North–Middle Fork convergence and the South Fork confluence. Habitat in the Up MN is characterized by pool-riffle morphology with expansive gravel bars and an extensive LWD jam (Figure 9a). Downstream of the South Fork confluence, the Low MN is characterized by dune-ripple morphology (Bethel 2004). Substrates consist mainly of smaller gravels and fines in this section (Figure 9b). Channelization in the Low MN is due to a lack of erosion capability but is compounded by extensive bank armoring along most of its length (Figure 9c).

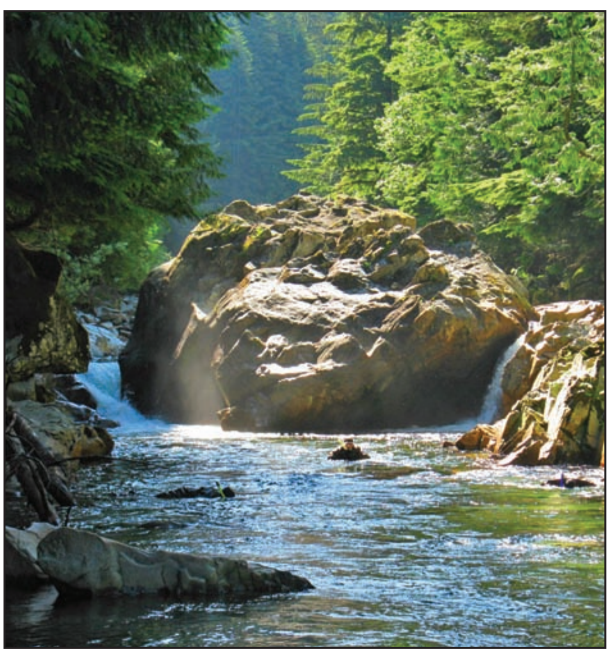


Figure 8c. An unnamed bedrock cascade barrier upstream of Weeks Falls in the Weeks Falls segment of the Mid SF.

Figure 8d. Alluvial pool-riffle habitat in the North Bend segment of the Low SF.

Figure 9a. Pool habitat and LWD jam in the Three Forks segment of the Up MN.

Figure 9b. Broad gravel bar in the Kimball segment of the Low MN.

Figure 9c. Rip-rap and channelized pool habitat in the Kimball segment of the Low MN.

4. Habitat and Water Quality

Methods

To quantify the amount, condition, and limitations of aquatic habitat in the USRW, surveys were conducted extensively at a landscape scale (Fausch et al. 2002). Habitat surveys were designed to compare habitat longitudinally within each fork and the Mainstem Snoqualmie and among river sections.

In the Snoqualmie forks, data were collected continuously in habitat units from near the headwaters to the mouth in all river segments. Exceptions included areas characterized by steep canyons and falls. Most of the Mainstem Snoqualmie was surveyed; however, the lower 200 m just above Snoqualmie Falls were not surveyed due to safety concerns. Tributary surveys were similar to main-stem channel surveys in that they were longitudinally continuous and data were collected at the habitat unit scale using the same habitat unit types. Tributaries were selected using a systematic scheme that combined basin area, distance between tributaries, and probability of fish presence. Tributary habitat was inventoried from the mouth (0 m) to 400 m.

During both main-stem channel and tributary surveys, habitat units were delineated, habitat variables were visually estimated within each unit, and coordinates were recorded at the base of each unit using a handheld GPS receiver. Habitat variables included average active and wetted width, average and maximum channel depth, LWD count, and gradient. Pieces of wood that intersected with the wetted width of the channel were considered LWD, but size criteria for LWD classifications were different between main-stem channel and tributary habitats. LWD in main-stems were pieces of wood >10 cm in diameter and >2 m in length, whereas LWD in tributaries were pieces of wood >10 cm diameter that spanned at least half the wetted width of the channel. Dominant and subdominant substrate sizes were visually estimated for each unit during main-stem channel and tributary surveys in 2010; however, substrates were not assessed during surveys in 2009 (Table 4). Unique stream features (e.g., erosion, road crossings, and migratory barriers) were documented during surveys to supplement quantitative habitat information.

Main-stem channel habitat

Depending on the wetted width of the channel, between two and six snorkelers and one data recorder surveyed habitat units (Torgersen et al. 2007). Surveys began at the most practical access point near the headwaters of each fork and proceeded continuously downstream until the mouth was reached in order to quantify landscape-scale variability in habitat characteristics (e.g., Vannote et al. 1980). Average and maximum depths (±0.5 m) were estimated using body length as a reference, and conferred in each unit by snorkelers (Torgersen et al. 2007). The data recorder waded or floated in a small pontoon, visually estimating all above-surface variables within each habitat unit including wetted and active channel widths (±1.0 m), which were calibrated using a laser range finder. Latitude-longitude coordinates were recorded with a handheld GPS unit at the downstream end of each habitat unit and at each unique feature.

Table 4. Substrate particle diameter ranges used to estimate dominant/subdominant substrate composition in each habitat unit during main-stem channel and tributary surveys.

Particle	Diameter (mm)
Silt, clay, organics	<3
Sand	<3
Small gravel	3–13
Medium gravel	13–38
Large gravel	38–76
Small cobble	76–152
Medium cobble	152–229
Large cobble	229–305
Small boulder	305–610
Medium boulder	610–914
Large boulder	>914
Bedrock	

Habitat unit lengths (±1.0 m) were estimated from aerial photos in ESRI ArcGIS 9.3.1 as the distance between unit coordinates.

Longitudinal variability in habitat characteristics was graphed for main-stem channels by smoothing habitat variable versus unit-length scatter plot data using the LOWESS function (locally weighted scatter plot smoothing) with a 0.30 or 0.60 sampling proportion and second degree polynomial (Sigma Plot 11.0). Elevation profiles were graphed using percent slope measurements taken every 100 m.

Pool and glide depths were compared among middle river sections, and among the upper Mainstem Snoqualmie (Up MN) and lower river sections of each fork using one-way analysis of variance (Kruskal-Wallis ANOVA on ranks). Dunn's pair-wise multiple comparisons were used to identify where differences in depth occurred among river sections. Depth comparisons were only made among river sections if all units of a particular habitat type were sampled. For example, shallow riffles or glides and turbulent cascades hindered accurate depth estimates, so depths were not estimated in the field and comparisons were not attempted under these environmental constraints. Also, glide depths were not compared among upper river sections because many were shallow and were not sampled. In contrast, glide depths were compared among lower river sections of each fork and the Mainstem Snoqualmie because all glides were deep enough sample.

Tributary habitat

Small-to-medium sized tributaries spaced approximately 3–5 km apart and likely to provide spawning or rearing habitat were selected for surveys. The lower 400 m of each tributary were surveyed by one person with a backpack electrofisher and one data recorder. Habitat units were delineated and width and depth (0.5 m) were measured or visually estimated. Length of each habitat unit and the distance surveyed were measured (1.0 m) with a hip chain. Latitude-longitude coordinates were recorded with a handheld GPS unit at the downstream end of each habitat unit and at each notable feature. In all upper and middle river sections and in the Mt. Teneriffe segment of the Low MF, tributaries were characterized by the degree of lateral confinement as either constrained or unconstrained based on visual estimates of valley-width-to-active-channel-width ratios (ratio <2 = constrained, > 2 = unconstrained). Tributaries in the Kimball, Three Forks, North Bend, and Sallal segments were characterized as lower reaches because they were all located downstream of major barriers in lower river sections (Gregory et al. 1989; Schwartz 1990; Reeves et al. 1998). One-way analysis of variance tests (Kruskal-Wallis ANOVA on ranks) were used to test for differences in habitat composition, slope, LWD abundance, and substrate size among confinement types. Post-hoc tests (Tukey's HSD or Dunn's) revealed where differences in habitat characteristics occurred among the confinement types.

Stream water temperature

In fall of 2008, loggers were deployed in each river section to record hourly water temperature and were removed in October and November 2010 (Figure 10). A large flood in January 2009 flushed the Up NF and Up SF loggers from the channel, rendering them above the water surface during periods of lower stream flows. Therefore, reliable mean daily water temperatures from Up NF and Up SF loggers were regressed with mean daily water temperatures from Mid NF and Mid SF loggers to estimate mean monthly temperatures in the Up NF and Up SF during low-flow periods. In 2009, Up NF/Mid NF regressions were calculated for all months except May, June, and November, and in 2010 for all months except January, May, June, September, and December (n = 412; $P < 0.000$; $r^2 = 0.92$). In 2009, Up SF/Mid SF regressions were calculated for all months except April, May, November, and December, and in 2010 for the months between June and November (n = 454; $P < 0.000$; $r^2 = 0.93$). The temperature logger in the Up MN was installed September 2009, and to estimate mean monthly water temperatures between September 2008 and August 2009 for the Up MN, mean daily water temperatures from Up and Low MN loggers were regressed (n = 317; $P < 0.000$; $r^2 = 1.00$). Stream temperature profiles, including monthly values calculated from regressions, were plotted for each river section for the period between September 15, 2008 and December 1, 2010. Extremely high hourly water temperatures (max: 25° C) recorded at the Low MN site during August 2010 tracked hourly surface air temperatures. Because these data were highly anomalous, they were removed from monthly mean water temperature calculations.

Elevated water temperatures alter the metabolic rate of ectothermic animals such as fish, and at extreme levels can lead to weight loss or even death. Out of concern for elevated water temperatures in the Snoqualmie River, the Washington Department of Ecology published two total maximum daily load reports to assess summertime water temperatures in the forks and Mainstem Snoqualmie (Onwumere and Batts 2004; Kadouni and Cristea 2006). A number of factors contribute to elevated summer temperatures in the Snoqualmie River. One contributing factor that we investigated was main-stem channel width-to-depth ratios during base flows in summer. If width-to-depth ratios are high across extensive surface areas of stream, solar inputs can work to override geomorphic cooling mechanisms such as hyporheic exchange (Kadouni and Cristea 2006). We suspected that width-to-depth ratios were high and

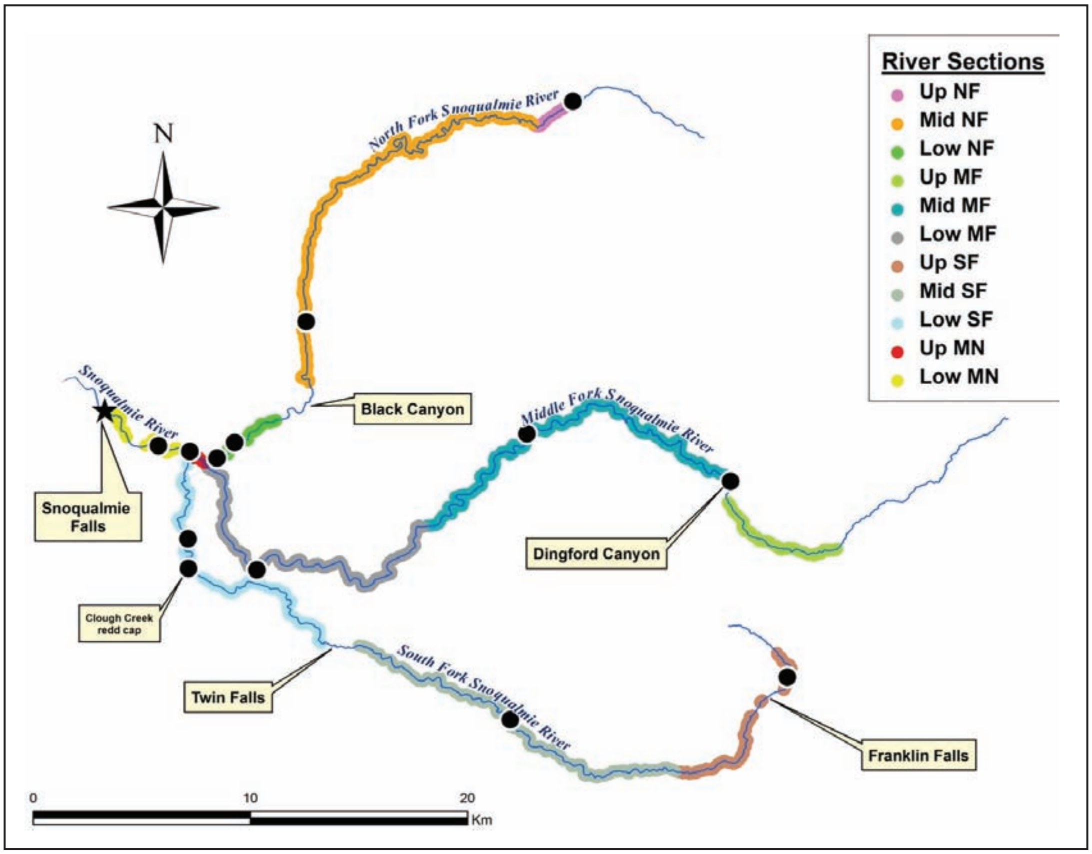


Figure 10. Locations where temperature loggers were installed in each river section (solid black round symbols). One logger was installed in Clough Creek (tributary to the Low SF) adjacent to capped redds to investigate trout incubation.

contributed to elevated water temperatures in certain river sections, so mean width-to-depth ratios were calculated for each river section. Data from cascade units, bedrock canyon segments, and shallow units were underrepresented in these ratios. Bedrock canyon habitats typically have narrower widths and deeply incised pools, so the addition of those habitats into the analysis would likely lower the mean width-to-depth ratio for a given river section. However, those reaches are limited in space and do not occur in the Mid MF, Low MF, and Up MN, where the highest water temperatures have been recorded in the past. Upper and middle river sections contained higher proportions of shallow units that were not sampled for depth, so width-to-depth ratios may be underestimated in those sections.

Stream discharge regimes and water quality

The U.S. Geological Survey (USGS) maintains at least one real-time stream discharge station in each of the forks and one in the Mainstem Snoqualmie upstream of Snoqualmie Falls (real-time gages: Mainstem Snoqualmie River near Snoqualmie 12144500, South Fork Snoqualmie River near Garcia 12143400, Middle Fork Snoqualmie River near Tanner 12141300, North Fork Snoqualmie River near Snoqualmie Falls 12142000; *http://waterdata.usgs.gov/wa/nwis/current/?type=flow*). Approved and provisional daily stream discharge data between September 2008 and December 2010 for each station were obtained from the USGS website and graphed. Two additional gages are located in Boxley Creek (real-time gage: Boxley Creek near Edgewick 12143900; non-real -time station: Boxley Creek near Cedar Falls 12143700), which originates from seeps flowing through a glacial moraine near the outlet of Chester Morse Lake in the Upper Cedar River Municipal Watershed. To investigate the extent to which fluctuations in surface elevation in Chester Morse Lake (real-time elevation gage 12115900; *http://waterdata.usgs.gov/wa/nwis/uv/?site_no=12115900*) influence the flow regime in Boxley Creek, and therefore in the Low SF downstream of Boxley Creek, we examined the relationships between surface elevation in Chester Morse Lake and discharge in Boxley Creek and in the South Fork Snoqualmie.

Other water quality variables (e.g., dissolved oxygen, pH) were not sampled for this study, but recent literature that included water quality sampling studies was reviewed and synthesized to provide a benchmark for water quality and environmental conditions.

Results

Main-stem channel habitat

The longitudinal range (km) of extensive surveys is summarized in Table 5 for each river section. Portions characterized by highly constrained canyon walls and large vertical drops were not surveyed (Black Canyon 3.38 km, Dingford Canyon 1.23 km, Franklin Falls 2.03 km, and Twin Falls 1.94 km).

Longitudinal habitat profiles showed differences in the spatial patterns of mean and maximum depth, active and wetted width, pieces of LWD and substrate sizes, and gradient in each fork and the Mainstem Snoqualmie. Mean depth generally increased, whereas maximum depth varied widely from upstream to downstream in each fork and the Mainstem Snoqualmie. Active and wetted channel width profiles showed variability in confinement and indicated relative locations of alluvial deposition and substrate transport zones. In each fork, wetted width decreased but active width increased near the confluence with the Mainstem Snoqualmie (Up MN or Low MN). In general, there was an inverse relationship between channel width and depth. Abundance of LWD and size of substrate were also inversely related, indicating zones of LWD and gravel deposition. Notwithstanding general similarities, the forks and Mainstem Snoqualmie differed fundamentally in form and function (Figures 11–14).

In the North Fork Snoqualmie, mean depth was greatest in the Lakebed and Black Canyon segments, and maximum depth peaked in the Lakebed segment. Active width was also greatest in the Lakebed segment, was constricted in the Calligan segment, and increased again in the Three Forks segment. An increase in mean depth and confinement in the Black Canyon was not reflected in longitudinal profiles because most of this segment was not surveyed. Accumulations of LWD peaked dramatically in the Lakebed segment and remained relatively low until a slight increase in the Three Forks segment (Figure 11).

In the Middle Fork Snoqualmie, maximum depth was greatest at the lower end of the Pratt segment and mean depth generally followed a similar pattern. Active width increased dramatically in the Goldmyer and Three Forks segments, and the most confined area was the Dingford Canyon. Accumulations of LWD also increased dramatically in the Goldmyer segment. Longitudinal patterns in the number of LWD and active channel width correlated inversely with substrate size in the Middle Fork Snoqualmie, clearly showing zones of alluvial deposition and transport (Figure 12).

Mean and maximum depth in the South Fork was greatest in the Weeks Falls and Three Forks segments. Active width increased dramatically in the Tinkham and Three Forks segments. An increase in mean depth and confinement near Twin Falls was not fully reflected in longitudinal profiles because most of the area surrounding this feature was not surveyed. Accumulations of LWD were moderately high throughout all segments, but increased dramatically in the Three Forks segment (Figure 13).

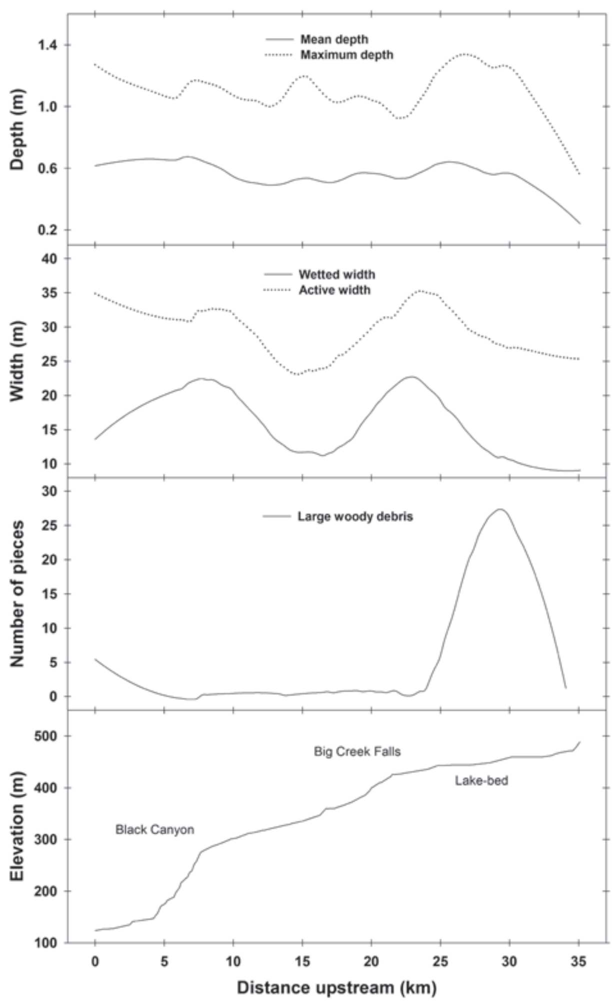
Mean and maximum depth in the Mainstem Snoqualmie increased slightly near the South Fork Snoqualmie confluence and more so near the confluence with Brockway Creek. The patchy inverse relationship between wetted and active width in the Mainstem Snoqualmie was due in part to channel confinement resulting from locations where bank armoring is extensive, but may also be a natural function of the lower erosive capability of the Mainstem in these areas. Substrate size decreased from gravel to sand from the Middle and North fork convergence downstream to the confluence with Brockway Creek. Accumulations of LWD increased upstream of the confluence with the South Fork and increased again more dramatically between the confluence with Brockway Creek and Snoqualmie Falls (Figure 14).

Habitat composition varied among river sections, but riffles and glides were the predominant habitat unit type in the forks, whereas pools were more predominant in the Mainstem Snoqualmie. The Up NF was composed mostly of cascades (61%), the Mid NF mostly of riffles (50%) and glides (31%), and the Low NF mostly of riffles (52%) and glides (38%). The Up MF was composed mostly of riffles (64%), the Mid MF of riffles (44%), pools (25%) and glides (24%), and the Low MF of riffles (50%) and glides (30%). The Up SF was composed mostly of riffles (50%) and cascades (27%), the Mid SF of riffles (45%) and glides (37%), and the Low SF of glides (55%) and riffles (31%). The Up MN was composed mostly of pools (66%) and riffles (21%) and the Low MN of pools (80%, Figure 15).

Mean values for depth, wetted width, and active width were summarized for river sections and habitat unit types, and in general, corroborated habitat type delineations (Appendix 1, Tables 1–3). The Mid MF contained deeper pools ($H = 27.67$, $P < 0.05$) and deeper glides ($H = 38.85$, $P < 0.05$) than the Mid NF and Mid SF, and glides were deeper in the Mid NF than in the Mid SF ($P < 0.05$). Pools were deeper in the MN than in the Low SF and Low NF ($H = 24.76$, $P < 0.05$); however glide depth did not differ statistically among lower river sections of the forks and the Mainstem Snoqualmie ($P = 0.09$). The Up MF con-

Table 5. Total length (km) of river section within the survey range, total length surveyed, and the percentage of the survey range snorkeled for depths and fish counts during extensive habitat and fish snorkel surveys in the upper Snoqualmie River watershed. All measurements and quantifications were estimated for units within the total survey range except for average and maximum depths and fish counts, which were only estimated in units that were deep or safe enough to snorkel. Most of the Black Canyon (North Fork: 3.38 km), Dingford Canyon (Middle Fork: 1.23 km), Franklin Falls (South Fork: 2.03 km) and Twin Falls (South Fork: 1.94 km) areas were not included in the total survey range. Refer to Figure 4 for a map view of river section delineations and the total survey range.

River	Total Survey Range (km)					Length Snorkeled (km)					Percent of Survey Range Snorkeled				
Section	Pool	Riffle	Glide	Cascade	Total	Pool	Riffle	Glide	Cascade	Total	Pool	Riffle	Glide	Cascade	Total
Up NF	0.17	0.36	0.28	1.03	**1.84**	0.17	0.20	0.28	0.95	**1.60**	100%	56%	100%	92%	**87%**
Mid NF	4.49	12.41	7.96	0.46	**25.32**	4.49	11.89	7.96	0.03	**24.36**	100%	96%	100%	6%	**96%**
Low NF	0.37	2.21	1.70	0.11	**4.39**	0.37	2.21	1.70	0.02	**4.30**	100%	100%	100%	23%	**98%**
Up MF	0.69	4.17	1.27	0.70	**6.83**	0.69	2.55	1.27	0.00	**4.51**	100%	61%	100%	0%	**66%**
Mid MF	5.56	10.28	5.83	0.76	**22.44**	5.56	8.34	5.83	0.00	**19.73**	100%	81%	100%	0%	**88%**
Low MF	3.39	8.41	5.55	1.07	**18.42**	3.39	6.69	5.55	0.20	**15.83**	100%	80%	100%	19%	**86%**
Up SF	1.15	4.49	1.20	1.23	**8.06**	1.15	2.66	1.15	0.47	**5.44**	100%	59%	97%	39%	**67%**
Mid SF	2.82	9.30	6.24	0.92	**19.28**	2.82	7.00	6.17	0.00	**15.99**	100%	75%	99%	0%	**83%**
Low SF	1.45	5.42	8.51	0.12	**15.49**	1.45	4.93	8.45	0.00	**14.82**	100%	91%	99%	0%	**96%**
Up MN	0.95	0.52	0.22	n/a	**1.70**	0.95	0.52	0.22	n/a	**1.70**	100%	100%	100%	n/a	**100%**
Low MN	3.29	0.58	0.58	n/a	**4.45**	3.29	0.53	0.58	n/a	**4.40**	100%	92%	100%	n/a	**99%**
Total	**24.32**	**58.15**	**39.35**	**6.39**	**128.21**	**24.32**	**47.51**	**39.16**	**1.68**	**112.68**	**100%**	**82%**	**100%**	**26%**	**88%**



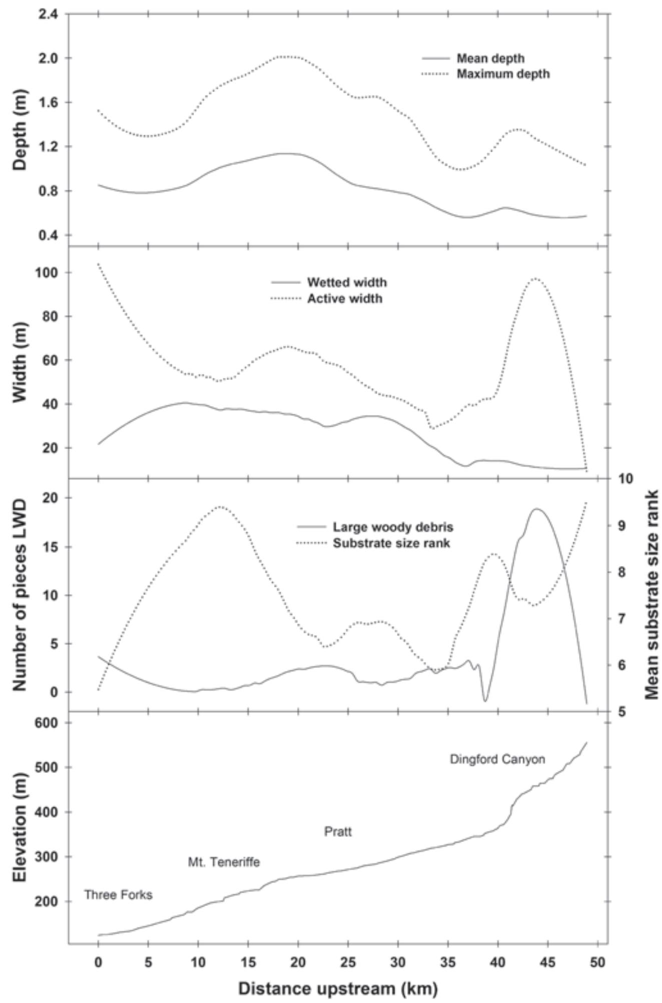


Figure 11. Longitudinal profiles of channel depth and width, number of pieces of LWD, and elevation in the North Fork Snoqualmie River. Scatter plot data for depth, width, and LWD were obtained at each habitat unit and were smoothed using trendlines. Elevation panels display average gradient per 100 m.

Figure 12. Longitudinal profiles of channel depth and width, number of pieces of LWD, substrate size, and elevation in the Middle Fork Snoqualmie River. Scatter plot data for depth, width, and LWD were obtained at each habitat unit and were smoothed using trendlines. Elevation panels display average gradient per 100 m. Dominant and subdominant substrate size rankings were averaged (1 = silt, 2 = sand, 3-5 = small to large gravel, 6-8 = small to large cobble, 9-11 = small to large boulder, 12 = clay, and 13 = bedrock).

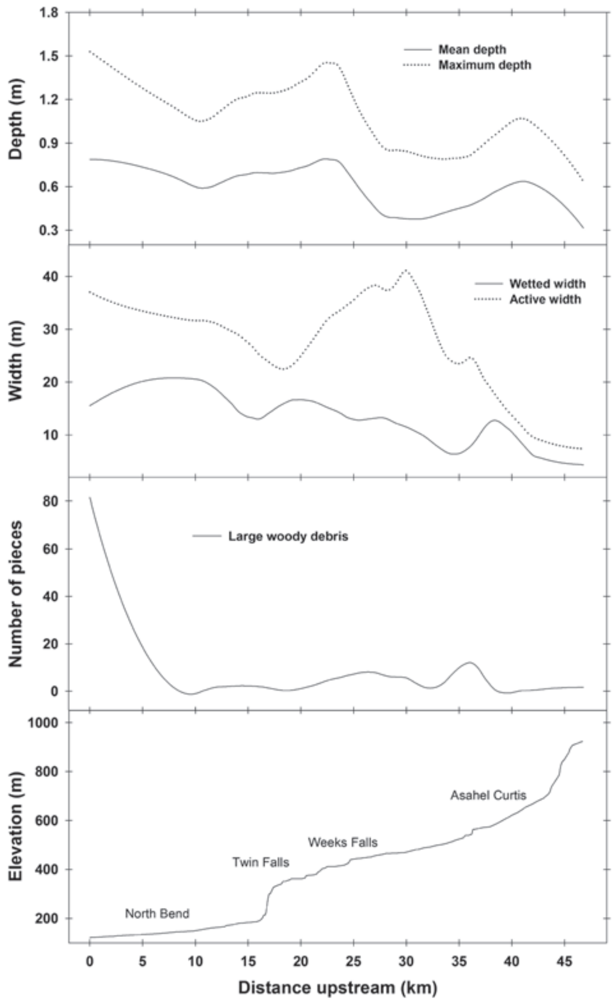


Figure 13. Longitudinal profiles of channel depth and width, number of pieces of LWD, and elevation in the South Fork Snoqualmie River. Scatter plot data for depth, width, and LWD were obtained at each habitat unit and were smoothed using trendlines. Elevation panels display average gradient per 100 m.

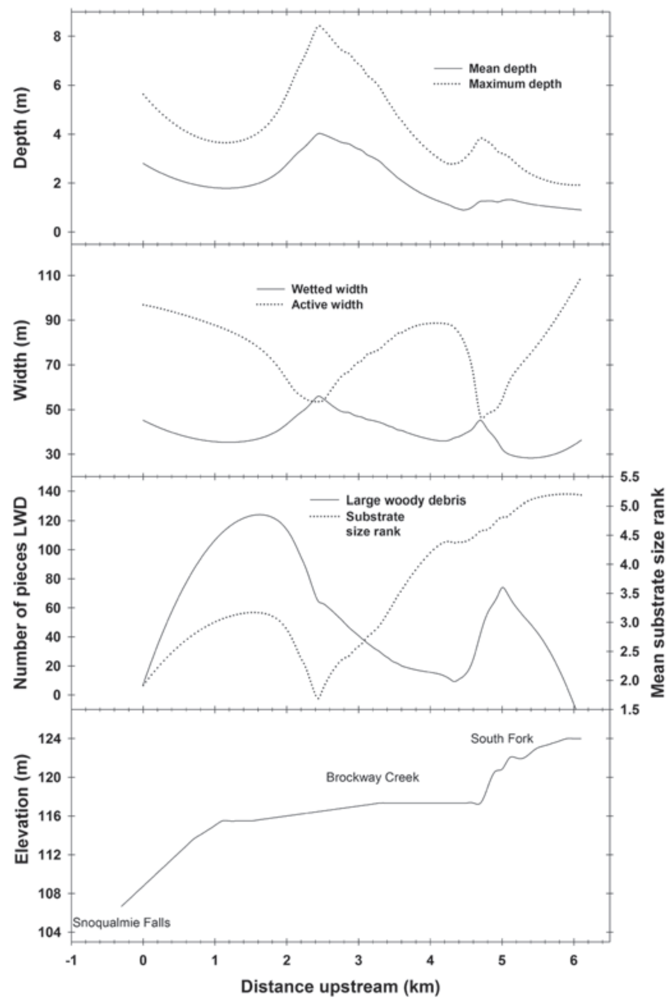


Figure 14. Longitudinal profiles of channel depth and width, number of pieces of LWD, substrate size, and elevation in the Mainstem Snoqualmie River above Snoqualmie Falls. Scatter plot data for depth, width, and LWD were obtained at each habitat unit and were smoothed using trendlines. Elevation panels display average gradient per 100 m. Dominant and subdominant substrate size rankings were averaged (1 = silt, 2 = sand, 3-5 = small to large gravel, 6-8 = small to large cobble, 9-11 = small to large boulder, 12 = clay, and 13 = bedrock).

tained the highest mean linear density of LWD, whereas the Low MF contained the lowest mean density. Density of LWD decreased in a downstream direction in the Middle and North forks, but increased downstream in the South Fork. The Low MN contained a higher linear density of LWD than the Up MN (Table 6). Substrates were largest, on average, in the Low MF followed by the Up MF, Mid MF, Up MN, and Low MN (Table 7). Some bank failures were noted during surveys and consisted of active slumping (Figure 16) or shallow debris avalanches in segments containing fine consolidated substrates layered over hardened lacustrine clay deposits (Figure 17). The highest frequency of main-stem channel bank failures occurred in the Mid NF ($N = 14$) and Mid MF ($N = 10$).

Tributary habitat

Tributary surveys were conducted in all river sections except the Up NF and Up MF and totaled 15.3 km. The location of each selected tributary and the spatial extent for each survey are provided in Figures 18a-d. Habitat measurements and estimates were averaged and summarized for each tributary (Table 8).

The designation of confinement type categories (lower, unconstrained, constrained) corroborated with other geomorphic reach type characteristics in each tributary. Lower tributary types encompassed aspects of both constrained and unconstrained tributaries (e.g., moderate or low gradients), but contained less LWD than unconstrained types and smaller substrates than constrained types (Figure 19a and 19b). Unconstrained tributaries generally represented floodplain channel types (Figure 19c), whereas constrained tributaries represented higher gradient montane

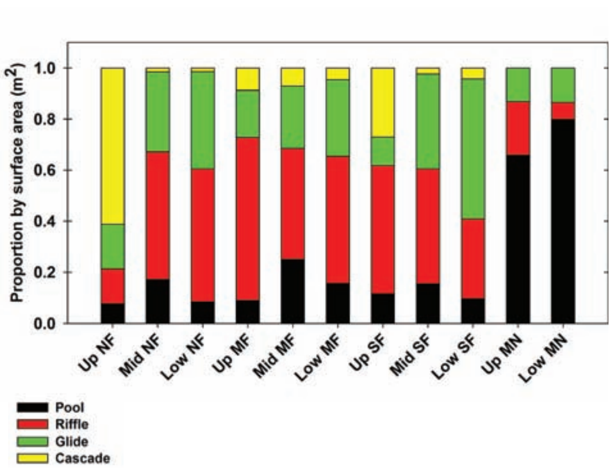


Figure 15. Habitat type as a proportion of the total surface area within the survey range in each river section of the upper Snoqualmie River watershed.

types (Figure 19d). Mean density of LWD was greater in unconstrained tributaries compared to both constrained and lower tributaries, and substrate size was greater in constrained versus both unconstrained and lower tributaries (Figure 20).

Statistical tests of variance for habitat composition and gradient corroborated confinement type designations. The proportion of pool by length of survey did not vary statistically among confinement types ($P = 0.238$), but the proportion of riffles was greater in constrained versus lower tributaries ($F = 4.92$, $P < 0.05$). The proportion of glide was less in constrained versus both unconstrained and lower tributaries ($H = 18.67$, $P < 0.05$). The proportion of cascade was greater in constrained versus both unconstrained and lower tributaries ($H = 21.07$, $P < 0.05$), but proportion of culvert did not vary statistically among confinement types ($P = 0.428$). Mean gradient was higher in constrained versus both unconstrained and lower tributaries ($H = 21.19$, $P < 0.05$).

Stream water temperature

Annual temperature profiles revealed variability in seasonal thermal transitions and inter-annual thermal regimes in each river section. Seasons were defined for each river section as: winter, January–March; spring, April–June; summer: July–September; and fall, October–December. Temperature profiles in the North Fork resembled profiles in the South Fork, and Middle Fork profiles resembled those in the Mainstem Snoqualmie. The Low NF and Low SF were buffered from extreme high and low temperatures, whereas the Low MF and Mainstem Snoqualmie sections experienced more extreme temperatures. Temperature profile curves revealed discrete thermal regimes throughout each year and river section in the North and South forks, whereas curves in the Middle Fork were proportional and converged during the coldest periods and separated during warm periods. The Low MF and Up MN experienced relatively extreme fluctuations in temperature among seasons. Conversely, the Low SF experienced the most contracted range of temperatures throughout each year. Summer temperatures in the Mid MF tracked those in the Low MF, whereas summer temperatures in the Mid SF and Mid NF surpassed those in the Low SF and Low NF during the warmest period of summer (Figure 21).

Stream width-to-depth ratios were low in the Up SF and Up MF, moderate in the Mid SF, Low MN, Up NF, Low NF, Low SF, and Mid NF, and high in the Mid MF, Up MN, and Low MF, where the most extreme temperatures were observed. The Up MN and Low MN contained the highest variability in width-to-depth ratios and variability was generally low among the remaining river sections (Figure 22).

Table 6. Mean linear density of LWD (number of pieces per km) calculated from data obtained during extensive habitat surveys. LWD was defined for main-stem channels as pieces of wood that were >10 cm in diameter and >2 m in length that intersected with the wetted width of the channel.

River Section	Pool	Riffle	Glide	Cascade	Average pieces/km
Up NF	58	256	112	21	85
Mid NF	159	30	94	0	72
Low NF	24	44	12	0	29
Up MF	682	339	186	57	316
Mid MF	127	52	67	37	74
Low MF	22	11	31	6	18
Up SF	17	12	76	16	23
Mid SF	160	66	74	40	81
Low SF	282	26	108	0	95
Up MN	258	23	9	n/a	153
Low MN	106	499	270	n/a	178
Average pieces/km	142	64	82	24	82

Table 7. Mean size rank (±1SE) of dominant and sub-dominant substrates estimated during 2010 habitat surveys in the Middle Fork and Mainstem Snoqualmie River. Substrates were not documented in 2009 during habitat surveys in the North and South forks of the Snoqualmie. Dominant and subdominant substrate size rankings: 1 = silt, 2 = sand, 3–5 = small to large gravel, 6–8 = small to large cobble, 9–11 = small to large boulder, 12 = clay, and 13 = bedrock.

River Section	Dominant	Sub-Dominant
Up MF	7.84 ± 0.01	7.88 ± 0.01
Mid MF	7.18 ± 0.01	6.65 ± 0.01
Low MF	8.50 ± 0.01	7.86 ± 0.01
Up MN	5.55 ± 0.08	4.82 ± 0.09
Low MN	3.06 ± 0.10	3.38 ± 0.10
Total	**7.60 ± 0.00**	**7.19 ± 0.00**

Stream discharge regimes and water quality

Annual stream flow data for the USRW were summarized for the period between September 2008 and November 2010. Large-scale floods in fall 2008 and winter 2009 were highlighted as extreme peaks in flow. Because stream flow gages are located at different distances upstream in each of the forks, gage data did not indicate relative contribution of stream flow by each fork. However, flow dynamics at gages were similar among the forks and the Mainstem Snoqualmie. In general, stream flows peaked during intense rainstorms during fall, rain-on-snow events during winter, and snow melt or rain-on-snow events during spring and decreased to base flows between the middle of July and the first half of October (Figure 23).

Monthly stream discharge in Boxley Creek and surface elevation of Chester Morse Lake correlated strongly between 2004 and 2010 (Pearson's Coefficient = 0.898, $P <$ 0.000). Conversely, discharge in Boxley Creek did not cor-

Figure 16. Active slumping in the Mid NF Lakebed segment (top) and debris avalanche near the Lakebed-Big Creek Falls segment interface (bottom).

Figure 17. Erosion of solid clay banks in the Mid NF Lakebed segment (top) and loose clay banks in the Mid MF Pratt segment (bottom).

relate with discharge in the South Fork Snoqualmie River (Pearson's Coefficient = 0.191, $P = 0.055$; Figure 24). Thus, flow in Boxley Creek and the Low SF downstream of the Boxley Creek confluence is influenced seasonally by reservoir surface elevation in Chester Morse Lake and Masonry Pool in the upper Cedar River municipal watershed, which is managed by Seattle Public Utilities.

In a recent water quality study (Kaje 2009), water quality variables were assessed, and priority restoration, protection, and outreach programs were suggested for each major water body in the Snoqualmie River basin (Table 9). The report provided much-needed context for aquatic ecosystem conditions and habitat enhancement or public outreach opportunities, and set a baseline for future water quality studies in the USRW. Sources of tributary habitat or water quality degradation identified during surveys are summarized in Table 10.

Conclusions

Our habitat surveys provide results that describe the quantity and quality of game fish habitat and the locations of several man-made or natural barriers to fish movement. A multiple-scale analysis of habitat enabled us to identify differences in geomorphic form and function of each mainstem channel body of water at varying levels. The various levels used for habitat analysis ranged from overall watershed functionality to specific locations of habitat degradation.

Longitudinal profiles of habitat were useful in the identification of geomorphic functionality and dynamics on a watershed scale. Resource managers can use large-scale and continuous spatial information of habitat to home in on limitations to aquatic production to aid in the development of long-term management and enhancement. For

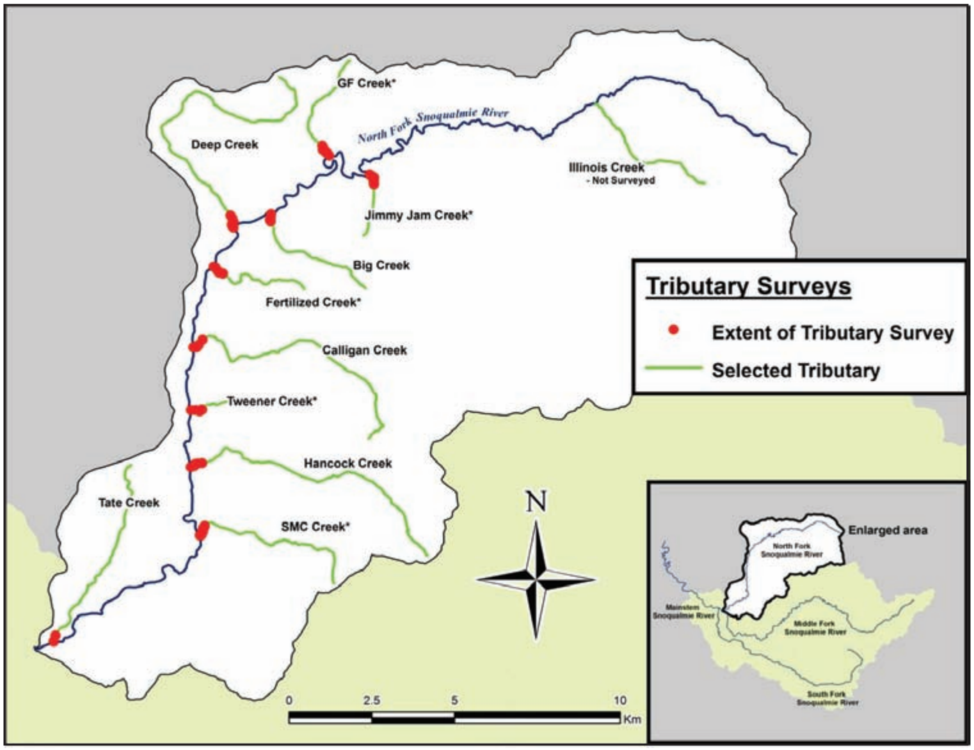


Figure 18a. Tributary surveys conducted in the North Fork Snoqualmie River sub-basin. Tributary names and aliases given for this study (those with an asterisk) are shown.

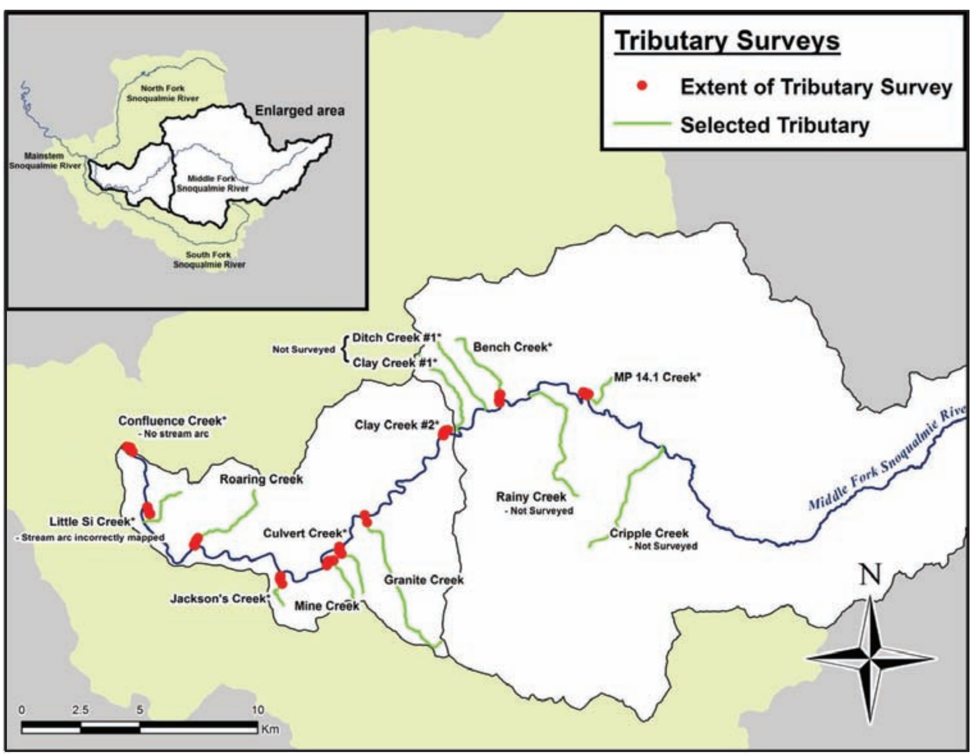


Figure 18b. Tributary surveys conducted in the Middle Fork Snoqualmie River sub-basin. Tributary names and aliases given for this study (those with an asterisk) are shown.

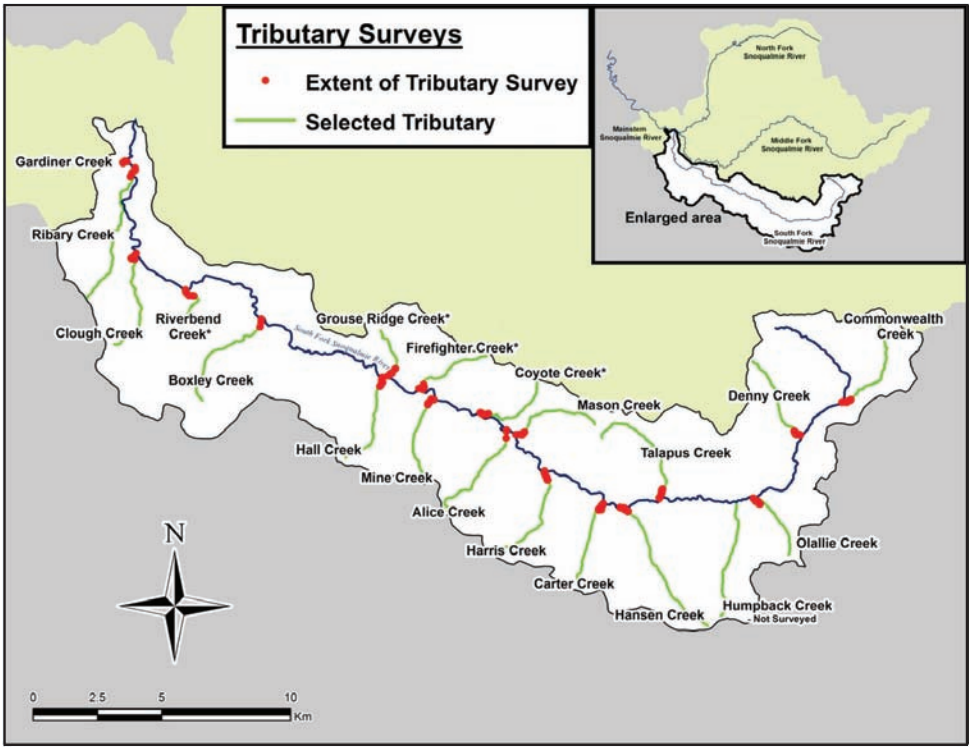


Figure 18c. Tributary surveys conducted in the South Fork Snoqualmie River sub-basin. Tributary names and aliases given for this study (those with an asterisk) are shown.

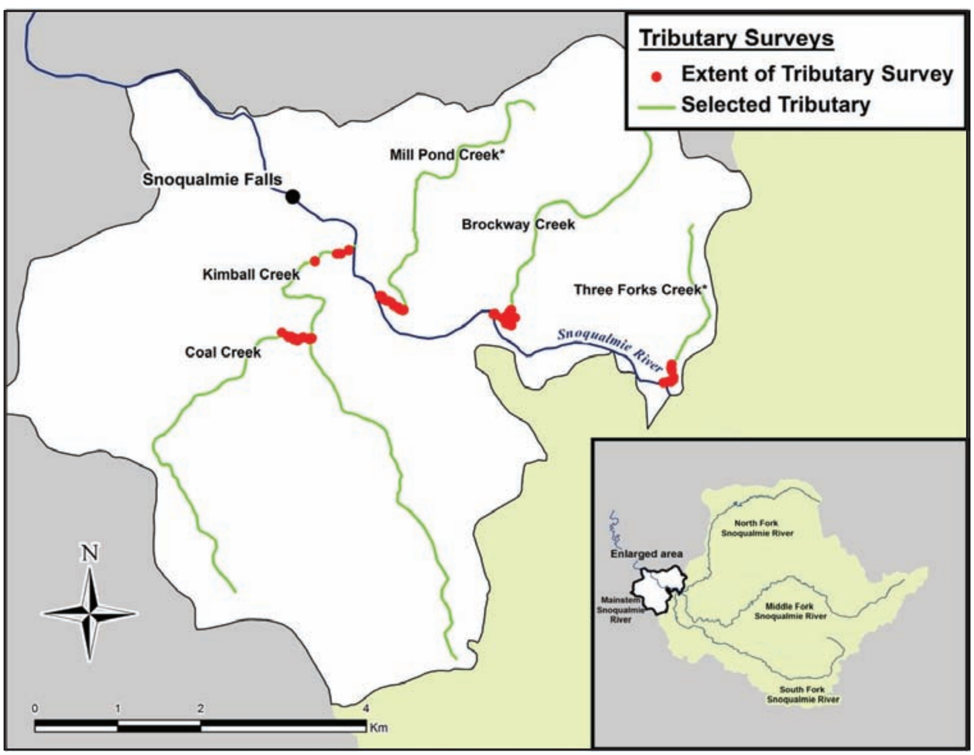


Figure 18d. Tributary surveys conducted in the Mainstem Snoqualmie River sub-basin. Tributary names and aliases given for this study (those with an asterisk) are shown.

Table 8. Habitat summaries from tributary surveys, which were conducted from 0 m (mouth) to approximately 400 m upstream. Values for slope, width, and depth indicate means (±1SE), and substrate values indicate means of size rank. Substrates were ranked by diameter (1 = silt, 2 = sand, 3-5 = small to large gravel, 6-8 = small to large cobble, 9-11 = small to large boulder, 12 = clay, and 13 = bedrock). LWD was defined for tributaries as wood >10 cm diameter that intersected the wetted width of the channel, and that spanned at least half the wetted width of the channel. Tributaries with an asterisk are unnamed, but names were given to each for reference during this study.

River Section	Tributary (* Alias for study)	Confinement type	Habitat units (N)	Length surveyed (m)	Slope (%)	Wet width (m)	Act width (m)	Mean depth (m)	LWD count	Dominant substrate	Sub-dominant substrate
Mid NF			**148**	**3,035**	**5.08 ± 0.04**	**5.28 ± 0.02**	**10.34 ± 0.04**	**0.24 ± 0.00**	**612**	7.3	**6.7**
	Jimmy Jam Creek*	Constrained	37	368	4.33 ± 0.12	2.64 ± 0.03	9.12 ± 0.16	0.18 ± 0.00	22	6.7	6.5
	GF Creek*	Unconstrained	15	379	4.13 ± 0.13	2.74 ± 0.05	13.49 ± 0.53	0.19 ± 0.01	303	5.6	5.9
	Big Creek	Constrained	14	96	13.82 ± 0.72	4.48 ± 0.19	10.13 ± 0.30	0.22 ± 0.01	6	10.3	8.4
	Deep Creek	Unconstrained	14	404	1.29 ± 0.04	8.62 ± 0.22	12.38 ± 0.29	0.35 ± 0.01	25	4.4	3.4
	Fertilized Creek*	Constrained	15	385	3.78 ± 0.23	2.02 ± 0.06	4.56 ± 0.12	0.26 ± 0.01	22	-	-
	Calligan Creek	Constrained	6	402	1.89 ± 0.17	9.76 ± 0.49	14.10 ± 0.41	0.26 ± 0.01	14	8.0	8.1
	Tweener Creek*	Constrained	9	241	9.61 ± 0.50	2.62 ± 0.16	5.77 ± 0.26	0.27 ± 0.01	172	-	-
	Hancock Creek	Constrained	9	403	2.92 ± 0.24	9.47 ± 0.35	12.19 ± 0.38	0.26 ± 0.01	8	9.1	7.9
	SMC Creek*	Constrained	29	357	6.30 ± 0.22	4.74 ± 0.07	7.08 ± 0.12	0.23 ± 0.00	40	9.3	7.7
Low NF			**5**	**325**	**1.64 ± 0.24**	**3.16 ± 0.21**	**16.42 ± 1.79**	**0.48 ± 0.05**	**11**	-	-
	Tate Creek	Lower	5	325	1.64 ± 0.24	3.16 ± 0.21	16.42 ± 1.79	0.48 ± 0.05	11	-	-
Mid MF			**81**	**1,583**	**1.77 ± 0.03**	**3.40 ± 0.03**	**6.40 ± 0.06**	**0.21 ± 0.00**	**144**	**4.2**	**4.4**
	MP14.1 Creek*	Unconstrained	30	390	1.33 ± 0.02	1.45 ± 0.02	2.88 ± 0.04	0.20 ± 0.00	68	2.5	2.3
	Bench Creek*	Constrained	25	403	2.31 ± 0.17	4.76 ± 0.05	7.50 ± 0.06	0.22 ± 0.00	21	5.0	6.8
	Clay Creek #2*	Unconstrained	24	384	1.21 ± 0.02	1.53 ± 0.04	3.60 ± 0.08	0.21 ± 0.01	35	3.1	2.1
	Granite Creek	Constrained	2	406	2.23 ± 0.55	7.62 ± 1.11	14.99 ± 2.78	0.21 ± 0.04	20	7.3	7.8

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Table 8. continued

River Section	Tributary (* Alias for study)	Confinement type	Habitat units (N)	Length surveyed (m)	Slope (%)	Wet width (m)	Act width (m)	Mean depth (m)	LWD count	Dominant substrate	Sub-dominant substrate
Low MF			**73**	**2,265**	**3.91 ± 0.07**	**2.32 ± 0.01**	**6.34 ± 0.05**	**0.22 ± 0.00**	**182**	**4.0**	**4.9**
	Culvert Creek*	Constrained	15	361	5.00 ± 0.29	2.12 ± 0.07	5.28 ± 0.22	0.14 ± 0.00	15	6.2	7.7
	Mine CreekMF*	Unconstrained	18	394	3.05 ± 0.12	1.94 ± 0.04	6.94 ± 0.25	0.24 ± 0.01	56	-	-
	Jackson's Creek*	Constrained	8	318	6.75 ± 1.21	1.88 ± 0.12	4.03 ± 0.20	0.26 ± 0.02	60	-	-
	Roaring Creek	Lower	15	391	3.00 ± 0.15	2.80 ± 0.05	9.60 ± 0.25	0.32 ± 0.01	9	-	-
	Little Si Creek*	Lower	9	400	4.13 ± 0.87	1.55 ± 0.11	4.55 ± 0.37	0.16 ± 0.01	26	-	-
	Confluence Creek*	Lower	8	401	1.13 ± 0.04	3.32 ± 0.12	7.26 ± 0.28	0.23 ± 0.01	16	2.1	2.4
Up SF			**74**	**1,138**	**5.75 ± 0.07**	**4.56 ± 0.02**	**9.30 ± 0.05**	**0.26 ± 0.00**	**69**	**9.0**	**8.0**
	Commonwealth Creek	Constrained	19	400	4.83 ± 0.20	5.65 ± 0.08	9.18 ± 0.09	0.32 ± 0.01	3	9.1	8.4
	Denny Creek	Constrained	25	360	5.54 ± 0.19	4.76 ± 0.07	9.84 ± 0.17	0.28 ± 0.00	24	9.3	8.4
	Olallie Creek	Constrained	30	378	6.56 ± 0.20	3.46 ± 0.05	8.96 ± 0.12	0.19 ± 0.00	42	8.8	7.4
Mid SF			**170**	**3,531**	**4.18 ± 0.03**	**3.75 ± 0.01**	**11.88 ± 0.07**	**0.26 ± 0.00**	**328**	**6.3**	**6.2**
	Talapus Creek	Constrained	29	271	6.69 ± 0.25	4.92 ± 0.06	8.41 ± 0.06	0.18 ± 0.00	64	8.2	8.0
	Hansen Creek	Constrained	16	400	3.82 ± 0.19	4.66 ± 0.10	11.20 ± 0.18	0.30 ± 0.01	27	5.6	5.1
	Carter Creek	Constrained	19	393	7.10 ± 0.26	2.18 ± 0.05	5.50 ± 0.17	0.20 ± 0.01	16	5.3	6.2
	Harris Creek	Constrained	27	398	2.62 ± 0.07	3.74 ± 0.11	6.44 ± 0.12	0.15 ± 0.00	41	7.2	7.1
	Mason Creek	Constrained	9	192	8.29 ± 0.54	2.86 ± 0.18	4.00 ± 0.25	0.23 ± 0.02	17	-	-
	Alice Creek	Constrained	4	400	2.79 ± 0.45	3.95 ± 0.27	6.90 ± 0.45	0.19 ± 0.02	24	7.0	6.7
	Coyote Creek*	Unconstrained	9	169	1.11 ± 0.04	5.08 ± 0.45	34.42 ± 1.72	0.35 ± 0.02	22	-	-
	Mine CreekSF	Constrained	14	386	5.50 ± 0.22	2.87 ± 0.05	12.51 ± 0.27	0.33 ± 0.02	40	-	-
	Firefighter Creek*	Unconstrained	13	423	1.38 ± 0.04	2.98 ± 0.13	29.14 ± 1.81	0.43 ± 0.02	47	-	-
	Grouse Ridge Creek*	Constrained	15	265	1.61 ± 0.04	2.75 ± 0.07	5.13 ± 0.22	0.16 ± 0.00	17	4.0	4.2
	Hall Creek	Constrained	15	234	6.47 ± 0.38	4.71 ± 0.07	8.76 ± 0.29	0.43 ± 0.03	13	-	-

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Table 8. continued

River Section	Tributary (* Alias for study)	Confinement type	Habitat units (*N*)	Length surveyed (m)	Slope (%)	Wet width (m)	Act width (m)	Mean depth (m)	LWD count	Dominant substrate	Sub-dominant substrate
Low SF			**42**	**1,534**	**1.52 ± 0.02**	**3.99 ± 0.04**	**11.17 ± 0.19**	**0.43 ± 0.01**	**133**	**1.4**	**0.4**
	Boxley Creek	Lower	2	429	1.70 ± 0.24	3.93 ± 0.54	9.08 ± 1.94	0.21 ± 0.05	12	-	-
	Riverbend Creek*	Lower	11	272	2.20 ± 0.13	3.38 ± 0.20	16.41 ± 1.12	0.44 ± 0.03	25	-	-
	Clough Creek	Lower	8	372	1.00 ± 0.00	4.22 ± 0.13	12.34 ± 0.65	0.53 ± 0.05	10	-	-
	Ribary Creek	Lower	9	248	1.55 ± 0.06	5.69 ± 0.19	13.59 ± 1.14	0.83 ± 0.06	41	-	-
	Gardiner Creek	Lower	12	213	1.08 ± 0.02	3.65 ± 0.13	7.11 ± 0.17	0.39 ± 0.01	45	1.4	0.4
Up MN			**11**	**320**	**2.00 ± 0.08**	**1.20 ± 0.03**	**4.14 ± 0.56**	**0.34 ± 0.01**	**39**	-	-
	Three Forks Creek*	Lower	11	320	2.00 ± 0.08	1.20 ± 0.03	4.14 ± 0.56	0.34 ± 0.01	39	-	-
Low MN			**53**	**1,824**	**2.04 ± 0.03**	**2.64 ± 0.07**	**8.10 ± 0.20**	**0.38 ± 0.01**	**200**	**6.3**	**5.3**
	Brockway Creek	Lower	15	634	2.85 ± 0.12	2.85 ± 0.42	16.33 ± 1.19	0.26 ± 0.01	55	-	-
	Mill Pond Creek*	Lower	18	370	1.60 ± 0.06	2.22 ± 0.08	5.40 ± 0.10	0.34 ± 0.02	73	-	-
	Coal Creek	Lower	16	404	2.12 ± 0.07	2.02 ± 0.05	3.50 ± 0.09	0.36 ± 0.01	41	6.3	5.3
	Kimball Creek	Lower	4	416	1.53 ± 0.13	4.59 ± 0.47	7.76 ± 0.94	0.75 ± 0.13	31	-	-

Figure 19a. An example of a low gradient, unconfined *lower* tributary type (Gardiner Creek). Tributaries in the *lower* category were located in lower river sections. *Lower* tributaries were typically low or moderate gradient with finer sediments and lacked significant accumulations of LWD.

Figure 19c. An example of an *unconstrained* tributary type (unnamed, alias: Firefighter Creek). Tributaries in the *unconstrained* category were located in middle river sections, were low gradient, and contained fine sediments and high abundance of LWD.

Figure 19b. An example of a moderately steep and confined *lower* tributary type (Roaring Creek). Some *lower* tributaries were intermediate in character to *unconstrained* and *constrained* tributaries.

Figure 19d. An example of a *constrained* tributary type (Talapus Creek). Tributaries in the *constrained* category were located in middle and upper river sections. Note the confinement of the valley on either side of the channel, steep gradient, lack of LWD, and larger substrates.

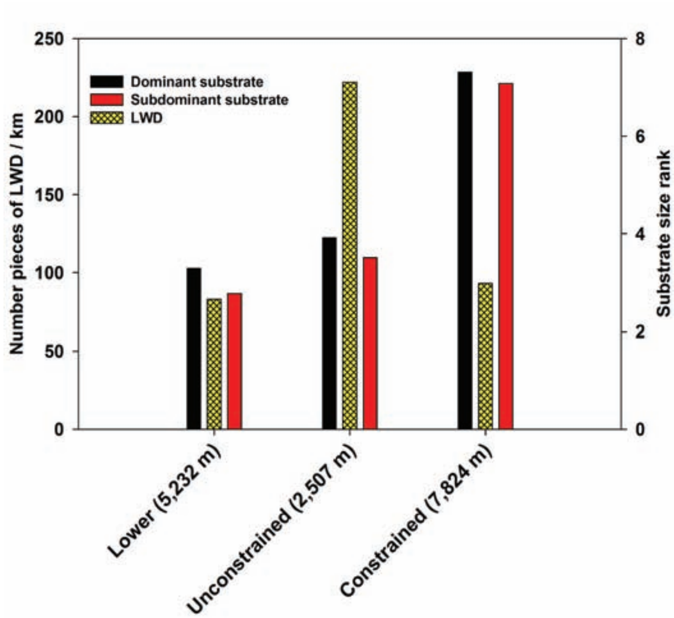

Figure 20. Density of LWD and mean substrate size rank among *lower*, *unconstrained* and *constrained* confinement type tributaries. The distance surveyed (m) for each confinement type is shown on the x-axis in parentheses. Dominant and subdominant substrate size rankings were averaged (1 = silt, 2 = sand, 3–5 = small to large gravel, 6–8 = small to large cobble, 9–11 = small to large boulder, 12 = clay, and 13 = bedrock).

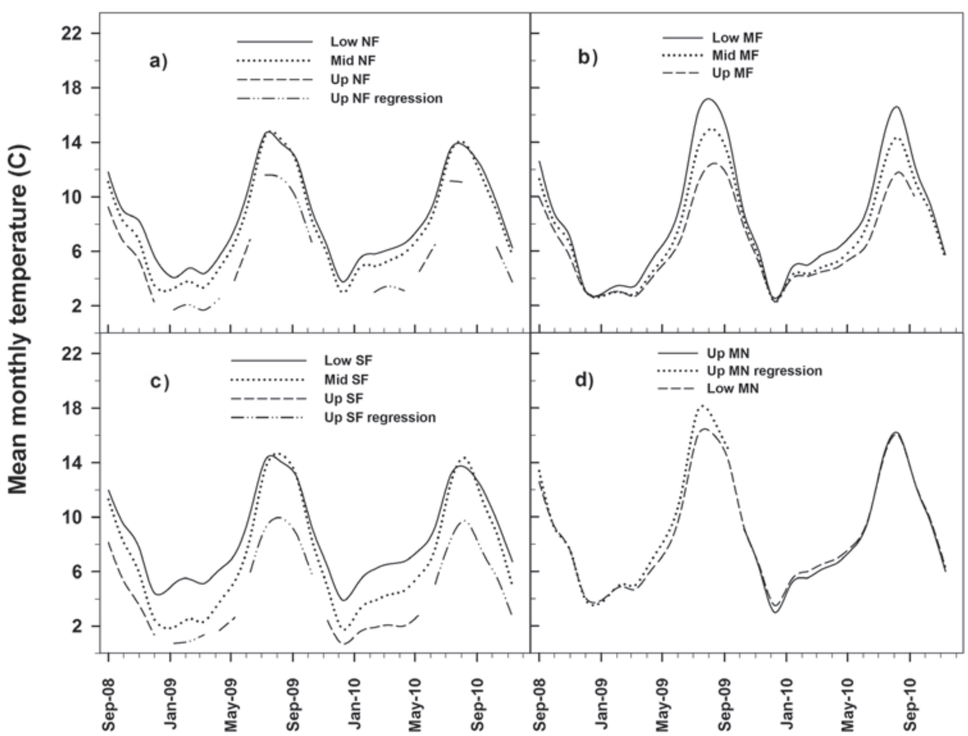

Figure 21. Temperature profiles for river sections in the a) North Fork Snoqualmie River, b) Middle Fork Snoqualmie River, c) South Fork Snoqualmie River, and d) Mainstem Snoqualmie River. Temperature loggers were installed in fall 2008 and removed in fall 2010, and hourly data were averaged by month. The Up NF and Up SF loggers were above the water surface during low-flow periods, so these data were regressed with more reliable and complete Mid NF and Mid SF data. Temperature data for the Up MN and Low MN were also regressed to estimate monthly temperature in the Up MN between September 2008 and September 2009.

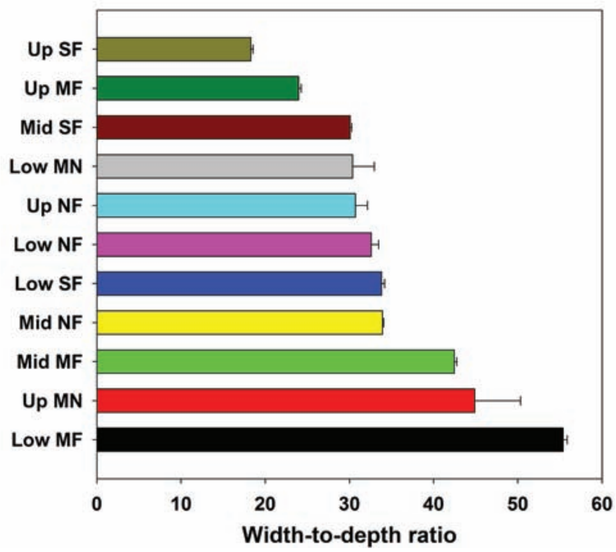

Figure 22. Mean (+2SE) width-to-depth ratios for base flow wetted widths in main-stem channels of each river section. Ratios were calculated from data obtained from each habitat unit.

example, Kocik and Ferreri (1998) identified locations of higher or lower production of Atlantic salmon (*Salmo salar*) by spatially modeling production based on the delineation of functional habitat units in a large watershed. In the USRW, maps that show where alluvial main-stem channel types are located can help resource managers understand where main-stem trout spawning and rearing habitat occurs more or less widespread. Moreover, because main-stem channel segments characterized as transport types typically do not support high densities of gravel beds, land managers can identify priority tributary or off-channel spawning and rearing habitats in those segments and initiate protection and restoration programs where needed.

Finer-scale habitat unit delineations enabled us to make quantitative comparisons and to comprehensively describe the types of habitats available to game fishes within main-stem and tributary channel types. Quantitative habitat unit information was used in statistical tests to corroborate broader categorizations of tributaries into three confinement types, which can be used in conjunction with main-stem channel type delineations to locate tributaries or main-stems that influence trout production. For example, unconstrained or lower gradient tributaries should generally be productive, and those types located in

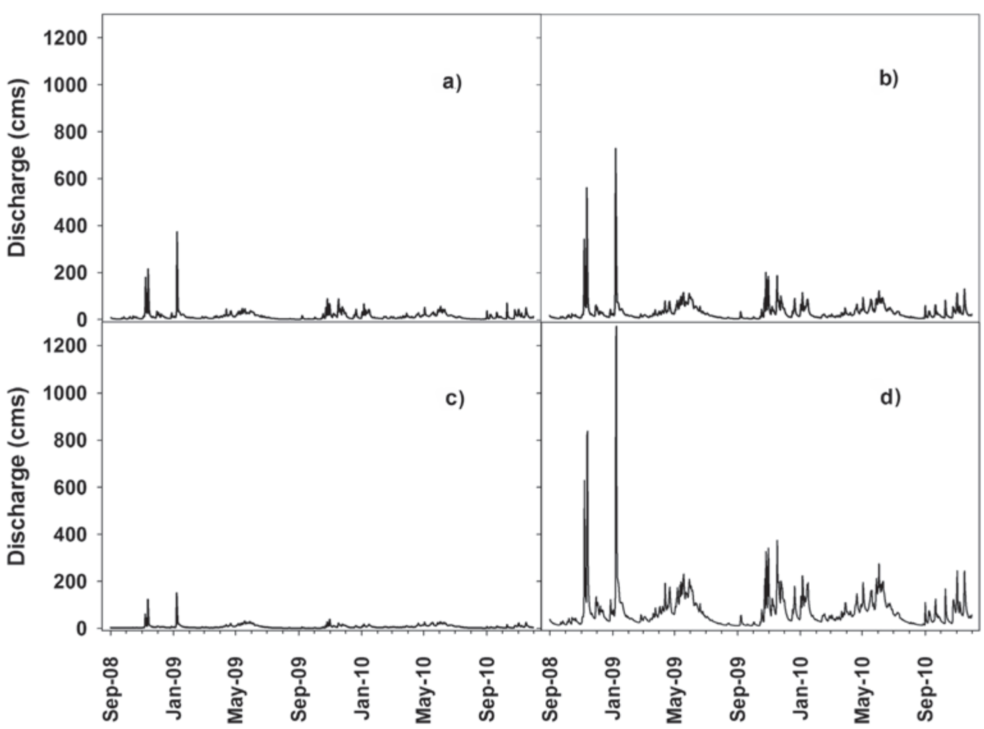

Figure 23. Mean daily stream discharge (cubic meters per second) in the a) North Fork Snoqualmie River (USGS gage 12142000), b) Middle Fork Snoqualmie River (USGS gage 12141300), c) South Fork Snoqualmie River (USGS gage 12143400), and d) Mainstem Snoqualmie River (USGS gage 12144500) between September 1, 2008 and November 30, 2010. Approved and provisional USGS data are shown.

Table 9. Priority water-quality improvement suggestions for five major sub-basins in the upper Snoqualmie River watershed (from Kaje 2009).

Sub-basin	Priority actions
North Fork Snoqualmie River	- Protect and enhance intact riparian areas and wetlands in both forested and rural residential areas through the use of incentives, acquisitions, restoration and enforcement of regulations. Focus on the main-stem (NF) as well as key cool-water tributaries, such as Tate Creek. - Conduct water typing in forested areas to ensure proper application of forestry regulations and best practices.
Middle Fork Snoqualmie River	- Conduct a detailed longitudinal temperature evaluation from approximately RM 30 (RKM 48.28) to the national forest boundary (near RM 12 [RKM 19.3]) including significant tributaries. - Conduct water typing in forested areas to ensure proper application of forestry regulations and best practices on State and federal forest lands. - Implement instream restoration projects (such as placement of large wood jams and boulder cluster) that encourage channel complexity and promote hyporheic flow which has been shown to be an effective means of lowering river temperature
South Fork Snoqualmie River	- Enhance riparian conditions along tributaries in rural residential and incorporated areas downstream of Twin Falls State Park. Couple riparian plantings with fencing to exclude livestock from streams wherever appropriate. - Conduct public education and outreach efforts to homeowners to encourage reductions in the use of fertilizers, pesticides and other household chemicals. - Encourage rapid expansion of municipal sewage treatment services to the entire incorporated area to reduce reliance on septic systems in existing neighborhoods. In the meantime, provide outreach and technical assistance to landowners (in both incorporated and unincorporated areas) regarding septic system operation and maintenance. - In cooperation with WSDOT, assess contribution of I-90 runoff to water quality impairment in the South Fork. - Implement the City of North Bend Comprehensive Stormwater Management Plan.
Kimball/Coal Creeks	- Enhance riparian conditions along Kimball Creek through removal of invasive plants and extensive riparian planting. - Install fencing to exclude livestock from the stream. - Investigate soil and water characteristics as well as surrounding land-use in upper Kimball Creek to identify potential causes of very low DO concentrations, low pH and the observed prevalence of iron-oxidizing bacteria in this portion of the stream. - Protect and enhance intact riparian areas and wetlands in the Coal Creek drainage through incentives and enforcement of existing regulations - Provide outreach and technical support to landowners regarding proper septic system operation and maintenance
Mainstem Snoqualmie River	- Protect and enhance forest cover, intact riparian corridors and wetlands through the use of incentives, restoration and enforcement of existing regulations. - Conduct outreach and provide technical assistance to small livestock operations in rural residential areas to protect human health and water quality. Emphasize exclusion of animals from streams and the importance of intact riparian areas. - In more densely developed residential areas (such as Fall City, Preston, Lake Mercel) provide incentives and education to promote responsible septic system operation and maintenance practices. - Initiate long term restoration of the riparian corridor in as many locations as possible, with the recognition that temperature benefits will not accrue for many years. - Install continuous temperature monitoring equipment at all flow gages in the Mainstem.

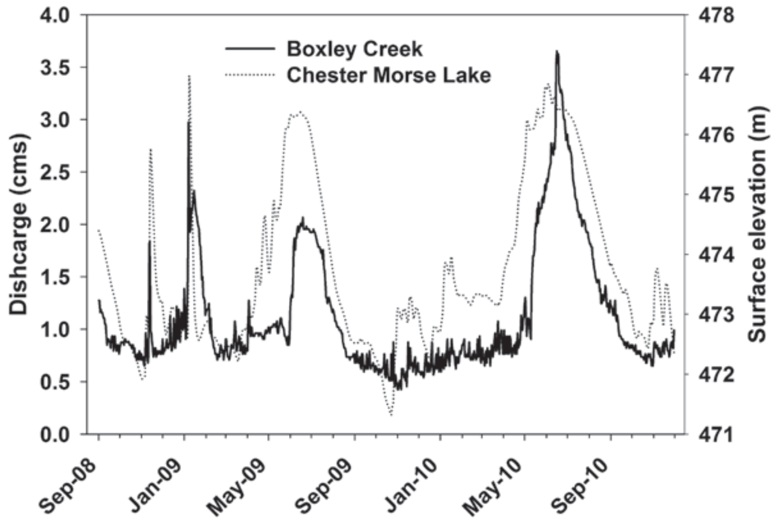

Figure 24. Mean daily stream discharge (cubic meters per second) in Boxley Creek (USGS gage 12143900) and mean daily surface elevation (meters) in Chester Morse Lake (USGS gage 12115900) between September 1, 2008 and November 30, 2010. Approved and provisional USGS data are shown.

constrained main-stem channel segments probably contain denser spawning gravel and rearing features than their respective main-stem channel habitats.

Confinement types can also be used to describe where interconnectivity is naturally diminished between tributaries and main-stems. Constrained or high gradient tributaries often contain fish limitations or barriers and thus can isolate populations that maintain themselves in upper reaches. While more vulnerable to localized large-magnitude disturbances (Wofford et al. 2005), fish populations in upper reaches of tributaries can add to the genetic diversity of main-stem populations if emigration occurs. This emphasizes the importance of identifying and protecting isolated habitats and fish populations from unnatural disturbances, which are often caused by road construction or logging practices.

Across the USRW, 48% of surveyed tributaries contained high levels of man-made habitat degradation in the form of perched or extended and undersized culverts, riparian or valley wall disturbance, and channel re-routing. Habitat degradation in main-stem channels consisted mainly of diking and artificial bank armoring (i.e., rip-rap), but also included loss of riparian vegetation, large patches of invasive vegetation (e.g., Japanese knotweed), and loss of connectivity with off-channel or floodplain habitats. Much of the land in the USRW that is currently managed by the U.S. Forest Service and Washington Department of Natural Resources was heavily logged over the first half of the 20th century, often on steep unstable slopes and down to the riverbanks. Over time, the USRW has recovered from these land practices as a natural ecosystem, yet negative effects from historical land use practices probably still influence riparian and aquatic habitats today. This study provides a large-scale, comprehensive baseline for habitat conditions that restoration groups can use to implement effective stream protection or restoration projects.

Habitat and the fishery

North Fork Snoqualmie River

Habitat in the North Fork appears to be suitable for continued trout production, but could probably be improved or better maintained. The Illinois Creek segment of the Up NF contains quality cascade and pool cover for all life stages of trout; however, low annual water temperatures may inhibit overall production and growth rates. The riparian zone in this segment appears stable and contains stands of old or second growth conifers that provide shade and recruit into the channel where the gradient lowers and energy dissipates near the Lennox Creek confluence. The Lakebed segment contains long deep glides and pools connected by short, shallow riffles and glides. Cover in the deeper pools is abundant because of the depositional nature of the segment combined with bank erosion that results in recruitment and accumulation of large amounts of LWD. Thus, it appears that the Lakebed segment contains habitat amenable to all life stages and may provide relatively high amounts of habitat suitable for larger trout if water temperature and food allowances permit. The Big Creek Falls and Calligan segments are similar to the Illinois Creek segment in that they contain pool cover, but

Table 10. Qualitative habitat condition summary for surveyed tributaries in the upper Snoqualmie River watershed. Degradation levels were designated based on extent and type of degradation. Tributaries with migratory barriers caused by road crossings were automatically designated as highly degraded, and other sources of degradation included loss of riparian buffer, erosion, substrate embeddedness, and loss of fluvial functionality among others. The upper portions of Ribary and Kimball creeks were not formally surveyed, but conditions were noted during reconnaissance. Unnamed tributaries or those with unknown names were given an alias (*) for this study. Aliases may differ from popular or other unofficial names for each tributary. Refer to ocations of tributaries and surveys.

River Section	Tributary (* Alias for study)	Degradation level	Degradation type
Mid NF	Jimmy Jam Creek*	High	Perched culvert, rip-rap cascade at culvert outlet
	GF Creek*	Low	
	Big Creek	High	Narrow, blown-down buffer, erosion and slope failure
	Deep Creek	Low	
	Fertilized Creek*	High	Perched culvert, no riparian buffer present through clear-cut, loss of surface water
	Calligan Creek	Low	
	Tweener Creek*	High	Perched culvert
	Hancock Creek	Low	
	SMC Creek*	Low	
Low NF	Tate Creek	High	Gravels embedded w/ silt and sand, loss of riparian buffer through residential areas, loss of channel migration at mouth
Mid MF	MP14.1 Creek*	Low	
	Bench Creek*	Low	Rip-rap limitation at mouth
	Clay Creek #2*	Low	
	Granite Creek	Low	
Low MF	Culvert Creek*	High	Perched culvert
	Mine CreekMF*	High	Perched culvert, man-made debris jam limitation near mouth
	Jackson's Creek*	High	Perched culvert
	Roaring Creek	High	Perched culvert, embedded substrate
	Little Si Creek*	Low	
	Confluence Creek*	Low	
Up SF	Commonwealth Creek	Low	
	Denny Creek	Low	
	Olallie Creek	Low	
Mid SF	Talapus Creek	Low	
	Hansen Creek	Low	
	Carter Creek	Low	
	Harris Creek	High	Concrete slab/other road crossing limitations (2)
	Mason Creek	High	Perched culvert, majority of low gradient reach consists of long culvert barriers under freeway (I-90)
	Alice Creek	Low	

— Table 10 continued on next page

Table 10. Continued

River Section	Tributary (* Alias for study)	Degradation level	Degradation type
	Coyote Creek*	High	Underground culvert—diminished habitable length, possible water quality impairment (proximity to I-90)
	Mine CreekSF	Low	Rip-rap limitation at mouth
	Firefighter Creek*	Low	Gravel road crossing under power lines: need crossing structure
	Grouse Ridge Creek*	Low	
	Hall Creek	High	Mass wasting and erosion, loss of buffer
Low SF	Boxley Creek	Low	Residential bank armoring, flows affected by reservoir management, probable increased density of nutrient inputs from private hatchery
	Riverbend Creek*	Low	Rip-rap limitation at mouth
	Clough Creek	High	Channel re-routed, loss of gravel recruitment to downstream reaches, erosion
	Ribary Creek	High	**Loss of riparian buffer throughout upper portions, suburban pollution
	Gardiner Creek	Low	
Up MN	Three Forks Creek*	High	Undersized culvert, excessively incised through residential area, loss of riparian buffer
Low MN	Brockway Creek	Low	
	Mill Pond Creek*	High	Dam at outlet of Mill Pond limits native fish movement, invasive warm water fish species flushed from lake into tributary during high water events
	Coal Creek	Low	Residential bank armoring, loss of riparian buffer
	Kimball Creek	High	**Loss of riparian buffer, erosion, high density residential development throughout upper headwater portions, urban pollution, increased storm runoff

** Upper portions of Kimball and Ribary creeks not formally surveyed, but conditions noted during reconnaissance

pools are interspersed by abundant riffles rather than cascades. Thus, there is less cover provided by turbulence than in the Up NF, and feeding lanes are probably more widespread and abundant, lessening the propensity for density-dependent feeding behavior. However, the confinement and lack of off-channel habitat in the Big Creek Falls and Calligan segments probably limits the amount of spawning and rearing for trout in these segments. Some tributaries that we surveyed in these segments contained perched culverts (Tweener*, Fertilized*, and Jimmy Jam* creeks) and no riparian cover (Fertilized Creek*). Furthermore, very little LWD has accumulated in the Mid NF, which diminishes habitat structure and complexity that would otherwise provide refuge areas for rearing juvenile trout. Habitat enhancement projects should be directed at the removal of perched culverts, planting of riparian flora where needed, and the placement of large LWD jams in the Big Creek Falls and Calligan segments should be investigated for feasibility. The pattern of confinement and sparse off-channel habitat continues downstream through the Black Canyon into the upper portion of the Three Forks segment in the Low NF. A large floodplain-pond system near the confluence with the Middle Fork increases the amount of off-channel habitat in the Three Forks segment (see Reproductive Life History chapter for location of Fishery Creek*). Tate Creek is a relatively large tributary that contains a long portion of low gradient habitat with sand and gravel. Habitat in lower portions of Tate Creek has been heavily influenced by residential development and spawning gravels have been embedded in fine sediments that accumulate. We cannot be sure whether the accumulation of fine sediments is a result of natural disturbances or is caused by development, road construction, or logging practices in upstream reaches. It is certain that Tate Creek has been channelized by residential land-use, development, and road construction, and the confluence with the North Fork flows through a constrained diked bank. Thus, flows and fine sediments in lower Tate Creek are not able to dissipate into the floodplain as they did historically. Habitat enhancement should be focused in Tate Creek, and restoration projects, including channel restoration and planting of native riparian flora, are advised in residential or upstream areas where logging has occurred.

Middle Fork Snoqualmie River

Habitat in the Middle Fork is suitable for continued trout production, but could probably be improved or better maintained. The Goldmyer segment of the Up MF is in relatively pristine condition and will continue to provide adequate habitat for all life stages of trout as long as the complexity of habitats remains interconnected. We did not survey tributaries in the Up MF; however, we noted that connectivity with some tributaries and off-channel habitat has been compromised as a result of perched or inadequate culverts along the forest road leading to the Goldmyer Hot Spring Resort. Further investigation and replacement of these culverts is recommended to ensure that spawning and rearing habitat reaches its full potential in the Up MF. Habitat in the Mid MF appears to be in good condition; however, a substantial amount of off-channel habitat has been compromised as a result of the Middle Fork River Road. We noted a number of perched or inadequate culverts along this stretch of river. A paving project has been planned for the Middle Fork River Road along the Mid MF and Low MF, and an assessment of all crossing structures was provided by Mason, Bruce & Girard, Inc. (2004). Thus, most of the inadequate crossing structures (e.g., Mine Creek culvert) will apparently be replaced if this project commences.

Roaring Creek, a tributary to the Low MF, provides habitat that is crucial to the production of trout and is in need of a more intensive full-length stream survey to document various sources of degradation. We noted a large perched culvert just downstream of the Mt. Si trailhead that should be replaced to restore connectivity to upstream reaches by spawning and rearing trout. Other degradation included bank failures along residential lots and embedded substrates near the mouth. Local residents informed us that the stream goes dry some years; therefore, upstream water use and diversions should be investigated and restricted if possible. Otherwise, most tributaries to the Mid MF and Low MF appear to be functioning well.

One major area of concern for habitat and water temperature was the significant increase in the width-to-depth ratios in the Mid MF and especially in the Low MF. High width-to-depth ratios can offset mechanisms that buffer water temperature from extreme seasonal air temperatures; therefore, we expected that the most extreme water temperatures would occur in the Low MF. The most extreme hourly temperatures were observed in the Low MF and during base flows in summer when water temperature was at a maximum (20°–24° C), trout were very sparsely populated in the lowermost segment of this river section (Three Forks). We also noted that during an extended freezing period in winter 2009, the Three Forks segment of the Low MF was completely frozen over in places, whereas the Mid MF did not freeze over, nor did other river sections in the USRW. Many riffles in the Mid MF and Low MF exhibited increased width-to-depth ratios during summer low flows, as nearly the entire active channel was wetted and very shallow flowing around poorly sorted cobble and boulder substrates (see Figure 7e for example and Figure 12 for locations where depth <1 m and wetted width >30 m). However, it appeared that the Mid MF was relatively buffered from the extreme temperatures during winter. One obvious difference between the Mid MF and the Low MF is that the Mid MF contains a high number of tributaries and the Low MF contains very few. Thus, the influx of tributaries may work to override high width-to-depth ratios in the Mid MF.

It is possible that high width-to-depth ratios are a natural occurrence but have been exacerbated as a result of historic land use practices that led to increased erosion of fine sediments through the elimination of riparian root matrices. Fine sediments that recruit from excessive erosion can accumulate within interstitial spaces, flattening and raising the bottom layer of the channel, and embedding substrates, which can lower egg-to-fry survival rates in some salmonid species (Jensen et al. 2009). A more stable annual flow regime would probably lessen erosion and downstream recruitment of fine substrates, but the flow regime in the Middle Fork is dynamic across the seasons; therefore, bank instability, erosion, and substrate embeddedness will continue into the foreseeable future. Habitat enhancement in the Mid MF and Low MF should be focused on restoring connectivity to off-channel habitats, placement of large LWD, and re-planting of native riparian flora where needed.

Extensive lacustrine clay deposits are typical features of Puget Sound drainages. The most extensive clay deposits in the USRW are located in the Pratt segment of the Mid MF. Some occur as hard clay deposits within eroding layers of sand, gravel, and cobble substrates. The broadest, most conspicuous clay deposits are located along a reach downstream of the Pratt River confluence and extend downstream to the Granite Creek confluence. These deposits contain whole toe slopes composed of softer, more easily eroded clay that chronically contributes suspended sediment to the Low MF. While clay banks are a natural occurrence, it is possible that land use (clear-cutting, wood removal) and development (bank armoring) have exacerbated the convergence between toe slope and stream channel, increasing the rate of erosion. The amount of clay that intersects with the stream channel appears to be dependent on channel migration (i.e., shifts in channel location), so as the channel migrates away from clay slopes, less erosion would occur. The strategic placement of LWD could help accumulate larger substrates and additional LWD to naturally alter or re-locate the main force of the stream flow and possibly lessen the rate of erosion.

South Fork Snoqualmie River

Habitat in the South Fork appears to be suitable for continued trout production, but could probably be improved or better maintained. The Commonwealth and Denny Creek segments of the Up SF contain quality cascade and pool cover for all life stages; however, low annual water temperatures may inhibit overall production and growth rates. The riparian zone in this segment is stable and contains stands of old or second growth conifers that provide shade and recruit into the channel where the channel gradient lowers in the Asahel Curtis segment. The Tinkham segment of the Mid SF contains some substantial LWD jams and pool habitat. However, pools in the Mid SF were shallowest among all river sections, which probably limits the maximum size and overall density of trout. Off-channel habitats are relatively interconnected with main-stem channels in upstream portions of the Tinkham segment; however, interconnectivity and off-channel habitat quality is compromised in the lower portions of the Tinkham segment, and most of the Weeks Falls and Grouse Ridge segments. Much of the loss of habitat can be directly attributed to the construction of Interstate 90, which resulted in the loss of valley-bottom portions of some tributaries (Mason Creek, Coyote Creek*, etc.). There are also some interconnectivity problems on the south side of the Mid SF along the Tinkham Road. For example, interconnectivity between Harris Creek and the main-stem channel appears to be limited by low flow, the accumulation of alluvium near the confluence, and crossing structures that probably limit fish movement. Further investigations into slope and channel conditions will help determine if enhancement projects might improve conditions for reproduction and rearing by main-stem channel trout in the Mid SF. While some LWD has historically been placed along modified banks in the Mid SF, placement of more permanent structures should be considered as those efforts did not appear to have widespread or sustained effects on habitat or trout production.

Habitat functionality in the main-stem channel of the Low SF through North Bend has been severely compromised as banks have been heavily armored, lessening interactions with the floodplain. However, the main-stem remains connected to at least two major tributaries used by all life stages of trout. The most upstream of these tributaries is Boxley Creek, which is influenced by a private hatchery. The outlet of the hatchery provides refuge and supplementary nutrients for high densities of rearing trout. The flow regime in Boxley Creek is influenced by surface elevation of Chester Morse Lake, which in turn influences seasonal productivity and probably flow-cued fish behaviors. A more detailed investigation of Boxley Creek is needed to determine the interactions between physical factors and biological productivity. The cumulative influence of streamflow from Boxley Creek on the South Fork is not known, but summer and winter base flow temperatures were less extreme in the Low SF compared to other lower river sections. Boxley Creek possibly helps stabilize summer temperatures in the Low SF as water levels are increased in Chester Morse Lake, in turn increasing discharge from the spring into Boxley and cool water influx from Boxley into the Low SF. Because the flow regime is artificially controlled, water-quality studies should include a focused investigation of the influence of Boxley Creek on stream temperatures, productivity, and effects on the Low SF.

The second tributary to the Low SF that is used by all life stages of trout is Clough Creek. The highest amount of spawning found during this study was found along a short stretch of Clough Creek. However, large culverts under Interstate 90 and dikes at the confluence diminish the portion of usable rearing habitat. Land-use practices have also diminished habitat quantity as the channel runs through a residential area that floods commonly during high flows and floods. Some residents have been proactive in efforts to restore the riparian zone, whereas others have detrimentally altered the channel to avoid being flooded. Habitat restoration in Clough Creek should be focused on restoring the native channel to ensure gravel replenishment, planting of native riparian flora, and acquisition of land that is chronically flooded and too costly to maintain.

Conditions in lower portions of other Low SF tributaries appear to be suitable for trout. However, land use and development have diminished the connectivity between upper and lower portions of some tributaries, such as Ribary Creek. While we did not survey upper portions of tributaries, we noted that habitat appeared to be excellent upstream of Interstate 90, but is poorly interconnected with lower reaches as it flows through commercial and industrial areas near North Bend through extended or undersized culverts. Furthermore, where the stream is exposed, the riparian has been altered or completely removed for commercial purposes (e.g., parking lots), and the channel contains litter. Habitat enhancement should first be targeted at planting riparian vegetation along the banks to isolate the channel from litter and provide shade, and to assess the feasibility of completely day-lighting the stream. Finally, a litter patrol group could adopt this portion of Ribary Creek, which is highly susceptible to the continual accumulation of commercial, industrial, and household litter.

Mainstem Snoqualmie River

Habitat in the Mainstem Snoqualmie appears to be suitable for the continued trout production, but could probably be improved or better maintained. Interconnectivity with off-channel and floodplain habitat has been compromised by road and railway construction and residential development. Passage into Brockway Creek was recently restored as a concrete box culvert was installed to replace an inadequate corrugated metal pipe. However, several small tributaries still lack connectivity with the main-stem channel as a result of the construction of Reinig Road and other land-use practices. The other small tributaries should be investigated to determine the adequacy of crossing structures, fish use, and the feasibility of restoring connectivity to the Mainstem Snoqualmie.

Roads and dikes parallel much of the Mainstem Snoqualmie, compounding a natural lack of erosive power in this portion of the watershed. A substantial amount of LWD counted in the Low MN consisted of old pilings. Thus, with the exception of a large LWD jam in the Up MN, the recruitment and accumulation of LWD is inhibited in the Mainstem Snoqualmie. Placement of large LWD jams along armored banks would increase the amount of cover and habitat complexity for trout and might aid in the accumulation of additional pieces of LWD that drift downstream during higher flows. Furthermore, placement of mid-channel LWD jams could aid in the natural construction of complex habitat, such as islands and side channels, both of which are in short supply in the Mainstem Snoqualmie.

The Kimball Creek/Coal Creek tributary system is the largest tributary to the Mainstem Snoqualmie, but is vulnerable to the dramatic increases in commercial and residential development that has occurred along Snoqualmie Ridge Parkway. Riparian vegetation should be assessed for headwater portions, and interconnectivity and land use should be assessed for the whole Kimball Creek system. The system includes a pond network that sprawls throughout the entire southwestern portion of the watershed and contains an abundance of habitat potential. Local habitat groups should be vigilant and proactive as commercial and residential development continues to envelop the Kimball Creek/Coal Creek tributary system.

Water temperature, discharge, and quality

Results from our study indicate that stream water temperature and discharge regimes differ between each fork and the Mainstem Snoqualmie. In general, stream water temperatures provided conditions suitable for the continued production of trout, but within the basin we expect distribution, growth, and survival to vary as a function of temperature, quality and quantity of food, and the availability of refuge habitat. It is important to note that temperature loggers were not targeted for installation at same-elevation sites, yet temperature regimes are probably shifted up or down based on elevation. Regardless, annual stream temperature profiles would generally be expected to be lower as elevation increases, but not all river section temperature profiles exhibited this behavior.

In general, upper river sections experienced the most truncated growing season for trout within each fork as temperatures rose to within the estimated optimal growth range (9°–14° C) between the middle of July and the beginning of October. Temperatures were the lowest and the range most truncated in the Up SF, but the temperature logger was also installed at a higher elevation than either the Up NF or Up MF (Figure 10). The Up SF is the highest elevation river section (see Figure 13). Regardless of the difference in logger elevations, growth would be expected to be somewhat reduced by the lower annual temperatures in upper river sections in each fork. Thus, we expect a smaller size-at-age is normal for trout inhabiting these river sections.

Temperatures during summer months in the Mid NF and Mid SF actually exceeded those in the Low NF and Low SF. Increased temperatures in the Mid NF might be explained by lake water temperature effect (Garrett 2010) as two large lakes (Hancock and Calligan) flow into this river section upstream of where the temperature logger was installed. Conversely, temperatures in the Low NF may be buffered from solar inputs as a result of the low width-to-depth ratio in the deeply incised Black Canyon. Temperatures in the Mid SF were relatively high during summer, but were also relatively low during winter. Thus, air temperature and solar inputs seemed to have more of an influence on water temperature in this section compared to the Mid NF. The growth period for trout is also more truncated in the Mid SF than in the Mid NF, so a steeper growth trajectory is expected in the Mid NF. Further, because the Mid SF lacks deep pools needed for fish over-winter survival, a lower abundance or maximum size of trout might be expected in this river section.

Relative water temperature extremes in middle river sections may be in part due to a lack of groundwater inputs that would otherwise buffer temperatures during extreme climatic conditions. For example, the surface layer of substrate in the South Fork basin is underlain mostly with shallow bedrock (Bethel 2004). Sediments that lack hydraulic conductivity (e.g., bedrock) can inhibit surface-to-groundwater exchange because of the loss of hyporheic filtration through more porous sediments. This exchange is important because it can have a cooling effect on stream water (Edwards 1998). Conversely, the Low SF was buffered from seasonal temperature extremes possibly because of cool water from spring-fed Boxley Creek. The origin of the spring is Chester Morse Lake as groundwater flows through a glacial moraine into Boxley Creek. Chester Morse Lake surface elevation is raised every year as drinking water for the City of Seattle is stored for later summer months. In 2010, surface elevation began to increase in early April, peaking in July and reaching a low point in early October. Regardless of the stabilizing mechanism, we expect trout should grow faster and live longer in the Low SF; however, habitat has been degraded by dikes and bank armor, which decreases the natural recruitment of LWD and reduces cover in the main-stem channel. One exception in the Low SF is the Three Forks segment, which is protected from bank armoring and development, enabling natural erosion and LWD recruitment into the channel. Higher densities of larger trout would be considered normal in this type of habitat as deep scour pools and complex wood structures provide refuge from high flows and terrestrial predators (e.g., osprey, otters) while providing forage opportunities in the current.

Temperature dynamics in the Middle Fork differed from the South and North forks. During the coldest period of winter, each river section in the Middle Fork experienced nearly identical water temperatures, whereas in the North and South forks temperatures remained segregated among river sections throughout the same period. Portions of the Low MF froze completely over during an unusually long period of freezing temperatures (2 weeks) during December 2009. However, river section temperature profiles became increasingly disparate in the Middle Fork during periods of warming in spring and summer. Water temperature disparity among river sections in the Middle Fork was greatest during summer and the Low MF experienced the highest observed temperatures among the forks of the Snoqualmie.

Unusually high temperatures were recorded by the Low MN temperature logger during the summer of 2010 (up to 25°C). These data were removed from analysis; however, further studies that investigate causal mechanisms of extreme water temperatures are warranted to determine if location-specific activity (e.g., thermal venting) influences water temperature in the USRW.

Of the Snoqualmie forks, the Middle Fork appeared to have the greatest overall influence on the temperature regime in the Mainstem Snoqualmie. However, in 2009 during an unusually hot period of a few days, summer temperature in the Low MN appeared to be buffered by cooler water input from the South Fork. In contrast, temperatures estimated in the Up MN during that same period surpassed observed temperatures in all other river sections. Width-to-depth ratios were highest in the Mid MF, Low MF, and Up MN, which probably contributed to the elevated temperatures observed in these river sections. Overall, water temperature sample sites in main-stem channels revealed that temperatures are suitable for trout populations in all river sections, but trout abundance and growth in some river segments are limited due to increasingly extreme conditions. Furthermore, as habitat complexity (i.e., refuge) diminishes, so does the trout population's ability to cope with extreme climatic, geologic, or landscape events. As we describe in the next chapter, there seem to be constraints on the growth, production, and distribution of trout that coincide with spatial and temporal variation in habitat availability and water temperatures.

Kaje (2009) identified some concerns regarding water quality in the USRW and generated prescriptions to address those issues into the future for each fork and the Mainstem Snoqualmie. Most suggestions included further water quality testing, riparian restoration and protection activities, and educating the public on eco-friendly land use and septic tank practices. Additionally, he recommended providing incentives for landowners that conduct stewardship activities on their land such as retaining riparian continuity.

5. Abundance, Distribution, Age, and Growth

Methods

Trout relative abundance and distribution: Main-stem channel surveys

In September 2008 a trout relative abundance pilot study was conducted by randomly selecting three 100 m reaches from the total population of 100 m reaches in each river section. Thirty-three 100 m reaches were snorkeled during the pilot study, and a sample size power analysis was conducted to determine the power and confidence in an estimate of trout abundance that would result by using a stratified random sampling design with 100 m transects as the population of interest. Due to the high variability in fish abundance estimates and unknown widths for the unsampled population of 100 m reaches, we determined that this method would result in inaccurate estimates of trout abundance at the river section level using the prescribed snorkel methods, so it was replaced with a method that would essentially result in a population census for each river section.

To obtain large-scale fish relative abundance estimates, continuous daytime snorkel/habitat surveys were conducted from headwater to mouth in each fork and the Mainstem Snoqualmie above Snoqualmie Falls (Torgersen et al. 2007). To reduce fish detection biases that can result from environmental conditions, surveys were conducted in midsummer to coincide with lower stream discharge levels, lower turbidity, and water temperatures above 9°C (Dolloff et al. 1993). In 2009, surveys were conducted between July 6 and August 26 and in 2010 between August 2 and August 29. All habitat units within the survey range were surveyed except for very shallow riffles and glides or turbulent cascades due to lack of visibility and safety concerns. Snorkel lanes encompassed the wetted width for each river section and latitude-longitude coordinates were recorded at the downstream end of each habitat unit. Fish were tallied by size group (0–50, 50–99, 100–149, 150–229, 230–299, 300–379, ≥380 mm total length) and species categories. Species categories included YOY (young-of-the-year Pacific trout), Onxx (coastal cutthroat trout, rainbow trout, and Pacific trout hybrids), WCT (westslope cutthroat trout), EBT (eastern brook trout), MWF (mountain whitefish), and SUCKER (largescale sucker). We were not able to distinguish between coastal cutthroat and rainbow trout during snorkel surveys; however, we were able to distinguish between trout in the Onxx snorkel category, WCT, and EBT. Estimates of fish length were calibrated under water prior to surveys using wooden dowels cut to known lengths. Calibration exercises were repeated until near 100% accuracy was achieved for each diver. Longitudinal patterns of fish abundance and trout size structure (YOY = 0–50, subadult = 50–149 mm, adult = 150–299 mm, large adult = 300–≥380 mm) were plotted against habitat unit length and scatter plot data were smoothed with the LOWESS function using a 0.30 or 0.60 sampling proportion and second degree polynomial (Sigma Plot 11.0).

Trout abundance estimates for main-stem channel habitats

To estimate total trout abundance by species in each river section it was assumed that habitat units were randomly selected and that all individual trout visible in each snorkel lane were counted. Snorkel lanes encompassed the wetted width of the channel in each survey except in the Low MN where turbidity and wider habitats rendered an undetermined amount of coverage of the wetted width (<50%). Trout count data were summed by species, length group, and habitat type in each river section. Trout abundance was estimated in each river section for each species, length group, and habitat type by combining the sum of fish counted during surveys with estimated counts that were calculated by applying an unbiased density estimator ($CI_{0.95}$) to the total surface area of non-snorkeled habitat units. To produce unbiased estimators, samples need to be obtained randomly. Our sampling regime rendered a near census of main-stem channel fish populations, which provided quantities that can surpass random sampling in accuracy and statistical power. Still, under the conservative assumption that habitat units were randomly selected and fish counts were accurate within each unit, trout abundance was estimated for each species, length group, and habitat type in each river section

$$Y_{ij} = \sum Y_{STij(snorkeled)} + \sum y_{ij(not\ snorkeled)}$$

where

$\sum Y_{STij(snorkeled)}$ = sum (by species and length group) of trout counted in the i^{th} habitat type within the j^{th} river section,

and

$$\sum y_{ij(not\ snorkeled)} = D_{ij} * A_{ij(not\ snorkeled)}$$

The density (fish/m²) of trout by species and length group observed in the i^{th} habitat unit type within j^{th} river section was estimated as

$$D_{ij} = Y_{STij} / A_{ij}$$

and was multiplied by $A_{ij(not\ snorkeled)}$, the total area of each habitat unit type (i) that was not snorkeled per river section (j). The unbiased trout mean density estimator,

$$Y_{STij} = \sum N_h * y_h$$

was used to provide an unbiased estimate of the total number of trout contained in all habitat units within the survey range and included the terms

$$N_h = \sum i_{j(total)}$$

where $\sum i_{j(total)}$ = the total number of each habitat unit type that was snorkeled per j^{th} river section, and

$$y_h = \sum trout_{ij} / \sum_{ij(snorkeled)}$$

where $\sum trout_{ij}$ = the number of trout (by species and length group) counted in each habitat unit type (i) per river section (j). The unbiased trout mean density estimator was divided by the term

$$A_{ij} = \sum Area_{ij}$$

where $\sum Area_{ij}$ = the total area of all habitat units (i) snorkeled per river section (j). The standard error of Y_{STij} was calculated as the square root of the variance estimator for Y_{STij}

$$SE(Y_{STij}) = \sqrt{Var(Y_{STij})} = \sqrt{(\sum N_h^2 [1-\{n_h/N_h\}] * s^2/\mathrm{n_h})}.$$

Confidence intervals (95%) for Y_{STij} were applied for each level of i and j (Cochran 1977)

$$Y_{STij} \pm Z_{1-\alpha/2} * SE(Y_{STij})$$

to provide a proxy for the range of trout abundance estimate values calculated for $\sum y_{ij(not\ snorkeled)}$. Thus, the confidence intervals for each trout population estimate reflected variance associated with fish density in habitat units that were snorkeled. Trout density was estimated for each species and river section by dividing abundance estimates for each species by the total surface area of stream in respective river sections.

Trout relative abundance and distribution: Tributary surveys

To obtain information on the abundance and distribution of fish species inhabiting lower reaches of tributary habitats standardized surveys were conducted in 44 selected tributaries. Surveys were conducted between March and May in 2009 and between January and September in 2010. Selected tributaries were surveyed from the mouth to approximately 400 m upstream by a two-person crew using an upstream single pass backpack electrofishing method (Smith Root LR 24 400-900v, 40–60Hz) without block nets to count fish (Bateman et al. 2005). Stunned fish were identified to species as CCT (coastal cutthroat), Onxx (hybrid or unidentified Pacific trout), RBT (rainbow trout), WCT (westslope cutthroat), and EBT (eastern brook trout). Species/length group categories were tallied and location coordinates were recorded at the downstream end of each habitat unit.

Every habitat unit within the tributary survey range (0–400 m) was sampled effectively during most surveys. Exceptions included tributaries with habitats that were not amenable to accurately quantifying fish abundance using single-pass backpack electrofishing methodology (≥1.0 m deep or ≥1.0 m² area), and surveys with these constraints on sampling were removed from statistical fish abundance comparisons. Trout density, YOY trout density, and coastal cutthroat trout density were compared among confinement types using one-way analysis of variance (Kruskal-Wallis one-way ANOVA on ranks). Dunn's pair-wise multiple comparisons were used to identify where differences in fish density occurred. Kimball, Ribary, Calligan and Hancock creeks were too wide and deep to effectively sample with single pass backpack electrofishing and were therefore omitted from statistical relative abundance comparison analysis.

Fish capture and processing in main-stem channel habitats

To obtain information on species-specific size structure, size-at-age, growth, diet, and species composition, main-stem channel fish sample reaches were identified within each river segment based on accessibility, spatial distribution, and known presence or abundance of fish. Sample reaches were distributed among river segments as practical and it was assumed that fish were sampled randomly from each sample reach. Sample reaches ranged in length from 50 m to 8 km and in width from narrow shallow margins to the entire wetted width. All fish species were captured on a seasonal schedule between October 2008 and October 2010 using one of three methods: 1) single pass backpack electrofishing without block nets; 2) single pass downstream raft electrofishing; or 3) wade or float-based angling. Wade-based angling was most frequently used in conjunction with backpack electrofishing in reaches containing habitats too deep for effective backpack shocking. Float-based angling constituted all sample reaches >300 m in length. Captured fish were held in containers of cold aerated water with cover to reduce stress. Fish were anesthetized using 6 ml of 10% solution MS 222 in 7.5 liters of fresh water and trout were identified to species as CCT (coastal cutthroat), Onxx (hybrid Pacific trout), RBT (rainbow trout), WCT (westslope cutthroat), and EBT (eastern brook trout). All fish were measured for total (TL mm) and fork length (FL mm), and weighed (0.1 g). Processed fish were allowed to recover in buckets of fresh water until able to swim away independently.

Species composition

Fish species composition in the USRW was assessed for main-stem channel habitats by synthesizing species proportions obtained during snorkel surveys and sampling events. Snorkel surveys revealed the longitudinal extent of trout (Onxx, WCT, and EBT), whitefish, and suckers, whereas fish capture and processing enabled differentiation among other fish species and revealed the minimum longitudinal extent of benthic species, which were inconsistently detected during snorkel surveys. Trout were identified using species-specific morphological characteristics common to each species including spotting, body color, hyoid teeth, and maxillary length (Behnke 2002). Species composition in tributaries was assessed by comparing proportions of species groups captured from tributaries in each river section.

Trout genetic samples were collected from sample reaches distributed across the USRW and were placed vials containing 95% ethanol (n = 291, lower caudal fin lobe clip and n = 14 egg and alevin samples). Samples were genotyped at seven microsatellite loci and 96 single nucleotide polymorphism loci. Full details of the methods used in the genetics analysis are provided in Appendix 3 (Thompson et al. 2011). Samples were divided into two genetic categories including species (coastal cutthroat, rainbow, westslope, or hybrids) and lineage (hatchery coastal cutthroat *O. clarki,* hatchery rainbow *O. mykiss,* native Snoqualmie coastal cutthroat: *O clarki,* native Cedar coastal cutthroat: Cedar *O. clarki*, and native Cedar rainbow: Cedar *O. mykiss*). Distribution of endemic Pacific trout species was assessed for these genetic categories for the 305 samples.

Age and growth

Trout scales (n = 1,418 trout) and otoliths (n = 88) were obtained from individuals ≥70 mm TL in each fork and the Mainstem Snoqualmie and were aged by the WDFW scale and otolith aging unit. Otoliths were obtained from inadvertent trout sampling mortalities and were analyzed to calibrate the scale aging process. Length frequency histograms were plotted for each trout species, river section, and season to compare with scale and otolith aging techniques. Length-at-age was plotted for trout to assess differences in growth trajectories between species and river sections.

Mortality and population age structure

Age-length probability matrices (age-length keys) were calculated for each trout species in each river section by sampling scale-aged fish proportional to the length frequencies observed in each river section. The unbiased estimator of the proportion θ of fish age a is (Quinn and Deriso 1999; Isley and Grabowski 2007)

$$\theta_a = \Sigma r_{la}$$

where r_{la} is the estimated proportion of fish in length group l and age is a. Species-specific length group-age proportions were applied to length group abundance estimates to provide an estimate of the abundance of trout by age per river section. Log_e transformed age-specific abundance estimate data were then plotted as linear catch curves for ages considered fully recruited to sampling gear (i.e., > age 1 or 2) (Miranda and Bettoli 2007). Catch curve slopes represented the logarithmic annual instantaneous mortality rates (Z) for each species and river section (Miranda and Bettoli 2007). The antilog of $Z(e^{-Z})$ is the annual survival rate (S) and 1 – S is annual mortality between age groups (Miranda and Bettoli 2007).

To estimate the mortality-corrected abundance of trout in each age group, $\log_e$ abundance was plotted using the linear catch curve equation with age as the independent variable. The antilog was then applied to these abundance estimates for each age group to provide untransformed age- and species-specific abundance estimates in each river section. Coastal cutthroat and unidentified or hybrid Pacific trout (Onxx) were pooled because of uncertainty of differentiating between these species groups during processing. The statistical power of these mortality rates is dependent on the number of age groups; therefore, robust mortality rates were obtained only for species with at least five representative age groups. Because of the difficulty inherent in obtaining representatives from the entire range of trout age groups in each river section, a combination of regression robustness indicators were utilized to identify the most statistically powerful mortality estimates (e.g., r^2, standard error, α, and P-values).

Diet analysis

Stomach contents were sampled from anesthetized trout, whitefish, and sculpin using gastric lavage. Diet samples were allotted by river section, season, and length group to sample the length frequency distribution proportionally across spatial and temporal strata. Stomach contents were analyzed to compare prey consumption and to evaluate seasonal and size-specific changes in diet. Contents were classified to order under a microscope and blotted-dry wet weights were measured to the nearest 0.001 g. Diet proportions by weight were calculated by order and by broader diet item categories including aquatic insects, terrestrial insects, trout eggs, fish, and amphibians.

Results

Trout relative abundance and distribution: Main-stem channel surveys

Trout were observed during extensive snorkel surveys and the Onxx category included endemic coastal cutthroat (Figures 25a and 25b), unidentified or hybrid Pacific trout (Figure 26), and rainbow trout (Figure 27). Mountain whitefish and largescale suckers were also observed along with non-endemic trout, including westslope cutthroat (Figure 28) and eastern brook trout (Figure 29). Small-bodied and benthic fishes such as YOY trout and whitefish, sculpin, longnose dace and western brook lamprey were encountered; however, we considered snorkel counts of these fish to be comparatively inaccurate so abundance was not estimated for these species. Trout and sculpin were the only fishes encountered upstream of Fantastic Falls in the North Fork, upstream of the Dingford Canyon in the Middle Fork, and upstream of Twin Falls in the South Fork, whereas all species were distributed in lower sections of each fork and in the Mainstem Snoqualmie (Figure 30). Large adult trout (>299 mm TL) were most dense in the Sallal Prairie (112/km) and North Bend (37/km) segments of the Low MF (Figure 31).

Longitudinal profiles of trout, whitefish, and sucker abundance varied between each fork and the Mainstem Snoqualmie. Peaks and troughs in abundance revealed longitudinal trends in fish abundance for these three species groups. Trout were observed in all river sections and segments and abundance varied among the forks and Mainstem Snoqualmie. Whitefish and suckers were observed, but only below the most-downstream major geologic barrier in each fork. Abundance of these two species generally diminished as a function of distance upstream in the Snoqualmie forks, but in the Mainstem Snoqualmie, more whitefish and suckers were observed in the Up MN compared to the Low MN (Figures 32 – 35).

In the North Fork, distinctive increases in the relative abundance of trout occurred throughout the upstream portions of the Up NF, in the Mid NF near Big Creek Falls, and in the Black Canyon/Three Forks segments of the Low NF. Trout abundance was low near the confluence with the Middle Fork, but increased steeply to the base of the Black Canyon. Adults were the most frequently observed trout size group in most segments except along the upstream and downstream borders of the Lakebed segment in the Mid NF, where sub-adults were more numerous. Few large adults were observed in the North Fork, but they were distributed throughout the Mid NF and Low NF, and their numbers increased slightly in the Lakebed, Black Canyon, and Three Forks segments. Young-of-the-year trout abundance increased near the downstream end of the Calligan segment and in the Lakebed segment of the Mid NF, whereas the number of sub-adult and adult trout declined in these areas. Mountain whitefish and largescale suckers were observed from the Three Forks segment upstream for about 5 km to the base of the Black Canyon. Sucker abundance increased toward the confluence with the Middle Fork (Figure 32).

In the Middle Fork, increases in the relative abundance of trout occurred in all sections, but each peak in abundance decreased in magnitude with distance upstream. Trout abundance was low near the confluence with the North Fork but increased steadily upstream where it peaked in the Sallal Prairie and Mt. Teneriffe segments. Most trout were adults, but an increase in large adult abundance occurred in the Mt. Teneriffe, Sallal Prairie and North Bend segments. The number of sub-adults decreased as the number of large adults increased in these segments. Young-of-the-year observations increased in the Goldmyer segment and to a lesser degree increased intermittently downstream to the confluence with the North Fork. Whitefish abundance generally tracked trout abundance but declined more rapidly upstream of the Pratt River confluence. Sucker abundance increased toward the confluence with the North Fork (Figure 33).

In the South Fork, the highest relative abundance of trout occurred at the confluence with the Mainstem Snoqualmie, and to a lesser degree, upstream and downstream of the Twin Falls vicinity. The South Fork was the only water body that contained a substantial number of westslope cutthroat and brook trout. Westslope cutthroat numbers were only substantial in the Up SF, whereas brook trout

Figure 25a. Adult pure native coastal cutthroat trout captured in the Up SF Asahel Curtis segment. Note the large spots especially toward the posterior end of the fish and the red cutthroat slash under the jaw. This fish was identified as a native Cedar *O. clarki* genetic strain.

Figure 25b. Large adult coastal cutthroat trout captured in the Low SF North Bend segment. Note the intensity of smaller spots covering the entire body, the extended maxillary and the yellow hue of the fish.

Figure 26. Large adult Onxx trout (cutthroat/rainbow hybrid) captured in the Low NF Black Canyon segment. Note the coastal cutthroat characteristics, such as a greatly extended maxillary and intensity of spots covering the entire body. The coloration and pronounced red band paralleling the lateral line more closely resemble a rainbow trout. This fish was identified as a native Cedar *O. clarki*/hatchery Snoqualmie *O. mykiss* genetic strain.

Figure 27. Large adult pure hatchery-lineage rainbow trout captured in the Low NF Three Forks segment. Note the strong rainbow trout coloration and pronounced red band paralleling the lateral line. This fish was identified as a hatchery Snoqualmie *O. mykiss* genetic strain.

Figure 28. Adult westslope cutthroat trout captured in the Up SF Commonwealth segment. Note that the spotting is limited to the posterior end of the fish, the red cutthroat slash under the jaw and the olive-rose hue of the body.

Figure 29. Adult eastern brook trout captured in the Mid SF Weeks Falls segment. Note the light colored spots over the dark body and vermiform markings on the dorsal fin.

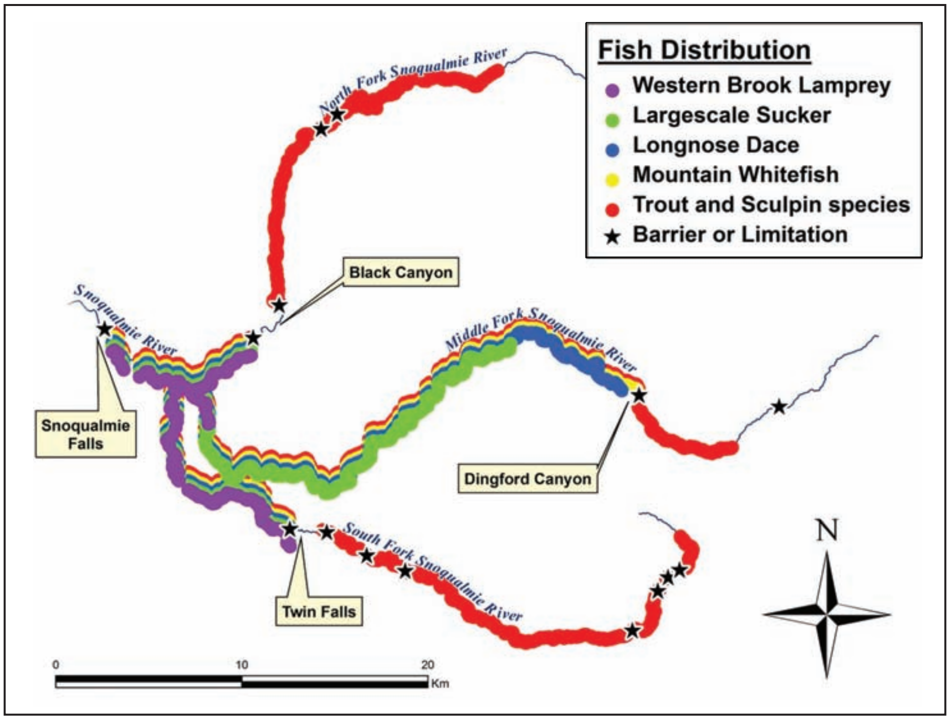

Figure 30. Distribution of fishes in the upper Snoqualmie River watershed. The range of distribution was assessed from fish sampling and snorkel survey data and does not include portions of the watershed that were not sampled or surveyed (i.e., canyons). These data should be considered the minimum extent of known distribution for each species.

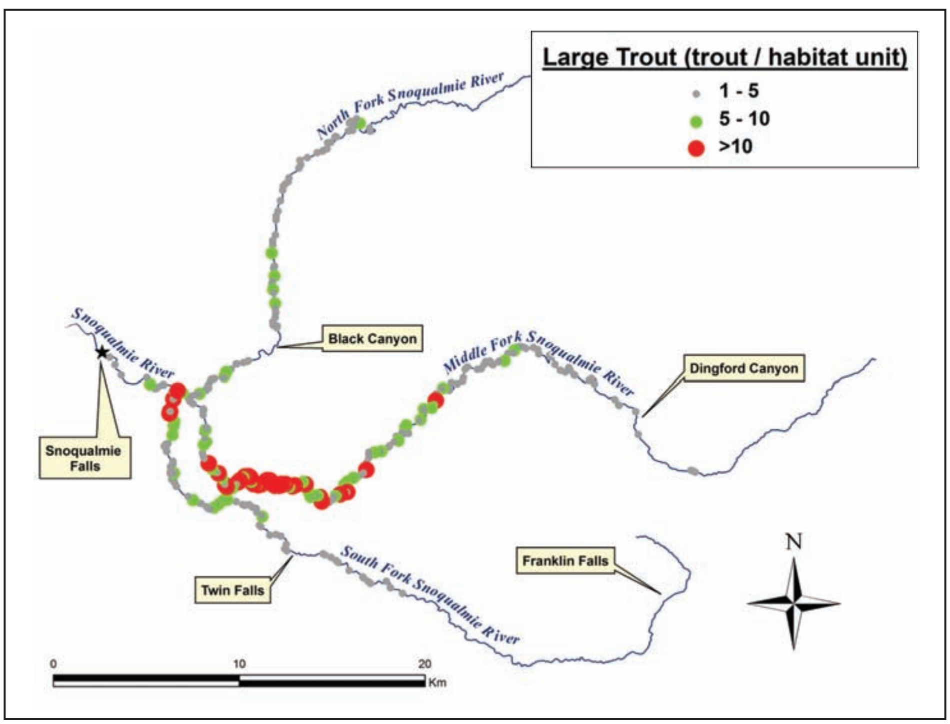

Figure 31. Relative abundance of large adult trout (number of trout >299 mm TL per habitat unit—all trout species combined). Trout were counted in habitat units during snorkel surveys

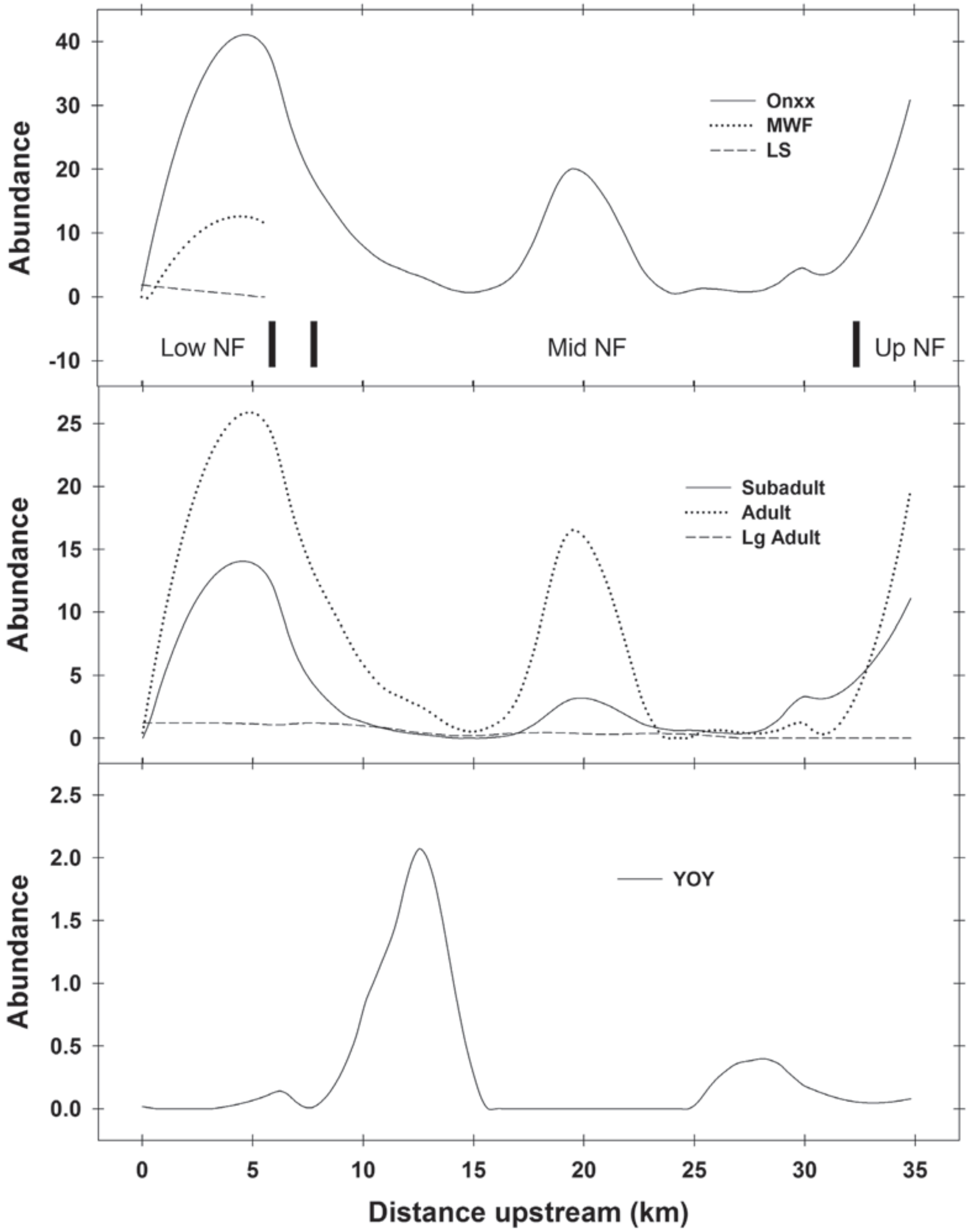

Figure 32. Longitudinal patterns of trout, whitefish, and sucker abundance in the North Fork Snoqualmie River. Scatter plot fish count data obtained at each habitat unit during extensive snorkel surveys were smoothed using trendlines. Species include Onxx = unidentified Pacific trout, MWF = mountain whitefish, and LS = largescale sucker. Plots show distribution by species (top panel) and size group for Onxx (middle panel). Young-of-the-year trout (YOY) were graphed separately because unreliable counts in the field prohibited comparisons with reliably-counted sizes (bottom panel). Vertical hashes in the top panel indicate river section delineations and the extent of non-surveyed canyon segments (i.e., most of the Black Canyon).

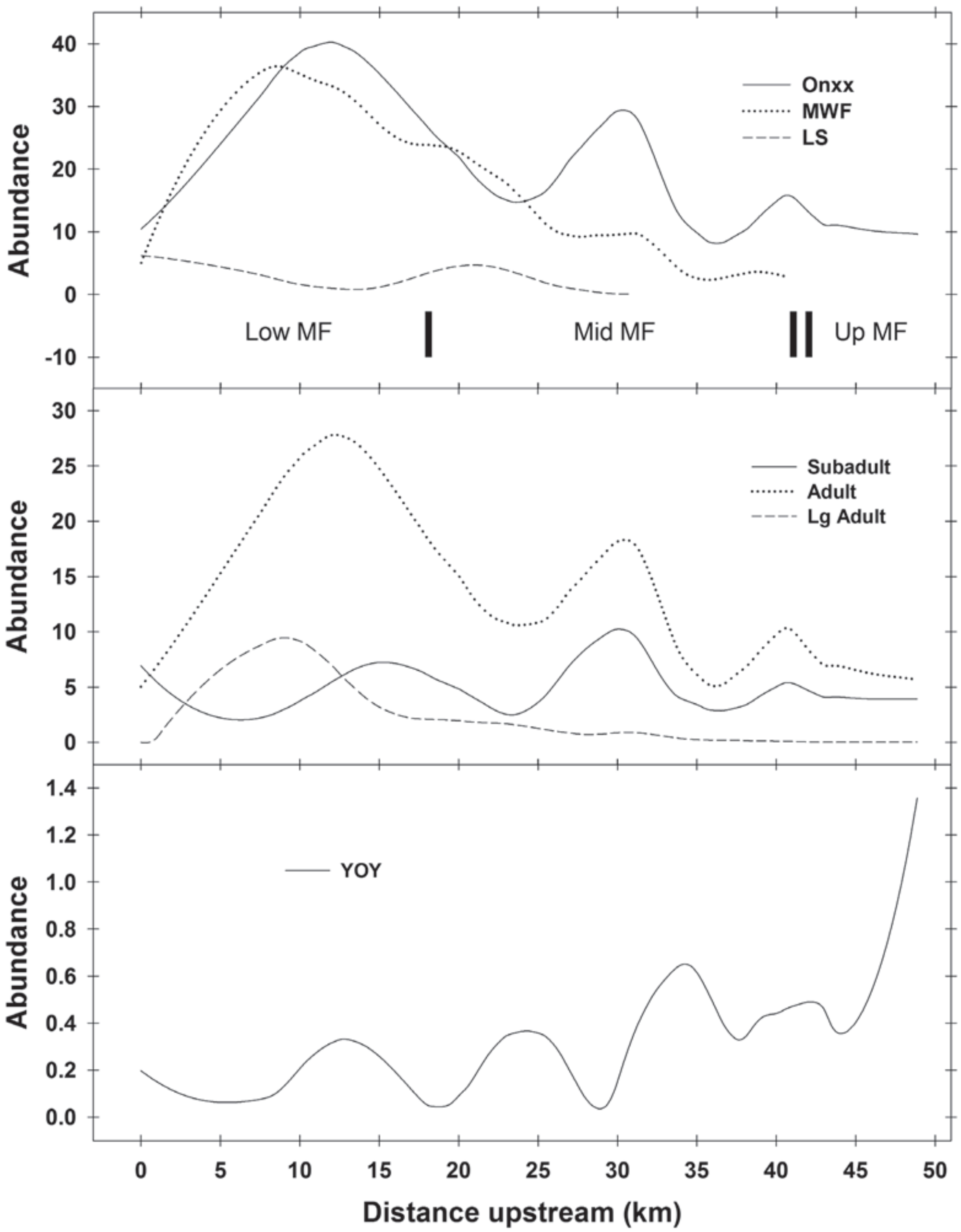

Figure 33. Longitudinal patterns of trout, whitefish, and sucker abundance in the Middle Fork Snoqualmie River. Scatter plot fish count data obtained at each habitat unit during extensive snorkel surveys were smoothed using trendlines. Species include Onxx = unidentified Pacific trout, MWF = mountain whitefish, and LS = largescale sucker. Plots show distribution by species (top panel) and size group for Onxx (middle panel). Young-of-the-year trout (YOY) were graphed separately because unreliable counts in the field prohibited comparisons with reliably-counted sizes (bottom panel). Vertical hashes in the top panel indicate river section delineations and the extent of non-surveyed canyon segments (i.e., most of Dingford Canyon).

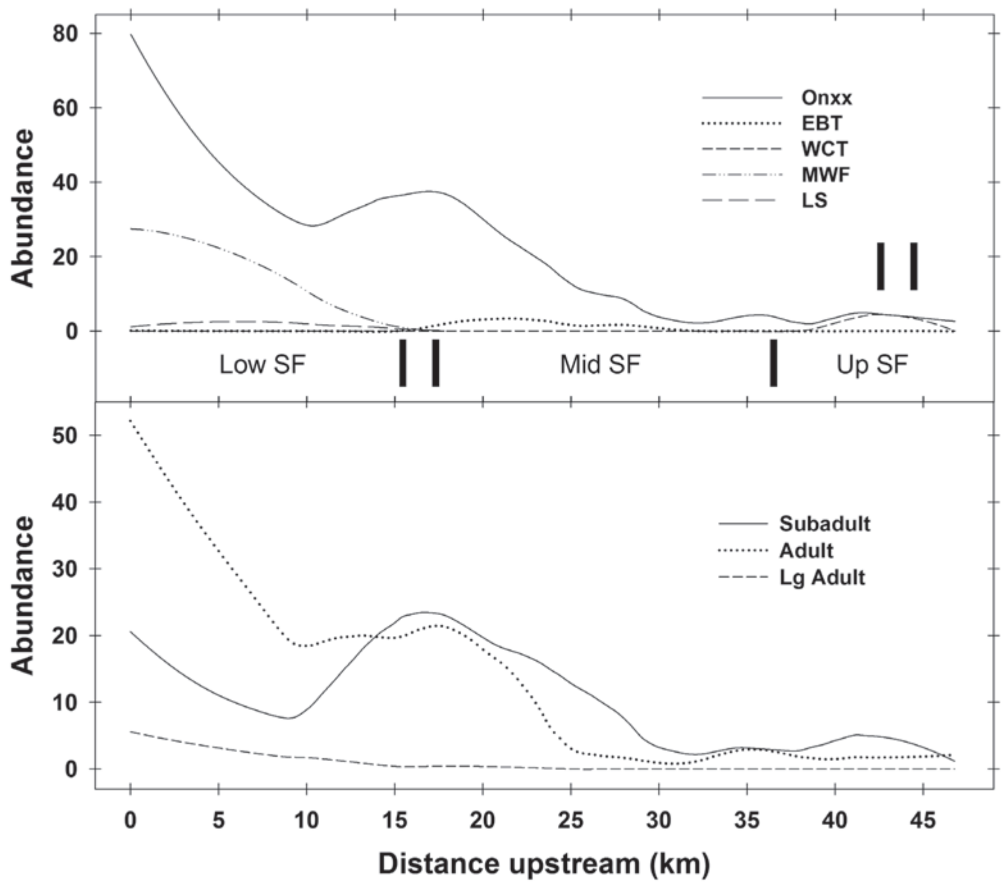

Figure 34. Longitudinal patterns of trout, whitefish, and sucker abundance in the South Fork Snoqualmie River. Scatter plot fish count data obtained at each habitat unit during extensive snorkel surveys were smoothed using trendlines. Species include Onxx = unidentified Pacific trout, EBT = eastern brook trout, WCT = westslope cutthroat trout, MWF = mountain whitefish, and LS = largescale sucker. Plots show distribution by species (top panel) and size group for Onxx (bottom panel). Young-of-the-year trout (YOY) were not observed in the South Fork Snoqualmie River. Vertical hashes in the top panel indicate river section delineations and the extent of non-surveyed canyon segments (i.e., most of Franklin Falls in the Up SF and Twin Falls between the Mid and Low SF).

numbers were only substantial in the Mid SF. Numbers of Onxx trout were relatively low along a majority of the Up SF and Mid SF, but increased markedly in a downstream direction downstream of Twin Falls. In the Up SF and Mid SF, a majority of trout were of the sub-adult size, but near Twin Falls, adult trout numbers increased. Downstream of Twin Falls adults were more abundant and large adult abundance increased to the confluence with the Mainstem Snoqualmie. No YOY were recorded in the South Fork Snoqualmie River. Whitefish numbers increased but sucker numbers decreased in a downstream direction (Figure 34).

In the Mainstem Snoqualmie, Onxx observations increased in the Up MN centered on a large LWD jam. The shape of the trout abundance profile tracked that of whitefish; however, there were fewer trout than whitefish. Sucker abundance related inversely to the whitefish and trout profiles throughout the upper portion of the Up MN. There was a shift in the interaction of fish abundance between species near the midpoint of the Up MN, where trout numbers decreased but whitefish and sucker numbers increased. There was little interaction between trout size groups in the Mainstem Snoqualmie; however, sub-adult numbers declined below adult numbers near the midpoint of the Up MN. Although six snorkelers were used to survey the Low MN, large channel size and increased turbidity prohibited reliable counts and abundance comparisons. No YOY were observed in the Mainstem Snoqualmie during snorkel surveys (Figure 35).

Density of trout varied among river sections and was generally higher in pools compared to other habitat

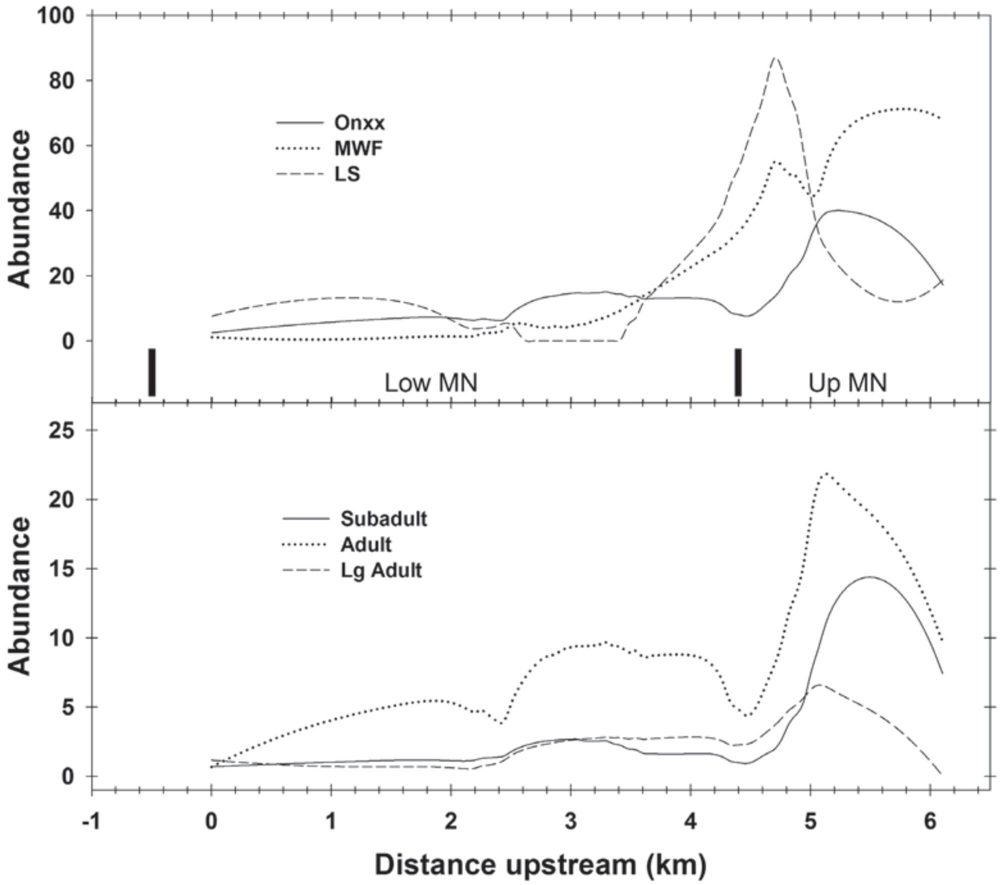

Figure 35. Longitudinal patterns of trout, whitefish, and sucker abundance in the Mainstem Snoqualmie River above Snoqualmie Falls. Scatter plot fish count data obtained at each habitat unit during extensive snorkel surveys were smoothed using trendlines. Species include Onxx = unidentified Pacific trout, MWF = mountain whitefish, and LS = largescale sucker. Plots show distribution by species (top panel) and size group (middle panel). Young-of-the-year trout (YOY) were not observed during snorkel surveys in the Mainstem Snoqualmie River. Vertical hashes in the top panel indicate river section delineations.

types. Exceptions occurred for Onxx in the Low MF where density was greater in cascades, and in the Up MN where density was greater in riffles. In the Up MF westslope cutthroat were observed only in glides. In the Low NF eastern brook trout were only observed in riffles and glides and in the Mid MF they were observed only in riffles (Figure 36). Density of Onxx trout generally increased in upper river sections of each fork as stream channels diminished in size. Lower river sections were less dense than upper but more dense than middle river sections. Variability in density among habitat units was greatest in upper river sections, moderate in middle river sections, and low in lower river sections (Figure 37). Fish biomass generally increased with decreasing elevation in each fork; however, the Mid SF contained less biomass than the Up SF, and the Mid NF contained low densities of biomass throughout most of its length (Figure 38).

Trout abundance estimates for main-stem channel habitats

Trout abundance was estimated for each species in main-stem channels using extensive snorkel survey fish count data (Appendix 1, Tables 4–6) coupled with an unbiased density estimator that was applied to the surface area of non-snorkeled habitat units (Appendix 1, Tables 7–8). The variance estimator and corresponding 95% confidence intervals revealed that abundance estimates were statistically robust (Table 11). It was not possible to accurately estimate the abundance of small bodied (<100 mm TL) fishes so abundance was estimated only for trout, whitefish and suckers in the following size-classes: 100–149, 150–229, 230–299, 300–379, ≥380 (mm TL). The Low MF and Low SF each accounted for 22% of the total trout estimated among all river sections, whereas the Up NF, Up

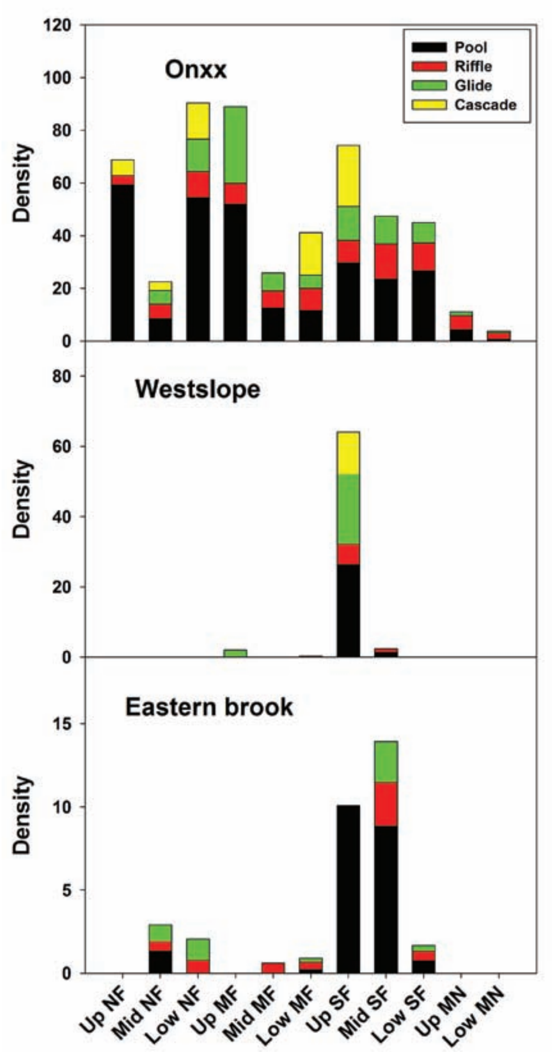

Figure 36. Observed mean density (number of fish per hectare) of trout >99 mm in different habitat types among river sections. Note the differences in scaling on the y-axes for each panel.

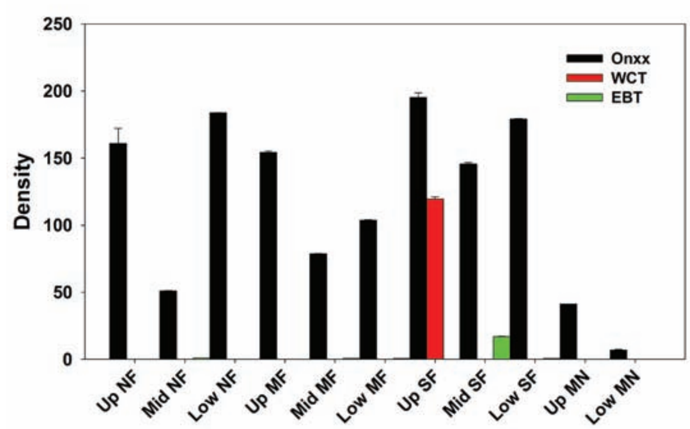

Figure 37. Estimated density (number of fish per hectare +$CI_{0.95}$) of trout >99 mm in each river section was calculated using data obtained during extensive snorkel surveys. Surveys were conducted during summer base flow conditions in summer 2009 and 2010. Species include Onxx = coastal cutthroat trout, rainbow trout or hybrids, WCT = westslope cutthroat trout and EBT = eastern brook trout.

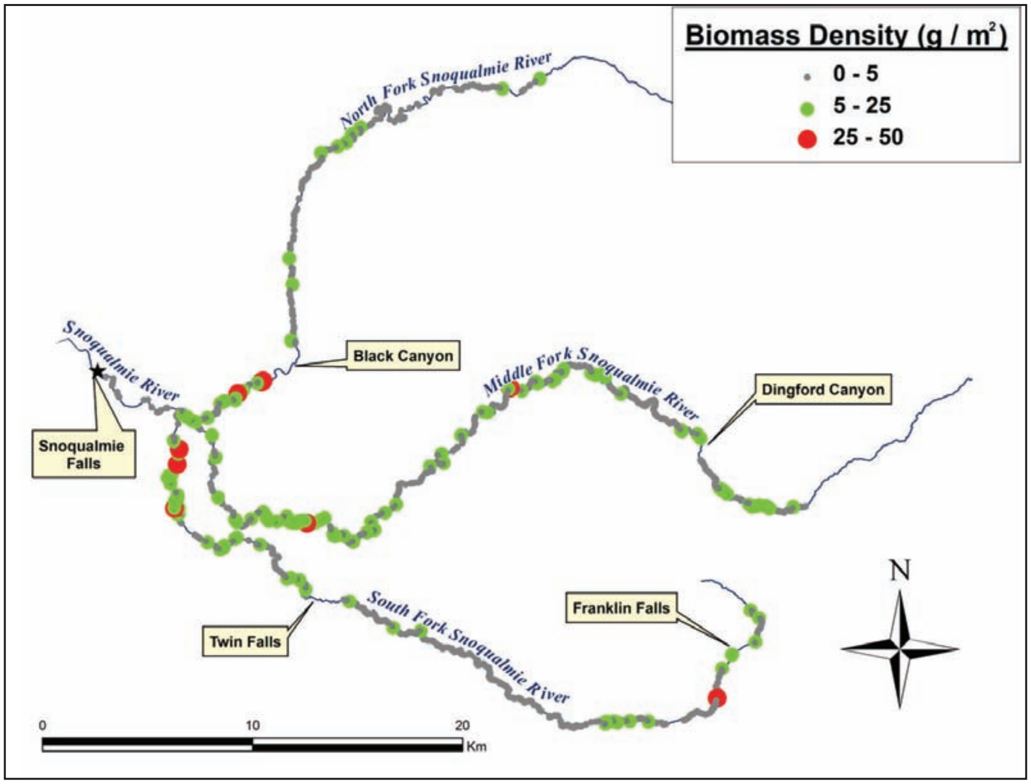

Figure 38. Estimated fish biomass density in snorkeled habitat units. The number of trout, whitefish, and suckers >99 mm counted in each habitat unit was multiplied by the average weight (g) per species and length group. That amount was then summed for each habitat unit and divided by the surface area (m^2) of each habitat unit in which the fish were counted.

MN and Low MN accounted for only 1% each. The Onxx category was the most abundant and widely distributed among trout species. Westslope cutthroat trout were the second most abundant, but were limited in distribution mainly to the Up SF. Eastern brook trout were the least abundant species of trout, but were most numerous in the Mid SF and were distributed more evenly throughout the USRW compared to westslope cutthroat (Table 11).

Trout relative abundance and distribution: Tributary surveys

Tributary surveys showed variation in fish species, size, and abundance among the lower reaches of tributaries. Similar to species distribution in main-stem channels, only trout and sculpin were detected in tributaries upstream of the major main-stem channel barriers in each fork. General results from tributary fish surveys are described by fork in the following paragraphs.

In the Mid NF, most trout were detected in GF Creek* and Deep Creek. GF Creek* contained 38% of all trout, and Deep Creek contained 88% of all brook trout detected in tributaries to the Mid NF. Only one fish (rainbow trout) was detected in Big Creek and was found upstream of a number of probable cascade barriers. No fish were detected in Fertilized Creek* (a fish type stream) upstream of 10 m from the confluence despite containing what seemed to be adequate in-stream habitat upstream and downstream of a perched culvert (i.e., connectivity to main-stem channel, low-to-moderate gradient, riffles and pools). The riparian buffer upstream of 10 m had been completely removed as a result of being clear-cut, and no surface water was present in this portion of the creek during summer months. Tweener Creek* was typed as non-fish, but sculpin were detected downstream and upstream of a perched culvert. Jimmy Jam Creek* contained only a few trout downstream and upstream of a perched culvert near the mouth. Tate Creek was the only tributary surveyed in the Low NF and contained high numbers of coastal cutthroat (n = 47, Table 12). Sculpin were the most densely populated fish species sampled in tributaries to the Mid NF (13/hectare, 57% of all fish) followed by Onxx (7/hectare) and rainbow trout (1/hectare). Only coastal cutthroat (46/hectare, 63% of all

Table 11. Trout (>99 mm TL) abundance estimates (Y^{ij}) and 95% confidence intervals ($CI_{0.95}$) calculated using data obtained during extensive snorkel surveys in the upper Snoqualmie River watershed. Surveys were conducted during summer base flow conditions in 2009 and 2010. Abundance estimates combined actual fish counts in snorkeled habitat units with a density estimator applied to the surface area of non-snorkeled habitat units. The species category Onxx includes coastal cutthroat trout, rainbow trout, unidentified Pacific trout or Pacific trout hybrids.

River Section	Onxx		Westslope cutthroat		Eastern brook trout	
	Y_{ij}	$CI_{0.95}$	Y_{ij}	$CI_{0.95}$	Y_{ij}	$CI_{0.95}$
Up NF	315	(298, 332)	0	-	0	-
Mid NF	2,100	(2092, 2108)	0	-	34	(33, 35)
Low NF	1,233	(1233, 1233)	0	-	3	(0, 35)
Up MF	1,146	(1128, 1164)	1	-	0	-
Mid MF	4,374	(4357, 4390)	0	-	13	(13, 13)
Low MF	7,054	(7022, 7087)	14	(14, 14)	23	(23, 23)
Up SF	1,222	(1195, 1249)	736	(720, 753)	2	(2, 2)
Mid SF	3,330	(3299, 3361)	16	(16, 16)	365	(359, 371)
Low SF	5,019	(4993, 5046)	0	-	16	(14, 17)
Up MN	267	(223, 311)	0	-	0	-
Low MN	150	(142, 157)	0	-	0	-

fish) and sculpin (27/hectare) were detected in Tate Creek, a tributary to the Low NF (Figure 39).

Trout represented 91% of all fishes (including sculpin) detected in tributaries to the Mid MF. Sixty-seven percent of all trout were YOY of which 63% were detected in MP 14.1 Creek* (*n* = 141) and the remaining 37% (*n* = 82) were detected in Clay Creek #2*. Conversely, no YOY were detected in Bench* and Granite creeks. Most non-YOY trout were not identifiable to species (71% Onxx), but the remaining trout were all identified as coastal cutthroat. In tributaries to the Low MF a majority of trout were coastal cutthroat (*n* = 482, 58%) followed by YOY (*n* = 283, 34%). Only 7% of all trout were unidentifiable to species and only one brook trout was detected in Low MF tributaries. Sculpin were less numerous than trout (*n* = 212) but were widely distributed among tributaries. Longnose dace were almost as numerous as sculpin (*n* = 206), but were essentially limited in distribution to one tributary (Confluence Creek*). Little Si Creek* contained 46% of all trout detected in tributaries to the Low MF and was followed by Roaring Creek which contained 20% (Table 12). Young-of-the-year trout were the most densely populated species in tributaries to the Mid MF (42/hectare). Overall, tributaries to the Low MF contained the highest mean density of fish detected in tributaries in the USRW (235/hectare). Coastal cutthroat were the most densely populated species (91/hectare) followed by YOY (53/hectare), sculpin (40/hectare), and dace (39/hectare, Figure 39).

Trout represented 81% of all fishes detected in tributaries to the Up SF, and all other fishes were sculpin. No YOY trout were detected in Up SF tributaries. The uppermost tributary, Commonwealth Creek, contained mostly westslope cutthroat (46%), whereas Denny Creek contained mostly Onxx (58%), and Olallie Creek contained mostly coastal cutthroat (89%). This pattern of westslope cutthroat in upper-most portions of the Up SF and coastal cutthroat in lower portions of the Up SF was similar in the main-stem channel. Tributaries to the Mid SF were dominated by sculpin species (67%) and trout species composition and abundance was highly variable among tributaries in this river section. Trout species composition in Talapus Creek, a tributary to the upper-portion of the Tinkham segment, was dominated by coastal cutthroat. Hansen Creek contained 611 sculpin (85% of all fish), and of trout, 69% were coastal cutthroat. Carter Creek contained more Onxx species (56%) than coastal cutthroat. The combination of

Table 12. Aquatic vertebrate species abundance summary for tributary surveys. Fish were enumerated using single pass backpack electrofishing. Species included: CCT = coastal cutthroat trout, Onxx = hybrid or unidentified Pacific trout, YOY = young-of-the-year Pacific trout, RBT = rainbow trout, EBT = eastern brook trout, WCT = westslope cutthroat trout, Sculpin = sculpin spp., Dace = longnose dace, Lamprey = western brook lamprey, Sucker = largescale sucker, 3-Stikle = Threespine stickleback, Pacific giant = Pacific giant salamander, Red legged = red legged frog, Tailed frog = tailed frog tadpole or adult, Warm water spp. = largemouth bass, yellow perch or sunfish spp.

River Section	Tributary name (*Alias for study)	Survey date	CCT	Onxx	YOY	RBT	WCT	EBT	Sculpin	Dace	Lamprey	Sucker	3-Stikle	Pacific giant	Red legged	Tailed frog	Warm water spp.	Total
Mid NF			**5**	**112**	**2**	**17**	**0**	**16**	**200**	**0**	**0**	**0**	**0**	**4**	**0**	**2**	**0**	**358**
	Jimmy Jam Creek*	9/24/10	2	0	0	0	0	0	22	0	0	0	0	2	0	0	0	26
	GF Creek*	3/22/10	0	66	2	7	0	1	52	0	0	0	0	1	0	2	0	131
	Big Creek	1/27/10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1
	Deep Creek	1/27/10	3	16	0	8	0	14	81	0	0	0	0	0	0	0	0	122
	Fertilized Creek*	4/20/09	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	6
	Calligan Creek	3/8/10	0	10	0	0	0	1	9	0	0	0	0	0	0	0	0	20
	Tweener Creek*	4/20/09	0	0	0	0	0	0	22	0	0	0	0	1	0	0	0	23
	Hancock Creek	3/8/10	0	13	0	0	0	0	6	0	0	0	0	0	0	0	0	19
	SMC Creek*	4/15/10	0	7	0	1	0	0	2	0	0	0	0	0	0	0	0	10
Low NF			**47**	**0**	**0**	**0**	**0**	**0**	**28**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**75**
	Tate Creek	3/17/09	47	0	0	0	0	0	28	0	0	0	0	0	0	0	0	75
Mid MF			**32**	**79**	**223**	**0**	**0**	**0**	**33**	**0**	**0**	**0**	**0**	**4**	**2**	**0**	**0**	**373**
	MP14.1 Creek*	7/27/10	7	18	141	0	0	0	0	0	0	0	0	2	2	0	0	170
	Bench Creek*	4/7/10	0	29	0	0	0	0	11	0	0	0	0	1	0	0	0	41
	Clay Creek #2*	7/22/10	23	21	82	0	0	0	17	0	0	0	0	1	0	0	0	144
	Granite Creek	3/5/10	2	11	0	0	0	0	5	0	0	0	0	0	0	0	0	18
Low MF			**482**	**62**	**283**	**0**	**0**	**1**	**212**	**206**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**1,248**
	Culvert Creek*	2/18/10	1	28	0	0	0	0	1	0	0	0	0	0	0	0	0	30
	Mine CreekMF*	4/2/09	54	1	10	0	0	0	42	0	0	0	0	0	0	0	0	107
	Jackson's Creek*	4/16/09	132	0	12	0	0	0	79	0	0	0	0	0	0	0	0	223
	Roaring Creek	3/26/09	120	0	46	0	0	0	1	0	0	0	0	2	0	0	0	169
	Little Si Creek*	3/20/09	167	0	215	0	0	0	8	1	0	0	0	0	0	0	0	391
	Confluence Creek*	2/23/10	8	33	0	0	0	1	81	205	0	0	0	0	0	0	0	328

—Table 12 continued on next page

River Section	Tributary name (*Alias for study)	Survey date	CCT	Onxx	YOY	RBT	WCT	EBT	Sculpin	Dace	Lamprey	Sucker	3-Stikle	Pacific giant	Red legged	Tailed frog	Warm water spp.	Total
Up SF			**40**	**36**	**0**	**2**	**30**	**0**	**26**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**135**
	Commonwealth Creek	9/22/10	0	18	0	0	30	0	17	0	0	0	0	1	0	0	0	66
	Denny Creek	9/23/10	6	18	0	2	0	0	5	0	0	0	0	0	0	0	0	31
	Olallie Creek	9/23/10	34	0	0	0	0	0	4	0	0	0	0	0	0	0	0	38
Mid SF			**201**	**161**	**26**	**34**	**0**	**105**	**1,076**	**0**	**0**	**0**	**0**	**35**	**0**	**9**	**0**	**1,647**
	Talapus Creek	9/21/10	87	7	1	0	0	0	53	0	0	0	0	3	0	0	0	151
	Hansen Creek	7/19/10	72	22	7	3	0	0	611	0	0	0	0	14	0	8	0	737
	Carter Creek	3/23/10	31	46	5	0	0	0	73	0	0	0	0	4	0	1	0	160
	Harris Creek	4/9/10	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
	Mason Creek	4/27/09	0	1	0	4	0	0	0	0	0	0	0	5	0	0	0	10
	Alice Creek	4/14/10	0	1	0	11	0	1	0	0	0	0	0	0	0	0	0	13
	Coyote Creek*	4/29/09	0	10	11	3	0	73	118	0	0	0	0	4	0	0	0	219
	Mine CreekSF	4/6/09	0	7	0	2	0	2	117	0	0	0	0	1	0	0	0	129
	Firefighter Creek*	5/1/09	1	30	2	9	0	29	98	0	0	0	0	2	0	0	0	171
	Grouse Ridge Ck.*	4/8/10	2	33	0	0	0	0	3	0	0	0	0	1	0	0	0	39
	Hall Creek	4/6/09	8	3	0	2	0	0	3	0	0	0	0	1	0	0	0	17
Low SF			**145**	**21**	**354**	**0**	**0**	**0**	**406**	**0**	**6**	**0**	**54**	**0**	**0**	**0**	**0**	**986**
	Boxley Creek	4/9/09	20	8	346	0	0	0	69	0	0	0	0	0	0	0	0	443
	Riverbend Creek*	3/26/09	57	4	0	0	0	0	45	0	3	0	0	0	0	0	0	109
	Clough Creek	4/8/09	30	1	0	0	0	0	221	0	2	0	0	0	0	0	0	254
	Ribary Creek	3/18/09	0	2	0	0	0	0	17	0	0	0	0	0	0	0	0	19
	Gardiner Creek	9/27/10	38	6	8	0	0	0	54	0	1	0	54	0	0	0	0	161
Up MN			**63**	**0**	**0**	**1**	**0**	**0**	**9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**73**
	Three Forks Ck.*	3/17/09	63	0	0	1	0	0	9	0	0	0	0	0	0	0	0	73
Low MN			**66**	**45**	**2**	**0**	**0**	**0**	**242**	**156**	**18**	**37**	**4**	**1**	**0**	**0**	**106**	**677**
	Brockway Creek	3/12/09	18	4	0	0	0	0	27	4	7	0	0	0	0	0	0	60
	Mill Pond Creek*	3/11/09	8	10	0	0	0	0	4	150	1	37	3	0	0	0	106	319
	Coal Creek	4/22/10	38	30	2	0	0	0	204	0	10	0	0	1	0	0	0	285
	Kimball Creek	3/11/09	2	1	0	0	0	0	7	2	0	0	1	0	0	0	0	13

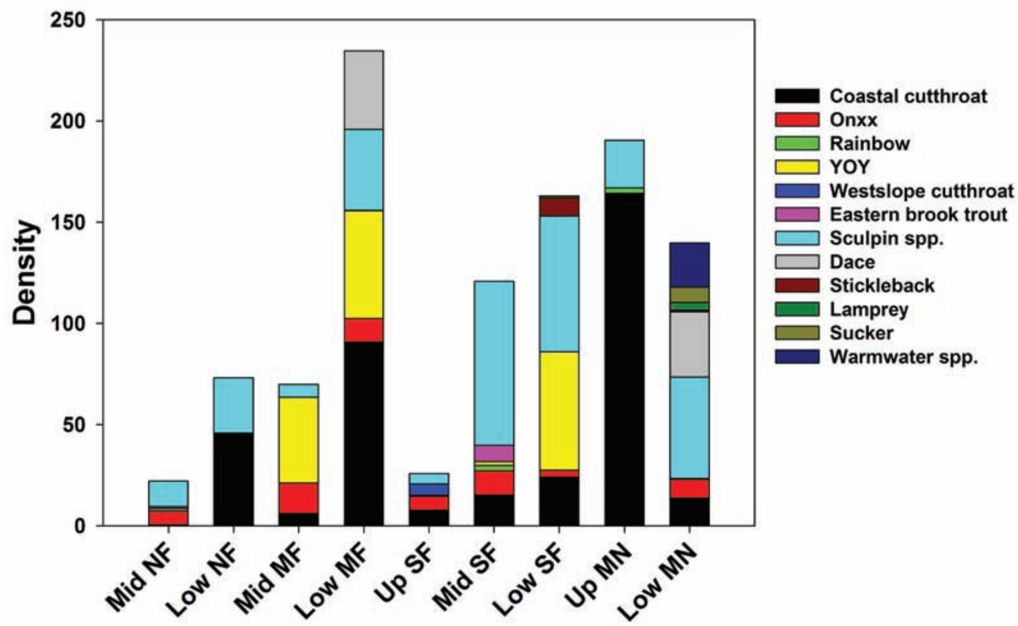

Figure 39. Mean density of fish (number of fish per hectare) by river section in the lower 400 m of surveyed tributaries. Fish were counted using continuous upstream single pass backpack electrofishing without block nets.

Harris, Mason, and Alice creeks contained low numbers of fish *(n* = 19). A majority of fish detected in these tributaries were rainbow trout (*n* = 11), and no coastal cutthroat, YOY, or sculpin were detected. One brook trout was detected in Alice Creek, and brook trout abundance increased in tributaries just downstream of Alice Creek. Fifty-eight percent of the trout detected in Coyote*, Mine, and Firefighter* creeks were brook trout, but 65% of all fishes were sculpin. Of Pacific trout species in these tributaries, most were Onxx (*n* = 47, 26%). The majority of all fishes detected in Grouse Ridge Creek*, which is downstream of Firefighter Creek* and flows into the Mid SF below Weeks Falls, were Onxx (*n* = 33, 87%). In the Mid SF, densities of trout were greater in the upper portion of the Tinkham segment compared to lower Tinkham and upper Weeks Falls segment areas. In the Low SF, Boxley Creek contained the highest number of trout among all surveyed tributaries (*n* = 374, 72%), and most of these were YOY (93%). Seventy-one percent of all fishes in Clough Creek were sculpin (*n* = 221). The remainder of Low SF tributaries contained mostly sculpin (41%) and coastal cutthroat (15%). Among all tributaries in the USRW, Gardiner Creek contained the only substantial numbers of threespine stickleback (*n* = 54, Table 12). Fish density in tributaries increased from the Up SF downstream to the Low SF. Sculpin were the most densely populated and widely distributed fish species in the Mid SF and Low SF (combined 77/hectare), followed by coastal cutthroat (combined 18/hectare). Young-of-the-year trout were more densely populated than coastal cutthroat (combined 20/hectare v. 18/hectare), but their distribution was limited to seven tributaries compared to ten for coastal cutthroat in the Mid SF and Low SF. Onxx were the most widely distributed, as they were detected in all sixteen tributaries surveyed in these two river sections. With the exception of Deep Creek in the Mid NF, the Mid SF contained the only substantial tributary-based populations of brook trout (Figure 39).

One tributary to the Up MN, Three Forks Creek*, was surveyed, and it contained a high density of coastal cutthroat (164/hectare). Four tributaries to the Low MN were surveyed, and each contained coastal cutthroat and Onxx trout. Abundance of coastal cutthroat (*n* = 38) and Onxx (*n* = 30) were highest in Coal Creek, a tributary to Kimball Creek, which flows into the Low MN. Coal Creek also contained a high abundance of sculpin species (*n* = 204), and the only YOY detected in Low MN tributaries (*n* = 2). Brockway Creek contained Pacific trout (*n* = 22, 37%), but also contained sculpin, dace, and lamprey downstream of Brockway Lake. Sculpin were the most densely populated fish species in tributaries to the Low MN (50/hectare), followed by dace (32/hectare) and trout (23/hectare; Figure 39).

Most trout detected in tributaries were between 25 mm (YOY) and 149 mm TL. Trout density was statistically higher in lower and unconstrained tributaries compared to constrained ones (H = 11.03, $P < 0.05$). Young-of-the-year trout linear density (number of YOY per m) was greater in

Table 13. Total counts of fish captured in main-stem channel habitats in each river section. Fish were captured using backpack electrofishing, angling, or boat electrofishing.

River Section	Coastal cutthroat trout	Rainbow trout	Onxx (Hybrid or unidentified Pacific trout)	Westslope cutthroat trout	Eastern brook trout	Mountain whitefish	Sculpin spp.	Longnose dace	Western brook lamprey	Largescale sucker	Total
Up NF	87	0	39	0	1	0	20	0	0	0	147
Mid NF	15	251	82	0	5	0	24	0	0	0	377
Low NF	74	150	35	0	3	5	33	20	0	0	320
Up MF	192	0	28	0	0	0	2	0	0	0	222
Mid MF	252	0	16	0	0	8	25	10	0	0	311
Low MF	338	2	45	0	0	9	20	28	0	0	442
Up SF	49	7	30	148	0	0	75	0	0	0	309
Mid SF	27	123	155	0	44	0	100	0	0	0	449
Low SF	203	47	40	1	3	64	64	5	3	4	434
Up MN	113	4	35	0	2	1	5	14	7	0	181
Low MN	123	2	4	0	0	0	0	0	0	0	129
Total	**1,473**	**586**	**509**	**149**	**58**	**87**	**368**	**77**	**10**	**4**	**3,321**

unconstrained versus constrained tributaries (H = 10.26, P < 0.05), and coastal cutthroat trout linear density was greater in lower versus constrained tributaries (H = 12.32, P < 0.05). Abundance of YOY did not correlate significantly with abundance of sub-adult or adult Pacific trout in tributaries (Spearman correlation: P > 0.050), indicating that adult main-stem channel fishes probably moved into tributaries, spawned, then moved back into main-stems as opposed to residing in tributaries.

Species composition: Field identification

Most trout captured in main-stem channels were identified as coastal cutthroat followed by rainbow and Onxx (hybrid or unidentified Pacific trout species). Species compositions obtained from fish capture indicated a substantial amount of trout species segregation among the forks. Composition analysis for benthic species was limited because they were not targeted during capture; however, all captured species were summarized in Table 13. The following paragraphs describe trout species compositions obtained from fish capture by fork.

The trout population in the Up NF was composed mainly of coastal cutthroat (69%), whereas the Mid NF contained the lowest proportion of coastal cutthroat (4%) and the highest proportion of rainbow trout (71%) in the USRW. The Low NF also contained mostly rainbow trout (57%); however, coastal cutthroat catch increased to 39% near the confluence with the Middle Fork in the Three Forks segment (Table 13).

Coastal cutthroat trout dominated the catch composition in all river sections of the Middle Fork. Eighty-seven percent of the trout captured in the Up MF, 94% in the Mid MF, and 88% in the Low MF were coastal cutthroat. No brook trout were captured and only 2 rainbow trout were captured in the Middle Fork (Table 13).

The South Fork contained the most diverse array of trout species in the USRW. The Up SF contained more westslope cutthroat trout (63%) than coastal cutthroat (21%), and the Mid SF contained more Onxx (44%, unidentified or hybrid), rainbow (35%), and brook trout (13%) than coastal cutthroat (8%). The Low SF contained mostly coastal cutthroat (69%), followed by rainbow (16%) and Onxx (14%), and both sections of the Mainstem Snoqualmie contained mostly coastal cutthroat (Up MN = 73%, Low MN = 95%, Table 13).

Dominant trout populations in the USRW can be sep-

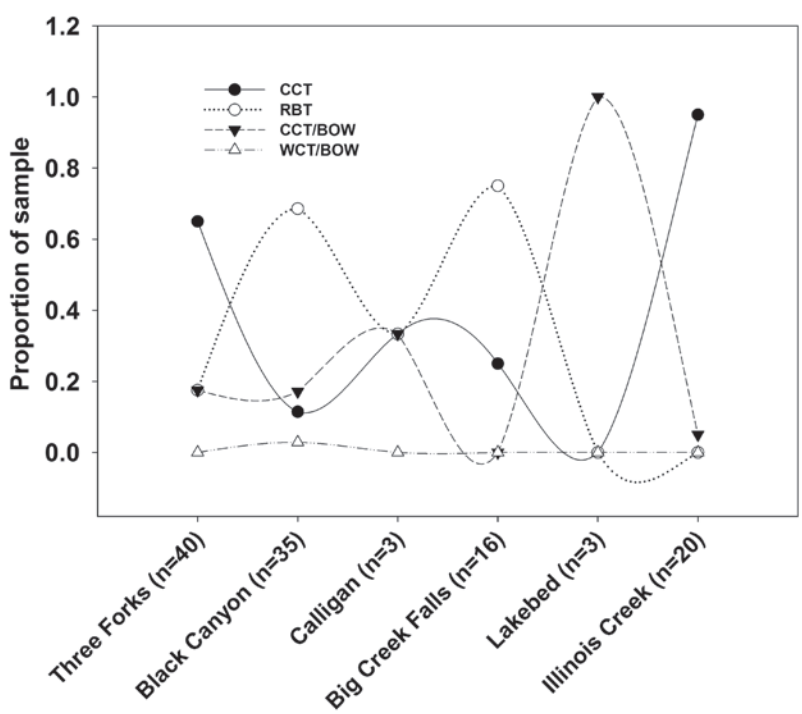

Figure 40. Longitudinal profile of Pacific trout genetic species composition from the Three Forks segment in the Mainstem Snoqualmie to the Illinois Creek segment in the North Fork Snoqualmie River. Species include: CCT = coastal cutthroat trout, RBT = rainbow trout, WCT = westslope cutthroat trout and combinations are hybrids. Genetic sample sizes (n) are given next to sample location.

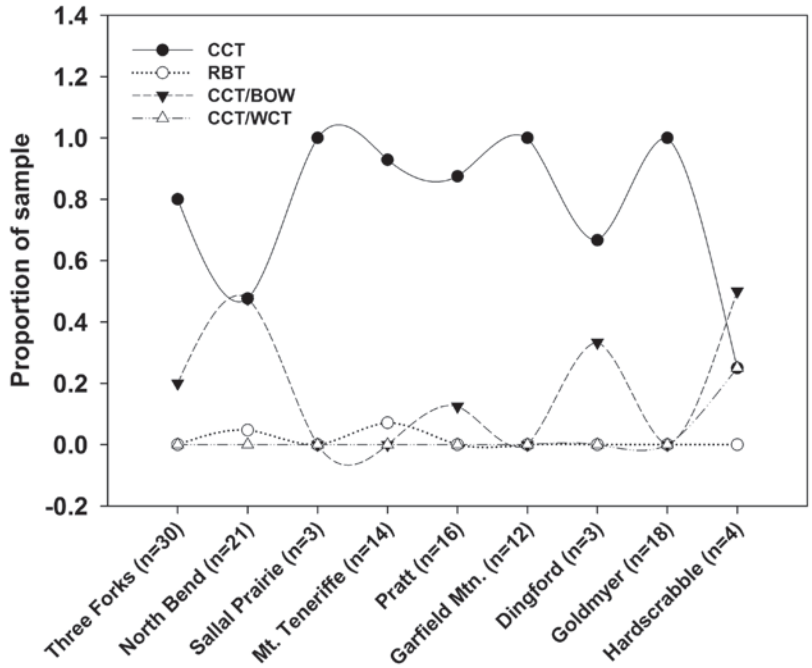

Figure 41. Longitudinal profile of Pacific trout genetic species composition from the Three Forks segment in the Mainstem Snoqualmie to the Hardscrabble segment in the Middle Fork Snoqualmie River. Species include: CCT = coastal cutthroat trout, RBT = rainbow trout, WCT = westslope cutthroat trout and combinations are hybrids. Genetic sample sizes (n) are given next to sample location.

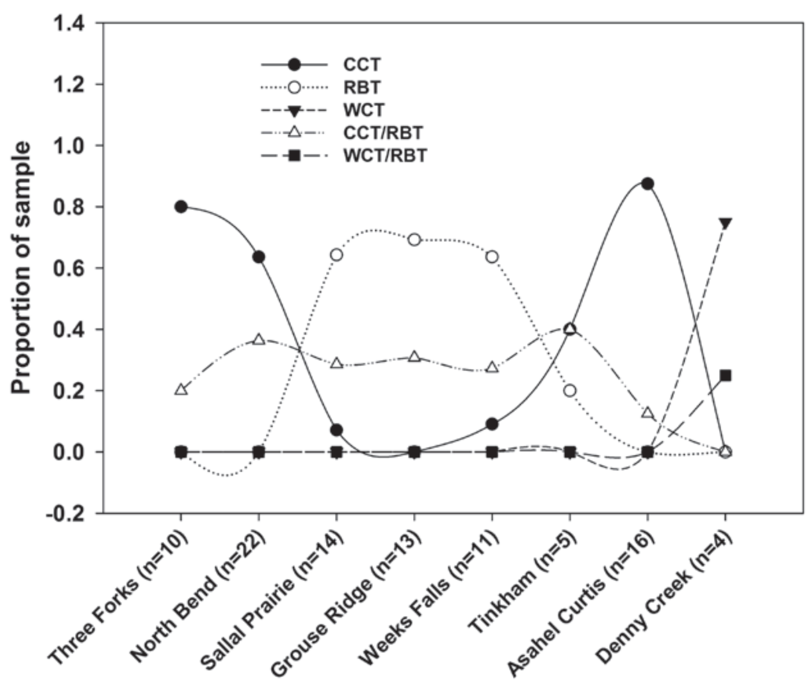

Figure 42. Longitudinal profile of Pacific trout genetic species composition from the Three Forks segment in the lower Mainstem Snoqualmie to the Denny Creek segment in the South Fork Snoqualmie River. Species include: CCT = coastal cutthroat trout, RBT = rainbow trout, WCT = westslope cutthroat trout and combinations are hybrids. Genetic sample sizes (n) are given next to sample location.

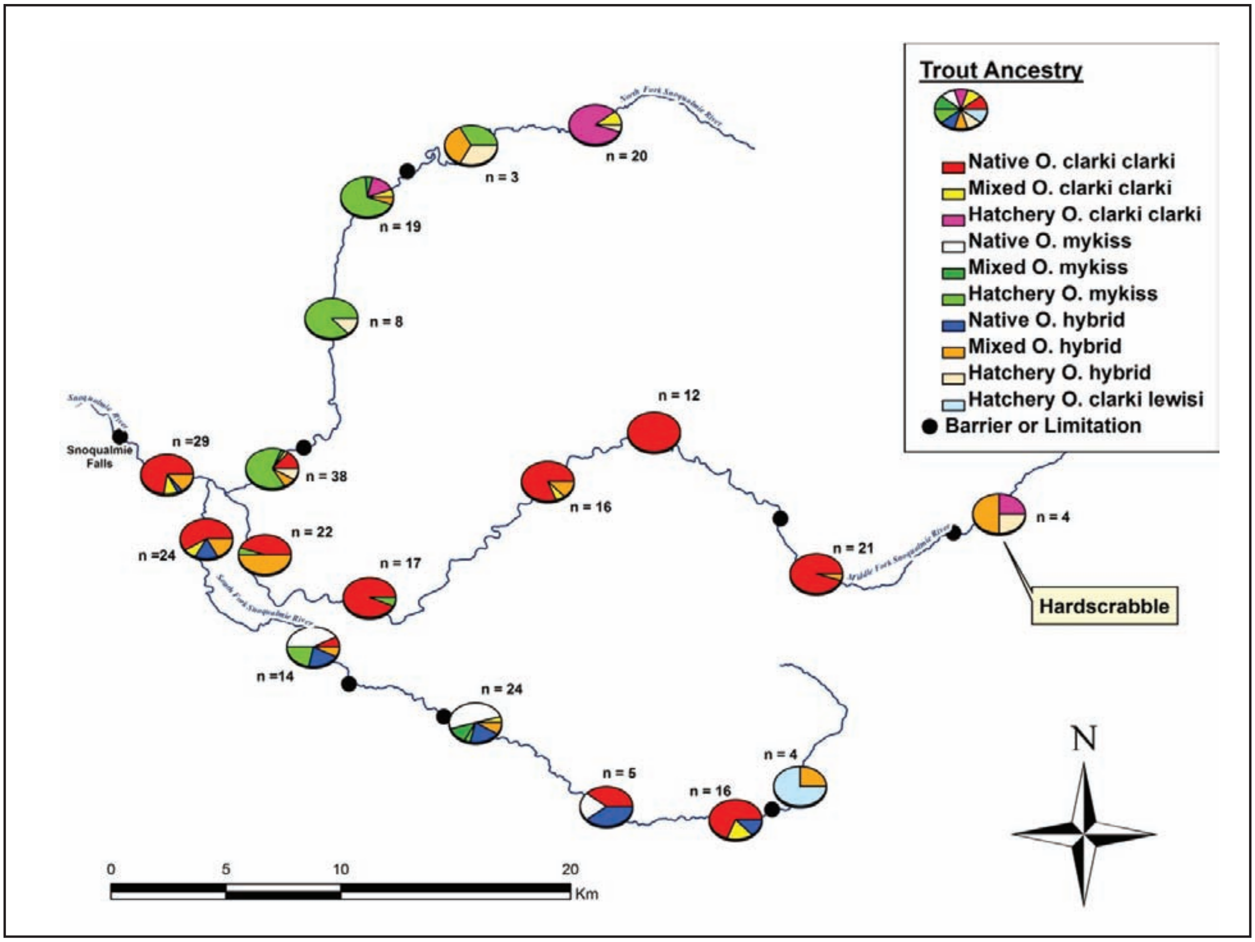

Figure 43. Distribution of the various native and hatchery-origin lineages of Pacific trout in the upper Snoqualmie River watershed. Trout were sampled from river segments and genotyped at seven microsatellite loci and 96 single nucleotide polymorphism loci (Thompson et al. 2011). Pie charts represent approximate sample locations. Captions next to pie charts indicate the total sample size for each sample location. Species abbreviations: *O. clarki clarki* = coastal cutthroat, *O. mykiss* = rainbow trout, O. hybrid = hybrid between *Oncorhynchus* species, and *O. clarki lewisi* = westslope cutthroat.

arated into six distinct demographic regions: 1) Up NF—coastal cutthroat, 2) Mid NF/Low NF—rainbow, 3) Low MN/Up MN/Low NF/Low MF/Mid MF/Up MF/Low SF—coastal cutthroat, 4) Mid SF—rainbow, hybrid, and brook, 5) Mid/Up SF Asahel Curtis—coastal cutthroat, and 6) Up SF—westslope cutthroat.

Species composition: Genetic identification

Pacific trout genetic sample sizes and species composition were plotted longitudinally for each sample reach and corroborated species composition patterns obtained from total catch in each fork and the Mainstem Snoqualmie (Figures 40–42). Pacific trout genetic lineage composition was mapped in all forks and the Mainstem Snoqualmie to display longitudinal and inter-sub-basin patterns in the genetic lineage composition of Pacific trout. Longitudinally distributed genetic samples revealed spatial patterns in the current distribution of native and hatchery-lineage Pacific trout species (Figures 43–44). More complete and detailed genetic analysis results can be found in Appendix 3 (Thompson et al. 2011) and are briefly described in the following paragraphs.

In the Up NF, a majority of trout genetics matched pure Lake Whatcom hatchery *O. clarki* (85%). In the Mid NF Lakebed segment, only three trout were sampled, but each contained different genetic backgrounds. None were of pure native ancestry, but one matched native Cedar *O. mykiss*. From the downstream border of the Lakebed segment downstream to the confluence with the Middle Fork, a majority of samples matched hatchery *O. mykiss* (69%);

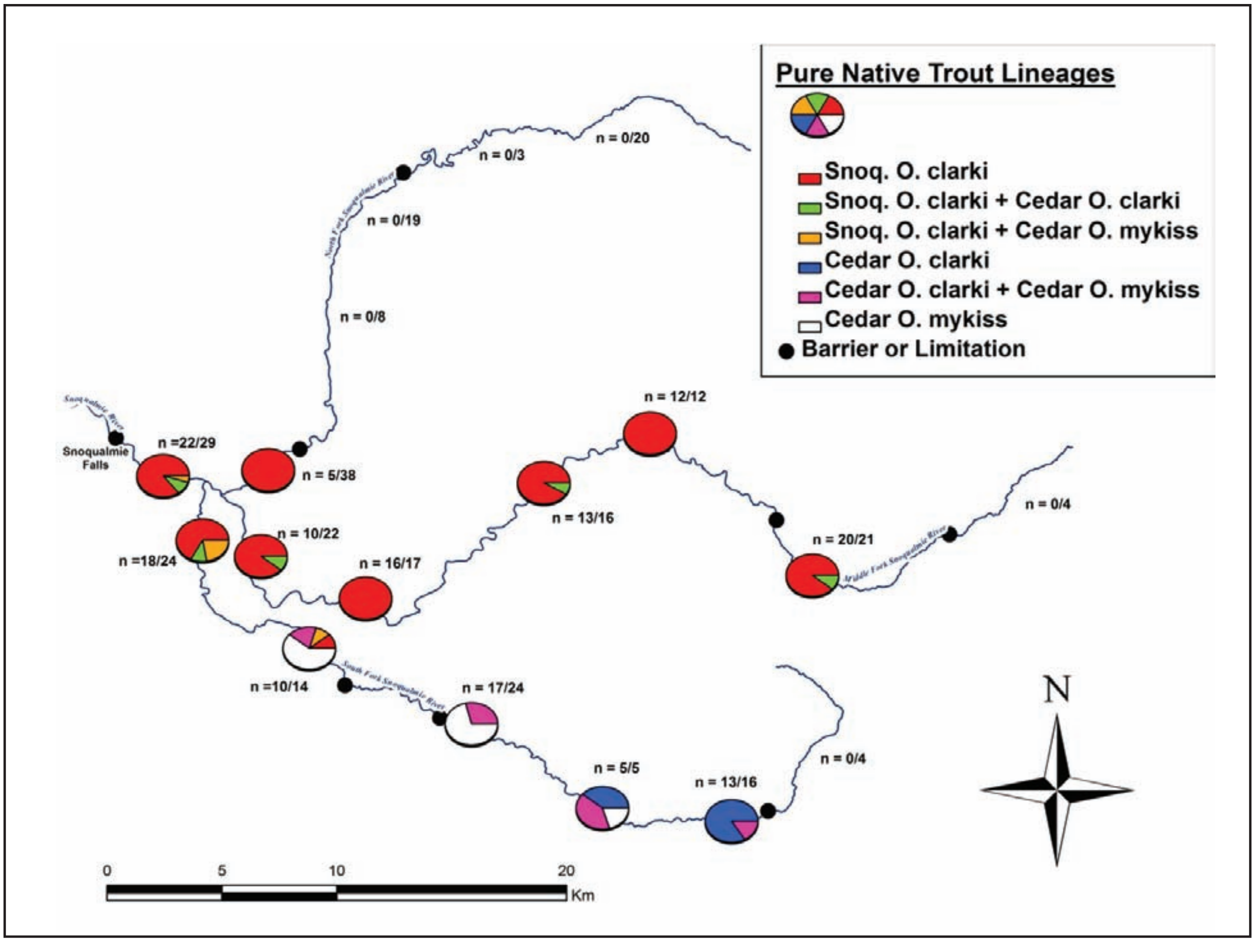

Figure 44. Distribution of pure native-origin lineage Pacific trout (*Oncorhynchus* spp.) in the upper Snoqualmie River watershed. Trout were sampled from river segments and genotyped at seven microsatellite loci and 96 single nucleotide polymorphism loci (Thompson et al. 2011). Pie charts represent sample locations. Captions next to pie charts indicate a ratio of the total number of pure native trout per total sample size for each sample location. Abbreviations: Snoq. = upper Snoqualmie River watershed, Cedar = Cedar River watershed, *O. clarki* = coastal cutthroat, *O. mykiss* = rainbow trout.

however, the presence of pure native Snoqualmie *O. clarki* increased in the Three Forks segment near the confluence with the Middle Fork (Figures 43–44).

In the Up MF, only four trout were sampled in the Hardscrabble reach, but all were mixed native and hatchery trout genetic ancestry. Downstream of Hardscrabble to the confluence with the North Fork, the majority of trout matched native Snoqualmie *O. clarki* genetics (76%, Figures 43–44).

Samples from the Denny Creek segment of the Up SF (n = 4) were either pure or hybridized hatchery westslope cutthroat. No samples obtained in the Up SF and Mid SF matched pure native Snoqualmie *O. clarki*. Conversely, most matched pure native Cedar *O. clarki* (29%), Cedar *O. mykiss* (29%), and hybridized Cedar *O. clarki*/*O. mykiss* (20%). The Asahel Curtis segment of the Up SF and Tinkham segment of the Mid SF contained the highest proportions of Cedar *O. clarki* (62%) and hybridized Cedar *O. clarki*/*O. mykiss* (19%). No coastal cutthroat trout of native lineage were sampled in the Weeks Falls and Grouse Ridge segments, but hybrid Cedar *O. clarki*/*O. mykiss* (21%) and Cedar *O. mykiss* (50%) represented the majority of genetic samples in those segments. A few mixed hatchery/native rainbow and coastal cutthroat trout were also sampled in these segments (25%). In the Low SF downstream of Twin Falls, pure hatchery *O. mykiss* were sampled (8%) as were native Cedar *O. mykiss* (16%) and hybrid Snoqualmie and Cedar *O. clarki*/*O. mykiss* (18%). Mixed native Snoqualmie *O. clarki*/Cedar *O. clarki* (5%) were sampled in the Low SF as were hatchery/native mixed coastal cutthroat

(5%) and hatchery/native mixed hybrids (13%). Between the Sallal Prairie segment and the North Bend–Three Forks segments, the proportion of pure Snoqualmie *O. clarki* increased (7% v. 50%). Pure Snoqualmie *O. clarki* dominated trout genetic composition in the Three Forks segments of each fork and the Up MN and Low MN river sections (Figures 43–44).

Age and growth

Length frequencies revealed growth of cohorts seasonally as peaks and troughs in abundance (Appendix 2, Figures 1–8), and growth was identified for these cohorts using scale-age-based length-at-age plots. Growth trajectories for coastal cutthroat and unidentified or hybrid Pacific trout (Onxx) were pooled because of uncertainty in differentiating between these species groups during field processing.

Growth for coastal cutthroat–Onxx was low in upper river sections in each fork. Growth trajectories and maximum age increased for coastal cutthroat–Onxx in middle sections and was highest in lower sections (including the Up MN and Low MN). Individual trout in the coastal cutthroat–Onxx sample reached a maximum of 5 years in the Up NF and Up MF, but only 4 years in the Up SF. Maximum length was around 220 mm FL for the 5-year-olds in the Up NF and Up MF and around 200 mm for the 4 year olds in the Up SF. The Mid NF and Mid MF sample

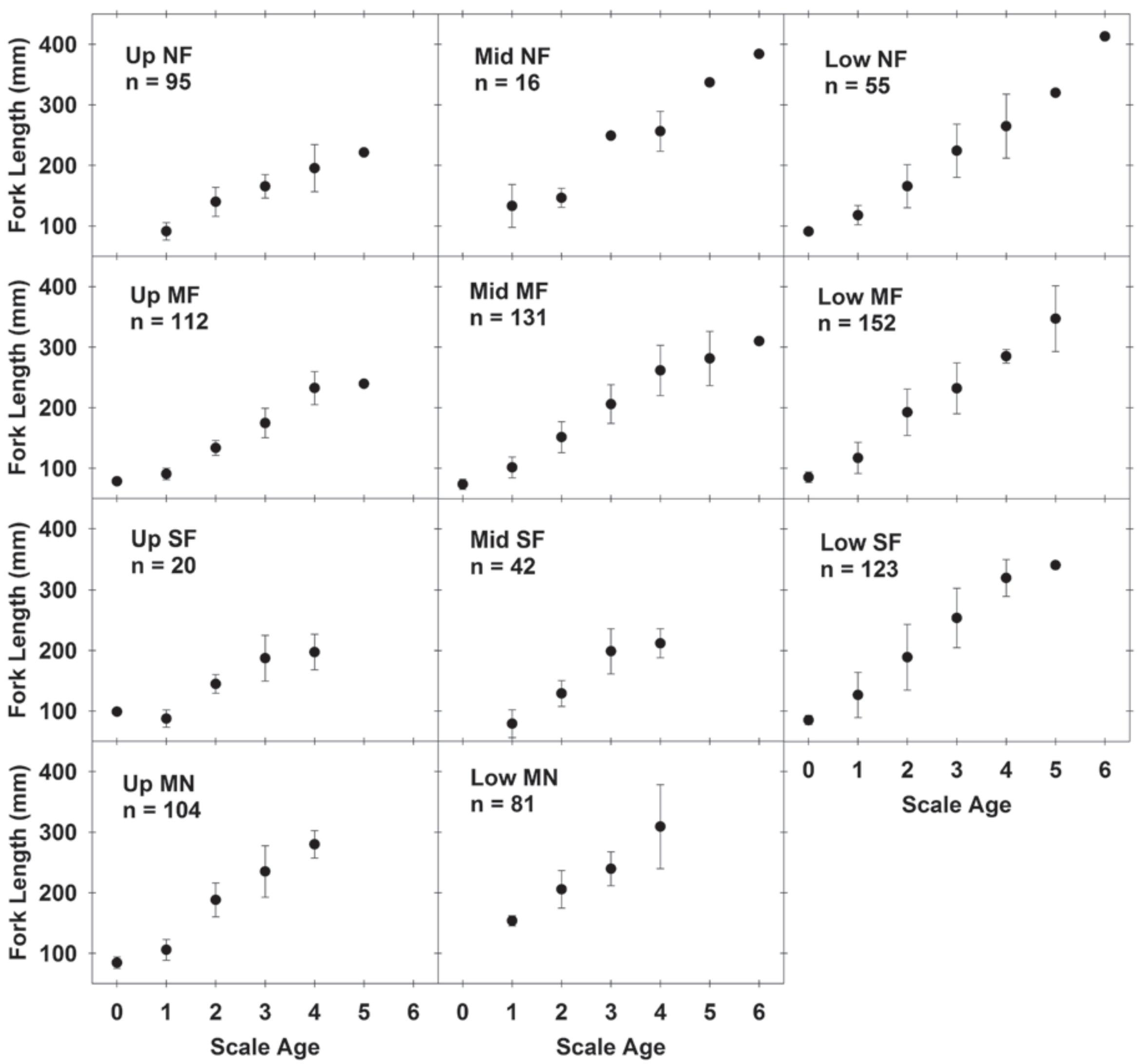

Figure 45. Scale-based mean (±SD) fork length-at-age for coastal cutthroat trout and hybridized or unidentified Pacific trout among river sections.

contained up to age 6 coastal cutthroat–Onxx. Growth of age 6 fish was greatest in the Mid NF at about 370 mm compared to about 300 mm in the Mid MF. Growth in the Mid SF was cropped to about 200 mm at age 4. The Low NF sample contained age 6 coastal cutthroat–Onxx, but the Low MF and Low SF samples only contained those up to age 5. Among all river sections, growth for age 5 coastal cutthroat–Onxx was greatest in the Low MF (≥350 mm), followed by the Mid NF (340 mm), Low SF (320 mm), and Low NF (310 mm). Growth was high in both sections of the Mainstem Snoqualmie; however, coastal cutthroat–Onxx did not surpass age 4 (Figure 45).

Rainbow trout were only captured in substantial numbers in the Low NF, Mid NF, Low SF, and Mid SF. Growth and maximum age were higher in the North Fork compared to the South Fork. Fish grew fastest to age 3 in the Low SF followed by the Low NF, Mid NF, and Mid SF; however, no rainbow trout over age 3 were captured in the Low SF. Conversely, rainbow trout reached the highest maximum age and size in the Low NF (age 6, 450 mm), followed by the Mid NF (age 6, 390 mm). Rainbow trout in the Mid SF lived to age 5, but growth was greatly reduced for fish of this age (<200 mm; Figure 46).

Westslope cutthroat trout were only captured in substantial numbers in the Up SF. Growth rates to age 3 were similar to coastal cutthroat–Onxx in this river section (190 mm); however, growth increased consistently between age 3 and 4 for westslopes, while growth varied for coastal cutthroat between these ages (Figure 47).

The Mid SF contained the only substantial numbers of brook trout. Growth for brook trout was relatively high compared to most other trout species in the USRW (age 3, 270 mm), but no fish greater than age 4 were captured (Figure 48).

Mean length-at-age values of Pacific trout reported by Pfeifer (1985) were compared to results from this study where spatially comparable data existed. Mean length for age 2 trout increased from 128 mm to 140 mm in the Up NF. The Mid MF and Low MF were pooled because different spatial strata were used to calculate mean length-at-age values between the two studies in these river sections. In the combined river sections, mean length-at-age increased from 163 mm and 169 mm to 173 mm for age 2 trout, and from 219 mm and 197 mm to 221 mm for age 3 trout. Length-at-age in the Mid SF decreased from 135 mm to 132 mm for age 2 trout and from 209 mm to 183 mm for age 3 trout, whereas in the Low SF it increased from 147 mm to 181 mm for age 2 trout and from 217 mm to 248 mm for age 3 trout (Table 14).

Mortality and population age structure

Coastal cutthroat–Onxx in the Low SF had the highest statistically significant mortality rate (70%), whereas the lowest rate was found for coastal cutthroat–Onxx in the Low

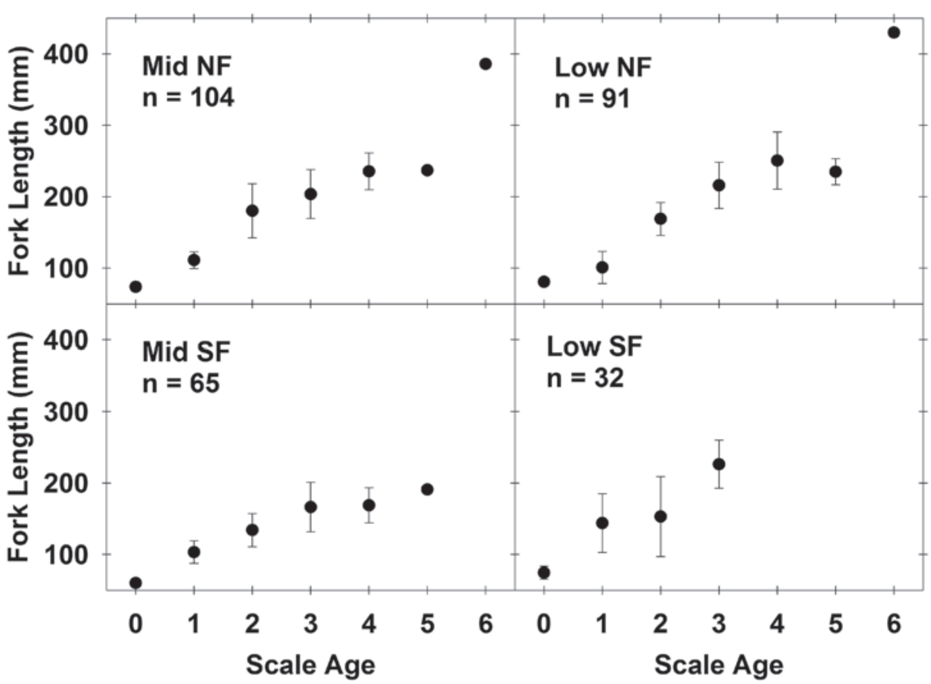

Figure 46. Scale-based mean (±SD) fork length-at-age for rainbow trout among river sections.

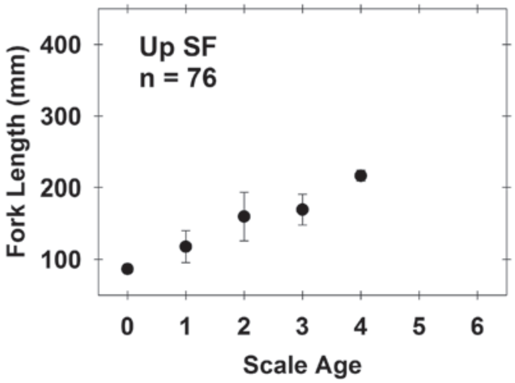

Figure 47. Scale-based mean (±SD) fork length-at-age for westslope cutthroat trout in the upper South Fork Snoqualmie.

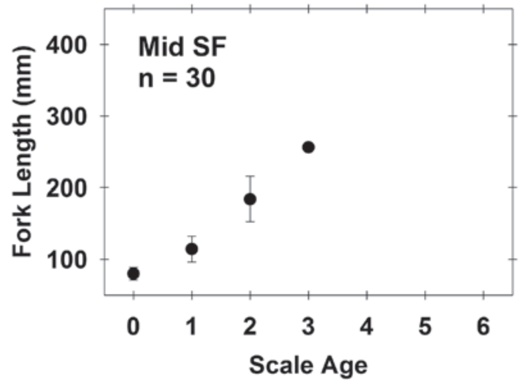

Figure 48. Scale-based mean (±SD) fork length-at-age for brook trout in the middle South Fork Snoqualmie

NF (54%). Mortality of rainbow trout in the Mid NF and Low NF were identical (66%), whereas rainbow mortality was relatively low in the Mid SF (56%; Table 15).

Overall production of trout was greatest for coastal cutthroat in the Mid MF (19,970 YOY), followed by coastal cutthroat–Onxx in the Low SF (11,873 YOY), rainbow trout in the Mid NF (9,557 YOY), and rainbow trout in the Low NF (4,376 YOY). The lowest production occurred for coastal cutthroat–Onxx in the Low NF (512 YOY), followed by rainbow trout in the Mid SF (2,969 YOY; Table 16).

Based on population age structure estimates, the highest linear density of trout was in the Up MF (2,414/km), followed by Low NF (1,732/km), Low MF (1,402/km), Mid MF (1,370/km), Up MN (1,101/km), Low SF (1,093/km), Up NF (821/km), Mid SF (646/km), Mid NF (602/km), Up SF (434/km), and Low MN (95/km).

Diet analysis

Diet items retained from lavaged trout (n = 1,226) included typical aquatic and terrestrial invertebrate species, trout eggs, prey fishes, crayfish, and amphibians (Figure 49). Seasonal mean proportions of diet items were calculated for each species and river section, and aquatic and terrestrial invertebrates were the most consistently consumed items most seasons (Appendix 1, Table 10). In most river sections, diet composition for coastal cutthroat–Onxx shifted from predominantly aquatic invertebrates in winter and spring to an increased amount of terrestrial invertebrates in summer and fall, whereas prey fish sources increased during spring and summer. Similarly, diet composition for rainbow trout shifted from aquatic to terrestrial inputs in summer, however in the Mid SF and Low SF this pattern was not observed. Instead, diets shifted to mostly aquatic invertebrates during summer. Similarly, westslope cutthroat trout and brook trout diets indicated an increase in terrestrial diet items in summer (Table 17).

Five percent of all trout diets contained fish (n = 62), 2% contained crayfish (n = 21), and only 1% contained amphibians (n = 7). Forty-eight percent of prey fish were identifiable (n = 30) and of those, 90% were sculpin (n = 27), 7% were salmonids (n = 2), and 3% were dace (n = 1). Coastal cutthroat–Onxx trout became piscivorous at approximately 120 mm, and the proportion of prey fish in cutthroat–Onxx diets increased with size (fork length) of predator. Rainbow trout did not exhibit the same preference for prey fish as they increased in size, but brook trout showed an even stronger preference at a smaller size than cutthroat–Onxx piscivores (approx. 120 mm; Figure 50).

Seasonal mean weight of adult (150–299 mm TL) trout diet contents was compared between middle river sections because growth for this life stage was dissimilar. For both the coastal cutthroat–Onxx and rainbow trout species categories, patterns in diet weight by item varied seasonally among and within middle river sections. In the Mid NF, the general trajectory of diet weight for both species categories followed a gradient from high during spring to low during winter. The Mid SF followed a similar pattern for rainbows, but overall diet weight was lower by one-third. The trajectory for cutthroat–Onxx in the Mid SF lacked a well-defined high point and peaked only slightly during summer, whereas it diminished dramatically during fall. Diet weight for coastal cutthroat–Onxx was greatest in summer in the Mid MF, and the other seasons followed a trajectory, at a lower magnitude, similar to that of the Mid NF. We lacked data on Mid SF brook trout diets during winter, but the other seasons followed a pattern similar to that of the Mid SF coastal cutthroat–Onxx category minus the drop in diet weight during fall (Figure 51).

During spring, mean diet weight for coastal cutthroat–

Table 14. Mean length-at-age comparisons for Pacific trout between years 1980, 1981, and 1984 (adapted from Pfeifer 1985), and years 2008, 2009, and 2010. Some historical data were not comparable with this study because of differences in spatial stratification used to calculate mean lengths. All trout were aged by estimating annuli from scales, and otoliths were used to confirm age estimates obtained during the current study.

River Section	Year Sampled	Age	*n*	Fork Length (mm)	Length Range (mm)	Dominant Species
Up NF	1980	2	24	128	89 - 164	Cutthroat
	2009–2010	2	39	140	105 - 193	Coastal Cutthroat
Up MF	1984	2	1	170	-	Cutthroat
		4	2	192	190 - 194	Cutthroat
	2009–2010	2	39	134	103 - 170	Coastal Cutthroat
		4	13	233	189 - 286	Coastal Cutthroat
Mid/Low MF	1981	2	32	163	108 - 210	Cutthroat
		3	24	219	171 - 279	Cutthroat
		4	1	318	-	Cutthroat
	1984	2	16	169	132 - 222	Cutthroat
		3	16	197	135 - 246	Cutthroat
		4	4	215	195 - 271	Cutthroat
		5	1	257	-	Cutthroat
		6	2	334	322 - 346	Cutthroat
	2009–2010	2	90	173	94 - 277	Coastal Cutthroat
		3	73	221	83 - 303	Coastal Cutthroat
		4	18	271	221 - 333	Coastal Cutthroat
		5	6	314	242 - 398	Coastal Cutthroat
		6	1	310	-	Coastal Cutthroat
Mid SF	1984	2	16	135	100 - 170	Rainbow
		3	20	209	170 - 253	Hybrid Cutt/bow
	2008–2010	2	30	132	86 - 173	Rainbow
		3	26	183	93 - 247	Rainbow
Low SF	1984	2	7	147	105 - 185	Hybrid Cutt/bow
		3	5	217	145 - 240	Cutthroat
	2008–2010	2	49	181	93 - 293	Coastal Cutthroat
		3	32	248	172 - 372	Coastal Cutthroat

Table 15. Linear catch-curve-based mortality rates for river sections. Annual survival is (*S*) and mortality is (*A*). Species categories include CCT = coastal cutthroat trout and unidentified Pacific trout, RBT = rainbow trout, WCT = westslope cutthroat trout, and EBT = eastern brook trout. The statistically significant regressions are shown in bold, but all were used to estimate population age structure.

River Section	Species	Age	Linear regression catch curve equation	Z	r^2	SE	ANOVA (P)	(1 - β)	$S = (e^{-Z})$	$A = S\text{-}1$
Up NF	CCT	2-5	6.758 - (0.840 * Age)	0.840	0.76	0.582	0.084	0.346	0.43	0.57
Mid NF	CCT	2-6	5.845 - (0.482 * Age)	0.482	0.45	0.740	0.132	0.297	0.62	0.38
	RBT	**2-6**	**9.165 - (1.092 * Age)**	**1.092**	**0.98**	**0.274**	**0.001**	**0.967**	**0.34**	**0.66**
Low NF	**CCT**	**1-6**	**6.239 - (0.768 * Age)**	**0.768**	**0.86**	**0.565**	**0.005**	**0.865**	**0.46**	**0.54**
	RBT	**2-6**	**8.384 - (1.072 * Age)**	**1.072**	**0.79**	**0.852**	**0.028**	**0.603**	**0.34**	**0.66**
Up MF	CCT	2-5	9.397 - (1.313 * Age)	1.313	0.74	0.950	0.091	0.331	0.27	0.73
Mid MF	**CCT**	**2-6**	**9.902 - (1.048 * Age)**	**1.048**	**0.98**	**0.248**	**<0.001**	**0.972**	**0.35**	**0.65**
Low MF	CCT	2-5	9.523 - (0.748 * Age)	0.748	0.81	0.450	0.066	0.394	0.47	0.53
Up SF	CCT	2-4	6.467 - (0.415 * Age)	0.415	0.24	0.462	0.424	<0.001	0.66	0.34
	WCT	2-4	6.512 - (0.477 * Age)	0.477	0.52	0.379	0.326	<0.001	0.62	0.38
Mid SF	CCT	2-4	8.128 - (0.858 * Age)	0.858	0.74	0.473	0.237	<0.001	0.42	0.58
	RBT	**1-5**	**7.996 - (0.831 * Age)**	**0.831**	**0.92**	**0.391**	**0.007**	**0.831**	**0.44**	**0.56**
	EBT	1-3	6.895 - (1.309 * Age)	1.309	0.68	0.805	0.261	<0.001	0.27	0.73
Low SF	**CCT**	**1-5**	**9.382 - (1.208 * Age)**	**1.208**	**0.85**	**0.781**	**0.016**	**0.702**	**0.30**	**0.70**
Up MN	CCT	2-4	7.143 - (1.125 * Age)	1.125	0.59	0.806	0.299	<0.001	0.32	0.68
Low MN	CCT	2-4	5.041 - (0.427 * Age)	0.427	0.52	0.340	0.327	<0.001	0.65	0.35

Table 16. Population age structure estimates for trout in the upper Snoqualmie River watershed. Abundance of trout by age was estimated by applying the linearized catch curve equation with age as the independent variable. The antilog was applied to $\log_e$ abundance estimates to provide untransformed age-and species-specific abundance estimates in each river section. Estimates are applicable only to the snorkel survey range in each specified river section. Estimates based on statistically significant mortality rates are highlighted in bold.

Species	Age	Up NF	Mid NF	Low NF	Up MF	Mid MF	Low MF	Up SF	Mid SF	Low SF	Up MN	Low MN
Coastal cutthroat/ unidentified Pacific trout	0	861	346	**512**	12,052	**19,970**	**13,671**	644	3,388	**11,873**	1,265	155
	1	372	213	**238**	3,242	**7,002**	**6,470**	425	1,437	**3,548**	411	101
	2	160	132	**110**	872	**2,455**	**3,063**	281	609	**1,060**	133	66
	3	69	81	**51**	235	**861**	**1,450**	185	258	**317**	43	43
	4	30	50	**24**	63	**302**	**686**	122	110	**95**	14	28
	5	13	31	**11**	17	**106**	**325**	81	46	**28**	5	18
	6	6	19	**5**	5	**37**	**154**	53	20	**8**	1	12
Rainbow trout	0	-	**9,557**	**4,376**	-	-	-	-	**2,969**	-	-	-
	1	-	**3,207**	**1,498**	-	-	-	-	**1,293**	-	-	-
	2	-	**1,076**	**513**	-	-	-	-	**563**	-	-	-
	3	-	**361**	**176**	-	-	-	-	**245**	-	-	-
	4	-	**121**	**60**	-	-	-	-	**107**	-	-	-
	5	-	**41**	**21**	-	-	-	-	**47**	-	-	-
	6	-	**14**	7	-	-	-	-	**20**	-	-	-
Westslope cutthroat trout	0	-	-	-	-	-	-	673	-	-	-	-
	1	-	-	-	-	-	-	418	-	-	-	-
	2	-	-	-	-	-	-	259	-	-	-	-
	3	-	-	-	-	-	-	161	-	-	-	-
	4	-	-	-	-	-	-	100	-	-	-	-
	5	-	-	-	-	-	-	62	-	-	-	-
	6	-	-	-	-	-	-	38	-	-	-	-
Eastern brook trout	0	-	-	-	-	-	-	-	987	-	-	-
	1	-	-	-	-	-	-	-	267	-	-	-
	2	-	-	-	-	-	-	-	72	-	-	-
	3	-	-	-	-	-	-	-	19	-	-	-
	4	-	-	-	-	-	-	-	5	-	-	-
	5	-	-	-	-	-	-	-	1	-	-	-
	6	-	-	-	-	-	-	-	0	-	-	-

Figure 49. Adult coastal cutthroat trout being lavaged in the Mid MF. Note the diet items, including caddis larvae (green rock worms), stonefly larvae, and a sculpin (bottom right).

Onxx in the Mid NF (n = 3) was nearly twice that for the same species group in both the Mid SF (n = 7) and Mid MF (n = 20). On average, five times the weight of fish, four times the weight of fish eggs, and one-third more aquatic invertebrates were consumed by Mid NF coastal cutthroat–Onxx. However, this same species/season group consumed one-third less the weight in terrestrial invertebrates compared to those in the Mid MF and Mid SF. Mean weight of terrestrial invertebrates increased dramatically during summer in the Mid MF, and on average composed well over half of the mean weight of all diet items consumed by middle river section trout for this time period. During summer in the Mid NF, mean weight of terrestrial invertebrates increased, but at a lower magnitude than in the Mid MF. Conversely, terrestrial invertebrates represented less of the mean weight for coastal cutthroat–Onxx in the Mid SF during summer, but prey fish in these diets outweighed those in all other middle river sections at least four-fold. Terrestrial invertebrates in the Mid SF composed less total weight of diet samples for all species and during all seasons compared to other middle river sections. During fall in the Mid NF and Mid MF, aquatic invertebrates constituted most of the weight of diets as terrestrial items diminished. During fall in the Mid SF, total diet weight contracted dramatically; however, only one diet was sampled from this species/season category. Diet weight and composition were similar among river sections during winter, but weights in the Mid SF were slightly higher than in the Mid NF and Mid MF (Figure 51).

Rainbow trout diet weight in the Mid NF and Mid SF followed the same trajectory as for coastal cutthroat–Onxx in the Mid NF, but at a lower magnitude. One noticeable difference in the pattern was that diet weights did not drop off as much during fall for rainbows in the Mid NF (n = 15) and Mid SF (n = 13) compared to coastal cutthroat–Onxx in the same river sections. Furthermore, prey fish represented a greater proportion of the weight of diets during that season for rainbows in both river sections (Figure 51).

On average, adult brook trout diets were composed of far greater amounts of prey fish than all other species in middle river sections. However, sample sizes were low and no brook trout diets were sampled during winter (Figure 51).

Conclusions

Relative abundance and distribution of trout

The major geologic barriers in each fork limited the upstream distribution of all fishes except trout and sculpin. These barriers included Fantastic Falls in the North Fork, Twin Falls in the South Fork, and Dingford Canyon in the Middle Fork. Trout were further segregated into sub-populations as a result of smaller geologic barriers along middle and upper river sections in each fork, but some interesting patterns of trout abundance, distribution, and species composition were evident and were not explained solely by the presence of geologic barriers (e.g., Neville et al. 2006). Trout abundance and size structure was highly variable and appeared to depend on a suite of local segment-scale dynamics that combined habitat type and size, proximity to cover (boulders, LWD, etc.), proximity and interconnectivity to off-channel habitat, and the water temperature regime.

When interpreting species distribution data, it is important to note that anglers and angler groups planted trout historically and continue to do so in alpine lakes. Prior to the founding of the Washington Game Department in 1933 (and at least up to 1979), loggers, miners, and sportsmen planted lakes and streams in the Puget Sound area with fish fry from various sources available to them at the time, and while fry can recruit to streams from lakes separating these two sources (lake versus stream plant sources) would be difficult (Bob Pfeifer, personal communication).

North Fork Snoqualmie River

The North Fork exhibited specific regions of high and low trout abundance and variability in species composition along its entire length. In southwestern British Columbia, Hartman and Gill 1968 found streams that featured a steep section (e.g., Up NF) and then leveled off to

Table 17. Seasonal mean proportion of diet items for trout, sculpin, and mountain whitefish among river sections.

Species	River Section	Season	*n*	Aquatic Invert	Terrestrial Invert	Eggs	Fish
Coastal cutthroat - Onxx	Up NF	Spring	23	0.90	0.10	0.00	0.00
		Summer	27	0.70	0.21	0.00	0.09
		Fall	16	0.76	0.24	0.00	0.00
	Mid NF	Spring	11	0.70	0.19	0.03	0.07
		Summer	5	0.53	0.45	0.00	0.01
		Fall	2	0.81	0.19	0.00	0.00
		Winter	1	0.83	0.17	0.00	0.00
	Low NF	Spring	9	0.70	0.26	0.00	0.04
		Summer	9	0.79	0.21	0.00	0.00
		Fall	17	0.62	0.38	0.00	0.00
		Winter	8	0.80	0.20	0.00	0.00
	Up MF	Summer	35	0.73	0.23	0.00	0.04
		Fall	27	0.66	0.34	0.00	0.00
	Mid MF	Spring	35	0.76	0.22	0.00	0.02
		Summer	36	0.58	0.42	0.00	0.00
		Fall	32	0.72	0.28	0.00	0.00
		Winter	19	0.84	0.16	0.00	0.00
	Low MF	Spring	33	0.82	0.16	0.00	0.02
		Summer	42	0.72	0.24	0.00	0.04
		Fall	31	0.85	0.14	0.00	0.01
		Winter	22	0.93	0.07	0.00	0.00
	Up SF	Spring	22	0.74	0.26	0.00	0.00
		Summer	3	0.46	0.54	0.00	0.00
		Fall	2	1.00	0.00	0.00	0.00
		Winter	5	1.00	0.00	0.00	0.00
	Mid SF	Spring	18	0.75	0.22	0.00	0.02
		Summer	20	0.75	0.15	0.02	0.08
		Fall	6	0.85	0.15	0.00	0.00
		Winter	12	0.95	0.05	0.00	0.00
	Low SF	Spring	34	0.64	0.31	0.00	0.04
		Summer	39	0.75	0.17	0.00	0.08
		Fall	55	0.90	0.08	0.00	0.02
		Winter	32	0.90	0.09	0.00	0.01
	Up MN	Spring	27	0.77	0.22	0.00	0.01
		Summer	27	0.76	0.22	0.00	0.02
		Fall	26	0.91	0.06	0.00	0.04
		Winter	5	0.77	0.22	0.01	0.00
	Low MN	Spring	21	0.76	0.18	0.00	0.06
		Summer	23	0.63	0.33	0.00	0.03
		Fall	19	0.61	0.38	0.00	0.01
		Winter	2	0.58	0.00	0.00	0.42

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Table 17. Continued

Species	River Section	Season	*n*	Aquatic Invert	Terrestrial Invert	Eggs	Fish
Rainbow trout	Mid NF	Spring	21	0.78	0.21	0.00	0.00
		Summer	31	0.67	0.33	0.00	0.00
		Fall	30	0.78	0.18	0.00	0.04
		Winter	14	0.87	0.13	0.00	0.00
	Low NF	Spring	26	0.76	0.22	0.01	0.01
		Summer	30	0.76	0.24	0.00	0.00
		Fall	11	0.82	0.17	0.00	0.02
		Winter	16	0.85	0.15	0.00	0.00
	Up SF	Summer	2	0.73	0.27	0.00	0.00
		Fall	1	1.00	0.00	0.00	0.00
	Mid SF	Spring	8	0.65	0.35	0.00	0.00
		Summer	15	0.89	0.10	0.00	0.01
		Fall	24	0.52	0.45	0.00	0.03
		Winter	30	0.96	0.04	0.00	0.00
	Low SF	Spring	3	0.64	0.35	0.00	0.01
		Summer	1	0.95	0.05	0.00	0.00
		Fall	13	0.91	0.09	0.00	0.00
		Winter	9	0.94	0.06	0.00	0.00
	Up MN	Spring	1	0.66	0.34	0.00	0.00
		Summer	2	0.80	0.20	0.00	0.00
Westslope cutthroat trout	Up SF	Spring	5	0.72	0.22	0.00	0.06
		Summer	23	0.69	0.31	0.00	0.00
		Fall	18	0.83	0.17	0.00	0.00
		Winter	13	0.95	0.05	0.00	0.00
Eastern brook trout	Mid NF	Spring	1	0.40	0.60	0.00	0.00
		Summer	1	0.29	0.67	0.00	0.04
		Winter	3	0.81	0.00	0.00	0.19
	Mid SF	Spring	6	0.75	0.16	0.00	0.09
		Summer	10	0.55	0.37	0.00	0.08
		Fall	11	0.60	0.15	0.00	0.25
		Winter	3	0.67	0.33	0.00	0.00
Sculpin species	Up NF	Spring	1	0.91	0.09	0.00	0.00
		Summer	2	0.85	0.15	0.00	0.00
		Fall	2	1.00	0.00	0.00	0.00
	Mid NF	Spring	1	1.00	0.00	0.00	0.00
		Summer	4	1.00	0.00	0.00	0.00
		Fall	3	0.73	0.00	0.00	0.27
	Low NF	Spring	1	1.00	0.00	0.00	0.00
		Summer	8	0.89	0.00	0.00	0.11
		Fall	6	1.00	0.00	0.00	0.00
		Winter	1	1.00	0.00	0.00	0.00

—Table 17 continued on next page

Table 17. Continued

Species	River Section	Season	*n*	Aquatic Invert	Terrestrial Invert	Eggs	Fish
	Up MF	Summer	2	0.72	0.00	0.00	0.28
	Mid MF	Spring	4	1.00	0.00	0.00	0.00
		Summer	2	0.96	0.04	0.00	0.00
		Fall	4	1.00	0.00	0.00	0.00
		Winter	2	0.35	0.03	0.00	0.63
	Low MF	Spring	3	1.00	0.00	0.00	0.00
		Summer	2	0.76	0.00	0.00	0.24
		Fall	4	1.00	0.00	0.00	0.00
		Winter	2	0.95	0.05	0.00	0.00
	Up SF	Spring	8	0.91	0.09	0.00	0.00
		Fall	5	1.00	0.00	0.00	0.00
		Winter	7	1.00	0.00	0.00	0.00
	Mid SF	Spring	8	1.00	0.00	0.00	0.00
		Summer	2	0.81	0.06	0.00	0.13
		Fall	3	1.00	0.00	0.00	0.00
		Winter	6	1.00	0.00	0.00	0.00
	Low SF	Spring	4	0.87	0.00	0.00	0.13
		Summer	2	0.60	0.16	0.24	0.00
		Fall	8	1.00	0.00	0.00	0.00
		Winter	8	1.00	0.00	0.00	0.00
	Up MN	Summer	2	0.92	0.00	0.00	0.08
		Fall	2	1.00	0.00	0.00	0.00
		Winter	1	1.00	0.00	0.00	0.00
Mountain whitefish	Low NF	Spring	2	0.80	0.20	0.00	0.00
	Mid MF	Spring	2	0.85	0.15	0.00	0.00
		Summer	1	1.00	0.00	0.00	0.00
		Winter	5	0.92	0.08	0.00	0.00
	Low MF	Summer	1	0.97	0.03	0.00	0.00
		Fall	2	0.69	0.31	0.00	0.00
		Winter	3	1.00	0.00	0.00	0.00
	Low SF	Spring	22	0.92	0.08	0.00	0.00
		Summer	1	0.75	0.25	0.00	0.00
		Winter	1	1.00	0.00	0.00	0.00
	Up MN	Summer	1	0.92	0.08	0.00	0.00

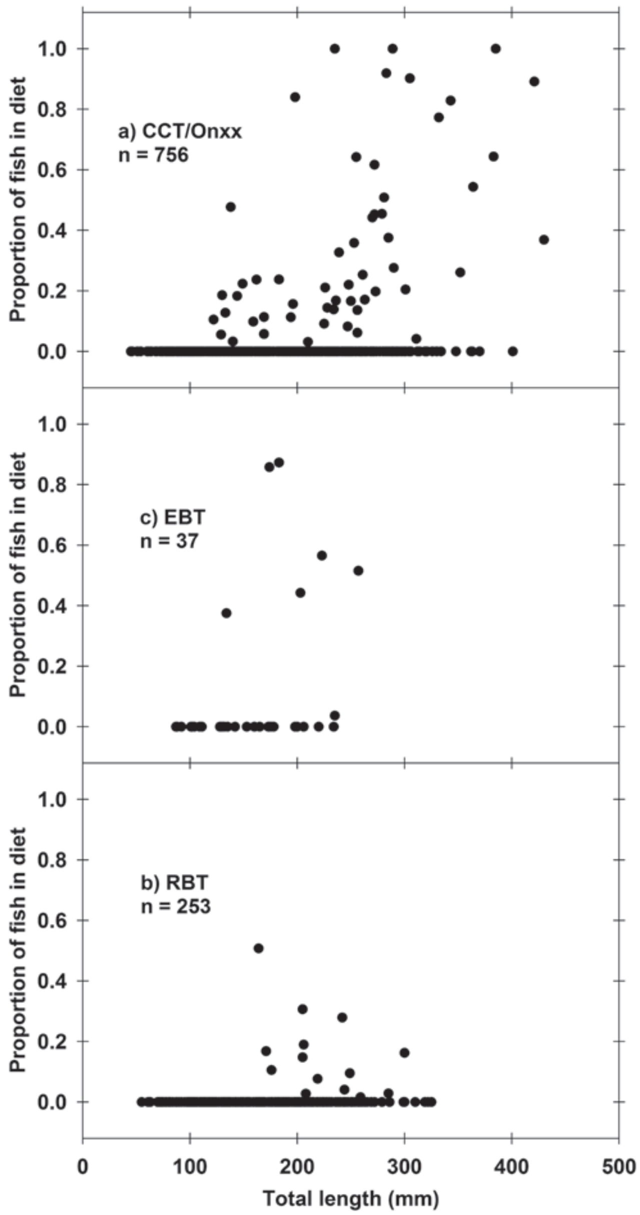


Figure 50. The proportion of diet by weight (g) comprised of prey-fish as a function of total length (mm) for (a) coastal cutthroat–Onxx, (b) brook trout, and (c) rainbow trout.

a slough-like character (e.g., Lakebed segment of the Mid NF) contained higher proportions of cutthroat than *O. mykiss*. Where they co-occurred, *O. mykiss* were found in lower reaches of steeper main-stem channels, whereas cutthroat were found in main-stem channel headwaters and small tributaries. The North Fork exhibited a similar pattern of distribution between these two species, as coastal cutthroat (hatchery *O. clarki* 85% of genetic samples) were more abundant at the headwaters (Up NF Illinois Creek segment). Sampling in the low gradient slough-like Lakebed segment was limited during this study, but Sweeny et al. (1981) detected a transition from mostly cutthroat in the upper Lakebed portions (85%) to mostly rainbows in the middle (67% and 65%) and lower (91%) Lakebed portions. The upper portion of the Lakebed segment connects with Lennox Creek and the middle portions connect with Sunday Creek, both of which are major tributaries to this sparsely populated river segment. Neither tributary was surveyed during this study, but previous surveys of 1 mile in each found a low abundance of cutthroat only (Sweeny

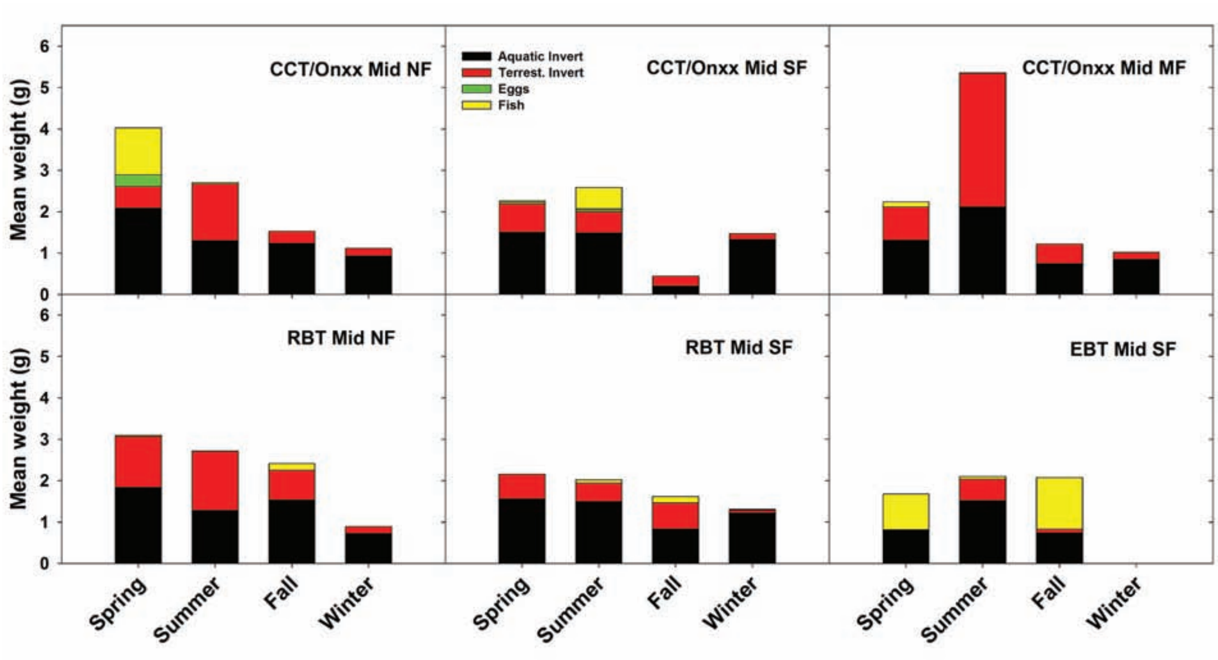


Figure 51. Seasonal mean weight of each diet content group per individual adult (150–299 mm TL) coastal cutthroat, unidentified or hybrid (CCT/Onxx), rainbow (RBT), and eastern brook trout (EBT) in middle river sections of each fork. Complete seasonal gravimetric proportions and sample sizes are given for each species in Table 17 and Appendix Table 14.

et al. 1981). One major tributary that flows into the lower portion of the Lakebed segment was surveyed during this study (GF Creek*) and contained mostly Onxx trout (87% of all trout). Although total abundance of trout may be low in the main-stem channel of the Lakebed segment, interconnectivity with tributaries provides access to an increasingly complex system of habitats that can accommodate various life stages.

Rainbow abundance peaked in the relatively steep and constrained Big Creek Falls segment (hatchery *O. mykiss* 75% of genetic samples). This segment is composed of steep riffle-cascade and pool main-stem channel habitat and there is little tributary or off-channel habitat available. The Calligan segment is naturally channelized and contains only limited off-channel habitat, and it contained surprisingly low numbers of trout (78% of which were rainbow from field identification). Additional sampling of the Lakebed and Calligan segments is needed to determine if the two species are segregated into one or the other of these two distinct habitats (complex v. simple). This information could help identify spatial patterns in habitat use between sympatric cutthroat and rainbow trout.

Very low numbers of trout were counted during snorkel surveys along a majority of the Calligan segment of the Mid NF. Based on fish capture results, the trout population in this segment contained mostly hatchery *O. mykiss*. Interestingly, although overall abundance was low, the trout population in the Calligan segment was well represented by all life stages, from YOY to large adults. One probable reason for the low numbers of trout is that the segment is naturally under-seeded due to a lack of access to adequate off-channel spawning and rearing habitat. More abundant yet smaller mature trout are less equipped to utilize main-stem channel spawning habitats, which contain larger substrates and higher velocity flows that can scour shallow redds made of smaller substrates. While larger females are more fecund and produce more offspring, the lack of off-channel rearing habitat for juveniles may be the ultimate limiting factor for trout abundance in the Calligan segment. Furthermore, tributaries in this segment are either not fully used or are degraded or access-limited. For example, the lower 400 m of the largest tributary (Deep Creek) contained mostly brook trout, which might occupy a spawning and rearing niche that could otherwise be occupied by native Pacific trout species. However, native Pacific trout and brook trout were found to inhabit Deep Creek concurrently and no Pacific trout redds were confirmed during spawning site surveys. Brook trout were more abundant in Deep Creek than any other tributary to the North Fork (n = 14, 45% of all trout detected in Deep Creek), but cutthroat, rainbow, and unidentified Pacific trout were also detected in substantial proportions. There are two other major tributaries to the

Calligan segment (Calligan and Hancock creeks), both of which are high gradient outlet streams draining large subalpine lakes (Calligan and Hancock lakes) that have been stocked with various strains of trout including rainbow, cutthroat, and brook. Both tributaries were surveyed during this study; however, due to their large size and complex and steep habitats, accurate fish counts were not attained for relative abundance comparisons with other tributaries. Regardless of the inability to compare trout abundance with other tributaries, surprisingly low numbers of trout and sculpin were encountered in both Hancock and Calligan creeks. There is a small wetland system within the lower 400 m of Calligan Creek that should be investigated to determine the amount of used or usable habitat for main-stem channel trout. A fourth smaller tributary to the Calligan segment is unnamed (Fertilized Creek*) and typed as fish bearing. This is a small creek with a short, steep cascade-delta region, but it levels off for nearly 500 m before it converges with the toe slope and gains in steepness. Past clear-cutting led to the complete removal of the riparian buffer on both sides of the creek through the low gradient 500 m reach, and only the lower half of this reach is accessible to main-stem channel fishes because of a culvert that is perched well above a small pool. Despite having no buffer and a perched culvert, we were surprised to not detect fish in this reach during our survey because the habitat appeared to be otherwise hospitable. One probable reason for the lack of fish during the survey is that while the channel was wetted during the spring survey it lost surface water during summer. Because off-channel habitat is limited in the Calligan segment, we recommend further investigations into this fish-type tributary to determine the feasibility of replacement of the culvert and re-planting of early-successional riparian vegetation to provide shade to the channel area once again during summer months.

The Black Canyon segment of the Low NF was densely populated, and genetic results indicated it contained mostly rainbows (hatchery *O. mykiss*, 67% of genetic samples), followed by unidentified Pacific trout (27%) and coastal cutthroat (Snoqualmie *O. clarki* 6% of genetic samples). Off-channel habitat was highly limited in the constrained Black Canyon segment, but increased downstream of the Black Canyon near Tate Creek and near the confluence with the Middle Fork as did the proportion of cutthroat (Snoqualmie *O. clarki*, 10% constrained v. 37% near confluence). Tate Creek is a relatively large tributary and contained coastal cutthroat. Sweeny et al. (1981) found similar longitudinal patterns in trout species composition and relative abundance in the North Fork, thus it appears that these trout populations are stable, at least on a decade-scale timeline. Similar to the Lakebed segment, the Three Forks segment contained access to off-channel and tributary habitat and higher proportions of coastal cutthroat, whereas similar to the Big Creek Falls and Calligan segments, the Black Canyon segment was constrained and off-channel habitat-limited but contained higher proportions of rainbow trout. Fish capture and sampling concentrated in the Lakebed and Calligan segments could enable a more definitive assessment of habitat use between sympatric rainbow and coastal cutthroat trout in the USRW, but it appears that rainbows might not require the complexity of habitats that coastal cutthroat require.

The majority of trout in the Up NF and Mid NF were of hatchery origin, which might suggest that native trout production is inherently low in these sections. We found weak genetic signals of native *O. clarki* and *O.mykiss* in individuals sampled, but native genetic signals were overwhelmed by hatchery genetic signals. Habitat in the Calligan and Black Canyon river segments seem to be the least diverse as off-channel habitat is more limited compared to other segments in the USRW. The combination of low production and a lack of habitat diversity could have caused native populations to be more vulnerable to colonization by introduced hatchery lineages. Hatchery fish introduced in multiple sequential plantings may have been relatively unchallenged if there were few native fish and little habitat complexity and thus no specialized niche for a native population. In contrast, the Low NF contained a greater density of complex habitat and higher trout production than other North Fork river sections and also contained the only pure native trout encountered in the North Fork during this study.

Middle Fork Snoqualmie River

The Middle Fork contained the most robust trout populations and the greatest abundance of large adult trout in the USRW. Most large trout counted in the Low MF were observed in riffle pocket water flowing along large cobbles and boulders in the Sallal segment. Very little LWD was counted in this segment, as it is relatively high gradient with large cobble and boulder substrates that create quality pocket water habitat. This well aerated habitat is suited for the production of large trout because it provides a balance of small but deep pool cover interspersed with riffle currents that oxygenate water and transport food items throughout the seasons. Trout in this segment may also experience higher growth rates because the water is turbid throughout much of the year, providing additional cover from predators (e.g., osprey) while feeding. Conversely, the lack of trout observed in the Three Forks segment was probably due to very high water temperatures during the survey. The increased channel width-to-depth ratio and low amount of cover (LWD) in this segment may also contribute to lower numbers of trout as they may be more vulnerable to predation. During summer we observed osprey successfully capture trout in this broad, shallow segment. Thus, fishery enhancement projects in the Three Forks segment might include placement of LWD to provide much needed cover for trout and would also increase habitat complexity.

Native coastal cutthroat dominated the trout species composition and distribution in the Middle Fork (Snoqualmie *O. clarki* 74% of genetic samples). Some unidentified Pacific trout were sampled in the Up MF and Low MF, but overall, native coastal cutthroat trout were the most abundant game fish in all sections of the Middle Fork. In contrast to the North Fork, the Middle Fork is productive and contains a highly diverse system of habitats. These two factors probably helped native trout outcompete their introduced hatchery counterparts as high numbers of locally-adapted native fish already occupied the wide array of habitats when less-well adapted hatchery-strains were being stocked into the Middle Fork (Appendix 3, Thompson et al. 2011).

The Middle Fork contained the largest, most diverse and intact suite of main-stem and off-channel habitats in the USRW. The presence of diverse habitats might be attributed to a number of factors, for example a large portion of the Middle Fork flows through U.S. Forest Service and WDNR lands where natural resource extraction, urban development, and affiliated habitat degradation have been greatly reduced or eliminated since the 1950s. Contemporary land uses are centered on recreation upstream of the Edgewick Road area (Mt. Teneriffe segment and upstream). Downstream of this area, the Middle Fork is more limited in off-channel habitat, is more highly developed, and the banks are armored and diked extensively in places. At least two tributaries (Roaring and Little Si* creeks) appear to be critical to trout production in the Low MF based on adequate interconnectivity with main-stem channels, high densities of trout, and the size structure, which included a high number of YOY Pacific trout.

Very low numbers of trout were encountered in the main-stem channel of the Three Forks segment of the Low MF downstream of Little Si Creek*. Extreme summer and winter water temperatures combined with a lack of riffle habitat (24% of segment by length v. 47% and 62% in the more highly populated segments of the Low MF) probably render most of this segment inhospitable to substantial numbers of trout during at least those two seasons. This further emphasizes the need for additional investigations of water temperature and the implementation of enhancement projects that add cover and refuge that trout can use during extreme conditions.

South Fork Snoqualmie River

The South Fork contained the most diverse and complex composition of trout in the USRW. Trout relative abundance in the South Fork was related to distance upstream, with low numbers near the headwaters and high numbers near the mouth at the confluence with the Mainstem Snoqualmie. We identified a number of factors, both physical and biological, that probably contribute to these patterns in abundance and composition.

The trout population in the upper portion of the Up SF (Commonwealth and Denny Creek segments) is composed mainly of non-native westslope cutthroat, but westslopes are essentially limited to these two river segments. Given that there are records for the stocking of this variety of hatchery cutthroat trout in the South Fork, it is likely that these westslopes are descendants of hatchery fish stocked into the South Fork or possibly from those that recruited from stocked alpine lakes. Furthermore, since this variety has not been stocked lately, hatchery fish may have found an unoccupied or only partially-occupied niche and were unchallenged or able to exploit the limited resources more effectively than the sparser native trout population, especially if they were introduced by stocking multiple times (see Appendix 3, Thompson et al. 2011).

Downstream of the steep bedrock-cascade portion of the Up SF, the channel levels off at the Asahel Curtis segment and the upper portion of the Tinkham segment; the areas where a high proportion of sampled fish were identified as native coastal cutthroat (Cedar *O. clarki*). The external characteristics of cutthroat sampled in both main-stem channel and tributary habitats in these areas were distinct from cutthroat found in all other river segments. They lacked the typical yellow body color and did not have the pattern of fine spots that cover the entire body. Instead their spots were larger in diameter and more clustered on the posterior end of the fish, much like the spotting on a westslope cutthroat (see Figure 24a). Native hybrids (Cedar *O. clarki*/Cedar *O. mykiss*) were also found in the Asahel Curtis segment. These trout are probably derived from a pre-Cordilleran population that occupied the Up SF and Mid SF when the Cedar River was the actual south fork of the Snoqualmie River (Appendix 3). The main-stem channel of the Up SF in the Asahel Curtis segment, and the nearby Tinkham segment of the Mid SF both contain substantial amounts of LWD, gravel, and off-channel habitat suitable for reproduction and rearing. Relative to other tributaries in the Mid SF and Up SF, tributaries in these two river segments contained substantially higher numbers of trout. Thus, the habitat is naturally more complex and abundant off-channel habitat has enabled smaller trout to reproduce and rear over a timeline that probably dates as far back as the pre-Cordilleran.

Pacific trout species were found in very low numbers in a majority of the steeper tributary habitats available to them in the lower portion of the Tinkham segment, and in the Weeks Falls and Grouse Ridge segments as well. The few tributaries that did contain substantial numbers of Pacific trout in these segments were unconstrained or low gradient. However, brook trout far outnumbered Pacific trout in these unconstrained tributaries to the Mid SF, thriving in a habitat that would probably otherwise be heavily used by native Pacific trout species. Similarly, main-stem channels in these locations contained the largest population of brook trout in the USRW (13% of main-stem channel trout). Increased competition with rearing brook trout in limited off-channel habitats and adults in main-stem channels may partially explain why Pacific trout numbers are relatively low in lower Tinkham and Weeks Falls segments. Further studies into the interactions between these two species in the Mid SF could help fishery managers identify why non-native species are able to thrive and outcompete native species.

The Grouse Ridge and Weeks Falls segments of the Mid SF were commonly populated by native Cedar strain rainbow (50%) and hybrids (21%). Interestingly, in the South Fork, Snoqualmie-type native cutthroat trout were found only in the Low SF below Twin Falls, whereas above Twin Falls only Cedar-type native cutthroat and rainbow trout were found. Conversely, upstream of the smaller geologic barriers in the North (Fantastic Falls) and Middle (Dingford Canyon) forks, both Cedar coastal cutthroat and rainbows were found. Thompson et al. (2011) suggested that the high proportion of Cedar strain trout in the South Fork upstream of Twin Falls is an outcome of the most recent glacial activity in the USRW (c. 14,000 ybp, see Appendix 3, Figure 8). In short, it seems the timeline of glacial activity and exposure of Twin Falls as a barrier to upstream migration were the main influences on the current distribution of native trout varieties in the South Fork, which was also heavily stocked with both rainbow and cutthroat (Appendix 3, Thompson et al. 2011).

Type and condition of habitat appear to influence trout abundance and distribution in the Low SF. For example, higher numbers of trout were counted in the main-stem channel below Twin Falls where deep pools provide cover and cascades provide pocket pools and strong currents convey food items. Boxley Creek joins the Low SF just below Twin Falls, and based on tributary survey results appears to be a major producer of Pacific trout species. Trout numbers decreased in the North Bend segment where the channel is extensively constrained by bank armoring and diking. It appears that some of the off-channel habitat in this segment has been lost to main-stem diking and development. However, the greatest amount of reproduction found during this study was in Clough Creek, a tributary to the South Fork's North Bend segment and most observed main-stem spawning occurred in this area. Regardless, loss of alternative off-channel spawning and rearing habitats in the North Bend segment might lead to the unusually high density of spawning that occurs in Clough Creek, which contains an abundance of appropriately sized gravels and adequate cover for spawners.

The greatest abundance of trout in the South Fork occurred in the lower North Bend and Three Forks segments. The lower portion of the North Bend segment marks the beginning of a relatively intact portion of the Low SF and continues downstream to the confluence with the Mainstem Snoqualmie. A large portion of the river in this area is protected from development, and the banks have not been armored. This has enabled a high amount of LWD recruitment and accumulation. As the banks continuously erode, large deciduous and conifer trees fall into the stream and provide a great number of deep scour pools with a high degree of refuge and cover. One of the most striking discoveries during this study occurred in a large LWD jam during October 2008 as at least 300 coastal cutthroat trout of various size were schooled together in a small, protected pool that was created by a large conifer and located on the margin of a deep glide. One tributary in this area (Gardiner Creek) contained a substantial number of Pacific trout, but we noted that other off-channel habitat was abundant and readily available to trout in the area as well.

Inadvertent fish introductions might influence the genetic structure of trout in the Low SF. For example, a private hatchery operates downstream of Twin Falls on Boxley Creek and large-bodied hatchery rainbow trout that had escaped from holding ponds in the hatchery were captured in Boxley Creek. Hatchery rainbow trout, identified by genetic analysis, were found in this vicinity of the main-stem channel of the South Fork and may have originated from this facility if trout commonly escape. It is unknown how many trout escape from this facility or other water bodies that contain hatchery fish (e.g., private ponds). More intensive genetic profiling centered on these water bodies might be warranted to determine the degree of current influx and introgression of hatchery trout into the fishery.

Age, growth, and mortality

In theory, the spatial pattern for growth of trout in streams of the Pacific coastal ecoregion would fit a gradient of relative high growth in the lower portions (high-order stream), and low growth in the higher, montane portions (low-order streams). Growth response is dependent on factors including water temperature regime, seasonal food availability, and availability of habitats that accommodate both feeding and refuge (Beauchamp 2008). Questions regarding growth can best be answered through more thorough growth analyses and modeling. Constraints on time prohibited these analyses; however, we were able to synthesize a large set of data that included habitat availability, water temperature and flow, age, growth, mortality, and diet composition. At a minimum, analysis of these data provided a starting point for further analysis that can more concisely define the factors that limit growth of trout in the USRW.

Among similar environments (i.e., river sections or similar elevation), growth of trout varied most strikingly between the Mid SF and the Mid NF. Generally, coastal cutthroat–Onxx in the Mid SF lived to age 4 (annual mortality: 58%) whereas they lived to age 6 in the Mid NF (annual mortality: 38%). Fork-length-at-age was higher for both age 3 and 4 coastal cutthroat–Onxx in the Mid NF compared to those in the Mid SF (approx. 250 mm and 260 mm v. 200 mm and 220 mm). Rainbows in the Mid SF lived to age 5, but fork length at this age was about 40 mm less compared to the Mid NF, and the overall growth trajectory was dramatically lower compared to the other middle river sections.

No trout >271 mm were captured in the Mid SF, and the lack of large trout samples corroborated low detections of large trout during snorkel surveys. Some 300–379 mm trout were observed during snorkel surveys (n = 23), but numbers of trout in this size group were much lower compared to the Mid NF (n = 87) and the Mid MF (n = 159), and only 2 trout >379 mm were observed compared to 23 in the Mid NF and 28 in the Mid MF. In 2009, water temperatures in the Mid SF were between 9°–14° C from mid-June to October 1, whereas in the Mid NF, this temperature range occurred between June 1 and mid-October. Thus, the optimal growth temperature range was expanded in the Mid NF compared to the Mid SF. Furthermore, the period where temperatures breached the upper optimal-growth threshold of 14° C was prolonged in the Mid SF (July 1 to Sept. 1) compared to the Mid NF (July 1 to August 1). Thus, given similar food and foraging-habitat resources, more extreme temperatures probably limit growth of trout in the Mid SF compared to the Mid NF. Also, colder springtime water temperatures in the Mid SF might cue relatively later spawning or prolong incubation and emergence well into the late summer, leading to a comparatively smaller average size-at-age throughout the life of fish in this river section (see Figures 45 and 46).

Growth comparisons between decades suggested a general increase in size-at-age for trout in most river sections except the Mid SF. Another exception was for age-6 trout in the Middle Fork, where size decreased. However, these comparisons should be interpreted cautiously as variability in aging techniques can cause bias when assessing size-at-age using calcified structures (Isely and Grabowski 2007).

Diet analysis

Diet content analysis enabled diet item proportional gravimetric comparisons between river sections. Aquatic insects were the most consistently consumed food source for trout in the USRW. An increase in terrestrial invertebrates occurred in spring and summer in the South Fork and Up MN and in summer and fall in the North Fork, Middle Fork, and Low MN. Among middle river sections, the relatively higher amount of terrestrial inputs was mainly due to the large amount of hymenoptera (flying black ant) found in diets in the Mid NF (n = 51, total of 31.5 g) and Mid MF (n = 36, total of 45.3 g). In contrast, low proportions of hymenoptera were found in diets in the Mid SF (n = 46, total of 3.82 g). Two possibilities for the overall lower amount of terrestrial diet items found in Mid SF trout diets are that there are less terrestrial invertebrates produced or that they're somehow inaccessible to trout in main-stem channels. Based on field observations, the riparian corridor surrounding the Mid SF appears to be adequately intact. Additional spatial coverage of diet sampling and the addition of invertebrate drift sampling in the Mid SF (including tributaries and additional sampling in the Tinkham and Weeks Falls segments) would help to determine the overall production, availability, and use of food items in that river section.

Prey fish were more prevalent in diet samples from adult and large adult coastal cutthroat–Onxx than in rainbow trout of the same size. Brook trout were only sampled in substantial numbers from the Mid SF (n = 30), but on average consumed higher amounts of prey fish than Pacific trout in all middle river sections combined (Mid SF brook trout: 0.31 g/fish v. Pacific trout species: 0.05 g/fish). Trout eggs were only found in diets from the Mid SF and Mid NF, whereas none were found in diets in the Mid MF. This may be a result of the increased amount of main-stem spawning habitat in these two river sections, where eggs would be readily available to main-stem trout. Conversely, spawning habitat in the main-stem channel of the Mid MF was limited; therefore, majority of spawning in the Mid MF probably occurs in tributaries where drifting eggs would have been less readily available to main-stem trout.

It is important to note that because of the difficulty inherent to sampling fish in an unbiased manner in medium and large streams, fish were opportunistically captured using a combination of methods as opposed to employing an explicitly randomized depletion sampling design. Some diet data might not be representative, so analyses of diet content data should be extrapolated with caution. Regardless, while capture methods may have influenced diet collections, we generally obtained large sample sizes that proportionally represented size/species structures in each sample reach (based on snorkel survey results).

6. Movement and Life History

Methods

Radio tag implantation

Radio-tagged trout were caught either by hook and line (*n* = 38) or backpack electrofishing (*n* = 2). Tagging criteria required that tag weight did not exceed 2% of fish body weight (Adams et al. 1998), which equated to approximately 240 mm TL. After capture, trout were held in containers of fresh water with vegetation for cover to reduce stress. Radio-tag surgery procedures followed those described by M. Mizell, personal communication: Fish were anesthetized using 6 ml of 10% MS 222 solution in 7.5 ltr of fresh water. After reaching full anesthesia, fish were measured (mm), weighed (g), scales were removed, and caudal fin clip genetic samples were taken. Fish were then placed in a surgery carriage and the gills were irrigated with water containing 3 ml of 10% MS 222 solution in 7.5 ltr of fresh water. A 5 mm incision was made through the muscular layer into the body cavity on the right ventral side approximately 20 mm anterior to the pelvic girdle. A curved copper tube with one sharp end (stinger) was inserted into a larger diameter, shorter, and dull copper tube (Figure 52). Both were inserted and moved inside the body cavity at least 20 mm posterior to the pelvic girdle where the stinger was pushed out making a small puncture in the right side of the body. The antenna of the tag was inserted into the inner stinger through the main incision and the stinger was pulled out of the body through the puncture, exposing the antenna. The antenna was pulled taught gently wedging the tag in the pelvic girdle region, and the incision was sutured, dried, and sealed using surgical glue applied to each incision area (Figure 53). After tagging, fish were allowed to recover in a container of fresh water with cover and were released when able to swim away. Tag frequencies ranged from 151.013 to 151.512 MHz, and the manufacturer estimated maximum tag life was 365 days (Advanced Telemetry Systems). Actual maximum tag life was 495 days.

Figure 52. Coastal cutthroat trout being radio-tagged in the Low NF. Note the copper tubing that is being inserted through the incision into the body cavity and will pierce out through the body posterior to the pelvic girdle to allow the radio tag antenna to protrude from the fish's body.

Figure 53. A tagged coastal cutthroat trout ready to be released back to the Low MF. Note the suture just anterior to the pelvic fins and the radio-tag antenna, which protrudes from the fish's body posterior to the pelvic fins.

Telemetry tracking

Dual 6-element Yagi antennas were mounted on a bracket attached to a truck hitch enabling us to track fish continuously while driving along the river. The antennas were connected to an Advanced Telemetry Systems R410 receiver in the cab, enabling the passenger to scan for specified tags and to toggle between left and right antennas for improved tag signal reception. Tagged trout were homed from the mobile receiver as radio tag signals intensified. To increase the precision of the estimated tag location, basic triangulation methods were employed around the perimeter of the tag signal. When confident of the location of the tag (±50 m), latitude and longitude coordinates and GPS satellite error (±1 m) were recorded. Tracking event movements were categorized as local (≤500 m), intra-section (>500 m but within river section), or inter-section (among river sections). Maps of the longer migratory routes (intra-section and inter-section categories) and corresponding temporal movement points were plotted. Mean directional movement (km ±SE) was plotted seasonally for each species group, and mean gross distance moved (km ±SD) was plotted for species and river section of capture and release.

Spawning ground surveys and incubation/ emergence timing

Pacific trout spawning habitat (i.e., gravel beds), recently emerged trout fry (≤40 mm TL), sexually ripe trout, and trout redds were noted during tributary surveys and helped to identify reaches for spawn surveys. Because there were no previous data on trout spawning in the USRW, exploratory spawning ground surveys were conducted between February 16 and May 27, 2010. During surveys (Gallagher et al. 2007), latitude-longitude coordinates were recorded at individual redds and each redd was flagged lateral to the pit. For each survey, flags were marked with the date and redd number. Each redd was measured as described in Reiser et al. (1997) at the head, pit, tailspill, and along its length. Redd size was computed as total area (Figure 54, Reiser et al. 1997)

$$A = (L/6)\ (3W_t + 2W_p + W_h),$$

where L = total length, W_t = width of the longitudinal midpoint of the tailspill, W_p = maximum width of the pit and W_h = width of the head.

Depths were recorded and dominant/subdominant substrates were estimated around the perimeter of each redd (Table 18). Coordinates were also recorded at sites where trout were actively constructing redds or spawning. Because size and conspicuousness of redds was variable among reaches, a subset of redds were agitated carefully with a spade-shaped net to confirm egg deposition. If an egg or alevin was dislodged from the egg pocket it was preserved for genetic analysis (n = 14).

Spatial-temporal spawning intensity maps were created to provide reference for future monitoring. Temporal frequency of redd construction and mean redd size were assessed for tributary and main-stem channel habitats, and habitat use by spawners was assessed by analyzing redd count proportions among habitat types and substrate size frequencies.

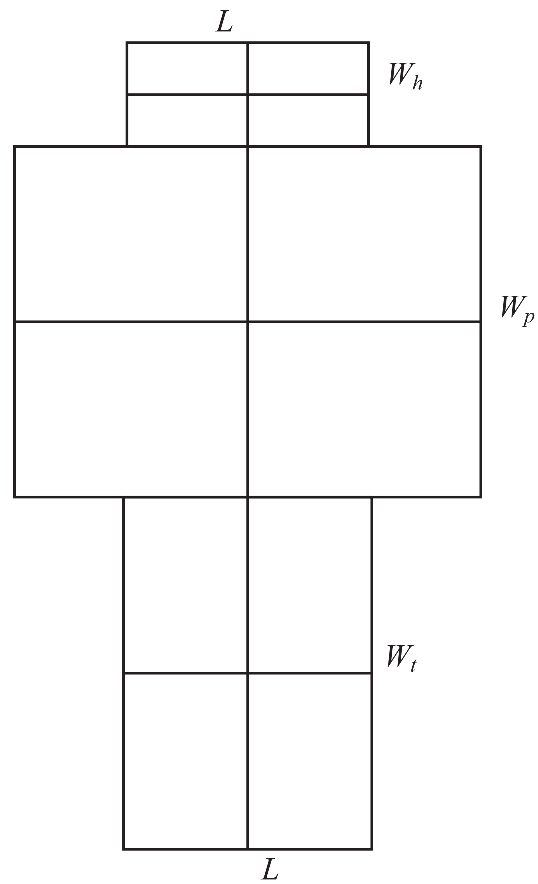


Figure 54. Schematic of measurements recorded for each trout redd (from Reiser et al. 1997). Dimensions were used to calculate redd surface area (cm²).

To investigate incubation rates and emergence timing, custom-built emergent-fry traps were installed over three Pacific trout redds in Clough Creek within 24 hours of redd construction (Figure 55, Research Nets Inc., 0.32 cm mesh, 46–61 cm dia.; Chotkowski et al. 2002). A temperature logger was installed near each trap prior to trap deployment and recorded hourly water temperatures. Clough Creek was selected as the trap deployment site due to its stable flows and the high abundance of spawning activity. After 30 days of being deployed, each cap was checked every 2 days for emerging fry by removing the bottle cap at the tip of the net, allowing captured fry to escape into a small aquarium net. Incubation rate was then calculated

Table 18. Fine-scale substrate particle size definitions and diameter ranges used to estimate dominant/subdominant substrate composition for individual redds.

Particle	Sub-particle	Diameter (mm)
	Sand	<2
Gravel	Very fine	2–4
	Fine	4–8
	Medium	8–16
	Coarse	16–32
	Very coarse	32–64
Cobble	Small	64–128
	Large	128–256

Figure 55. Emergent fry trap used to investigate trout incubation rates. Traps consisted of 0.32 cm (1/8") mesh netting sewn into a conical shape with a 1000 ml bottle at the end of the cone in which emergent fry were trapped. A small float was attached to the end of the cone to retain the conical shape of the trap. Traps were secured to the stream bed using 1.27 cm (1/2") steel bars.

as temperature units (Quinn 2005) for fry captured from emergent-fry traps

$$TU = \sum t^*d,$$

where t = mean daily temperature (above 0° C) experienced by fertilized eggs and non-emerged alevins and d = number of days the fertilized eggs and non-emerged alevins experienced that temperature until being captured (emerging) from redd caps.

A subset of gonads taken from Pacific trout ≥150 mm TL during sample events was used to estimate annual weight lost to gamete production. Gonads were removed, weighed, and gonad-to-body-weight ratios were calculated for lower, middle, and upper river sections. These data also provided gonad growth trajectories that corroborated the observed beginning and end of the spawning season.

Results

Radio tagging and telemetry tracking

Forty trout were radio tagged and released during this study, but six trout either expired or the tags malfunctioned soon after release, rendering a total of 31 trout with which to conduct movement analysis. Coastal cutthroat, Onxx (hybrid or unidentified Pacific trout), rainbow, and brook trout were tagged. The spatial distribution, characteristics, and detection and movement histories of tagged trout are summarized in Table 19. Among release sites, a majority of movements occurred as localized small-scale movements upstream or downstream from the point of release. Inter-section movements were limited to trout released in lower river sections and the Up MN; however, intra-section movements were common. One trout released in the Up SF made a large downstream inter-section movement, but it was assumed that this trout died and floated passively downstream about the same time a major flood occurred in January 2009 (Figure 56).

Twelve intra- and inter-section moving trout were graphed to show spatial and temporal patterns of the longer migratory routes. One of three trout tagged in the Mid NF (rainbow) showed intra-section movement, initiating a slow downstream movement in winter that lasted over a period of about five months. One of three trout tagged in the Mid MF (cutthroat) showed intra-section movement, and in late May it moved downstream about 1 km then returned upstream about 1.5 km over a six week period. In the Low NF, one of three trout (cutthroat) showed inter-section movement during late summer, initiating a slow downstream migration into the Mainstem Snoqualmie. In mid-fall, this trout swam about 1.5 km upstream into the

Table 19. Characteristics, detections, and cumulative movements of trout that were radio-tagged, released, and tracked in river sections. Assumptions of post-tagging mortality rendered some tagged trout unusable for analysis. Bold rows indicate tagged trout that were used for movement analysis.

Species	TL (mm)	FL (mm)	Wt (g)	Tag frequency	River Section of release	Date released	Last day detected	Number of detections	Gross movement (km)	Net movement (km)
RBT	**402**	**386**	**621.0**	**151.102**	**Mid NF**	**06/19/2009**	**08/31/2010**	**26**	**5.362**	**-2.39**
RBT	**295**	**279**	**275.0**	**151.094**	**Mid NF**	**06/19/2009**	**06/29/2010**	**18**	**2.76**	**-0.654**
RBT	**401**	**395**	**755.0**	**151.191**	**Mid NF**	**09/14/2009**	**12/01/2010**	**28**	**2.156**	**0.063**
CCT	**381**	**369**	**513.0**	**151.063**	**Low NF**	**06/18/2009**	**11/23/2009**	**9**	**3.51**	**-1.006**
RBT	**444**	**430**	**929.0**	**151.083**	**Low NF**	**06/18/2009**	**05/04/2010**	**20**	**4.549**	**1.125**
RBT	290	273	205.0	151.203	Low NF	09/15/2009	12/14/2009	5	1.976	-0.367
CCT	**354**	**339**	**350.0**	**151.030**	**Mid MF**	**06/17/2009**	**09/16/2010**	**28**	**6.077**	**-0.057**
CCT	**327**	**310**	**253.0**	**151.043**	**Mid MF**	**06/17/2009**	**07/13/2010**	**22**	**3.795**	**0.248**
CCT	**335**	**319**	**346.0**	**151.052**	**Mid MF**	**06/17/2009**	**09/16/2010**	**29**	**3.906**	**0.054**
CCT	320	301	257.0	151.142	Low MF	08/03/2009	08/03/2009	0	-	-
CCT	**249**	**234**	**130.0**	**151.221**	**Low MF**	**09/24/2009**	**10/14/2010**	**26**	**1.835**	**-0.125**
CCT	**287**	**273**	**195.0**	**151.230**	**Low MF**	**09/25/2009**	**03/25/2010**	**12**	**2.045**	**5.857**
CCT	**294**	**278**	**205.0**	**151.243**	**Low MF**	**09/25/2009**	**12/13/2010**	**29**	**3.77**	**-0.252**
CCT	286	271	181.0	151.252	Low MF	09/25/2009	12/14/2009	5	1.108	-0.112
CCT	**262**	**250**	**148.0**	**151.271**	**Low MF**	**09/25/2009**	**02/24/2010**	**8**	**2.654**	**1.62**
Onxx	**419**	**398**	**736.0**	**151.284**	**Low MF**	**09/30/2009**	**02/24/2010**	**10**	**1.747**	**0.224**
Onxx	**293**	**278**	**220.0**	**151.292**	**Low MF**	**09/30/2009**	**04/05/2010**	**13**	**1.568**	**0.359**
CCT	**276**	**264**	**165.0**	**151.313**	**Low MF**	**10/01/2009**	**12/10/2010**	**29**	**8.768**	**0.334**
Onxx	**266**	**252**	**161.0**	**151.322**	**Low MF**	**10/01/2009**	**11/12/2010**	**24**	**15.269**	**-12.836**
Onxx	**302**	**285**	203.0	**151.382**	**Low MF**	**10/09/2009**	**09/15/2010**	**19**	**8.038**	**-4.596**
CCT	298	285	216.0	151.392	Low MF	10/09/2009	10/09/2009	0	-	-
CCT	**288**	**276**	**212.6**	**151.262**	**Up SF**	**10/13/2008**	**08/27/2009**	**20**	**0.178**	**-0.012**
WCT	**254**	**241**	**152.0**	**151.512**	**Up SF**	**10/23/2008**	**08/27/2009**	**16**	**5.145**	**-4.816**

—Table 19 continued on next page

Table 19. Continued

Species	TL (mm)	FL (mm)	Wt (g)	Tag frequency	River Section of release	Date released	Last day detected	Number of detections	Gross movement (km)	Net movement (km)
EBT	281	271	211.2	151.113	Mid SF	10/10/2008	10/10/2008	0	-	-
EBT	**240**	**237**	**151.0**	**151.213**	**Mid SF**	**10/22/2008**	**11/09/2009**	**24**	**2.628**	**0.556**
CCT	**335**	**328**	**354.4**	**151.021**	**Low SF**	**10/08/2008**	**03/09/2009**	**10**	**6.878**	**-0.312**
CCT	**385**	**372**	**508.9**	**151.013**	**Low SF**	**10/08/2008**	**08/10/2009**	**21**	**20.74**	**-0.052**
CCT	**291**	**287**	**239.6**	**151.071**	**Low SF**	**10/09/2008**	**08/31/2009**	**21**	**9.335**	**-7.979**
RBT	**286**	**274**	**228.0**	**151.301**	**Low SF**	**10/30/2008**	**02/24/2010**	**30**	**6.696**	**-3.866**
RBT	271	256	166.0	151.150	Low SF	09/09/2009	09/09/2009	0	-	-
RBT	**311**	**297**	**277.0**	**151.163**	**Low SF**	**09/09/2009**	**06/01/2010**	**17**	**1.096**	**0.002**
CCT	264	249	181.0	151.182	Low SF	09/10/2009	09/10/2009	0	-	-
RBT	**274**	**255**	**188.9**	**151.402**	**Low SF**	**01/13/2010**	**12/10/2010**	**19**	**2.288**	**0.578**
CCT	**272**	**259**	-	**151.123**	**Up MN**	**07/24/2009**	**09/15/2010**	**20**	**6.545**	**-0.758**
CCT	**317**	**298**	-	**151.133**	**Up MN**	**07/24/2009**	**06/29/2010**	**10**	**2.605**	**-0.9**
CCT	294	277	217.0	151.342	Up MN	10/06/2009	10/06/2009	0	-	-
Onxx	**317**	**298**	**279.0**	**151.333**	**Up MN**	**10/06/2009**	**02/25/2010**	**8**	**1.522**	**-0.395**
CCT	**322**	**305**	**302.0**	**151.353**	**Up MN**	**10/06/2009**	**11/12/2010**	**28**	**2.083**	**-0.0491**
CCT	309	293	261.0	151.361	Up MN	10/08/2009	12/15/2009	4	0.97	-4.984
CCT	**336**	**318**	**300.0**	**151.374**	**Up MN**	**10/08/2009**	**11/12/2010**	**27**	**2.741**	**-0.205**

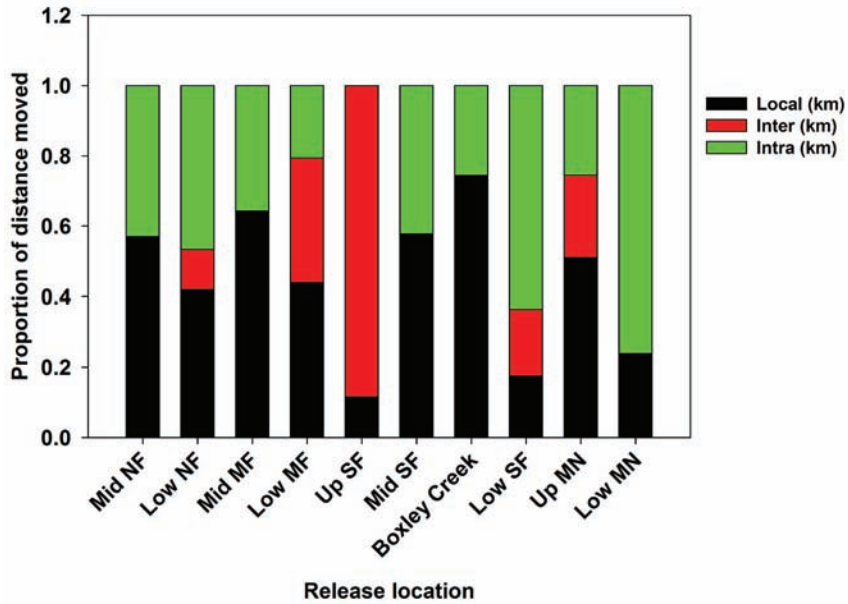


Figure 56. Proportion of distance moved (km) by trout per movement category (local ≤500 m, intra >500 m within river sections, and inter = between river sections) as a function of release location. All inter-section movements in the Up SF were likely due to a mortality that passively drifted downstream to the Mid SF.

Low MF where it remained well into December. One of the other three trout tagged in the Low NF (rainbow) showed only localized movements throughout the first 6 months of being tagged. In December, this trout initiated a slow migration upstream about 1.5 km where it was last detected (Figure 57). Trout tagged and released in the Low MF (cutthroat and Onxx) showed diverse movement patterns. These patterns ranged from local to large-scale movements within and between river sections, with longer migrations occurring in spring and fall months (Figure 58). Trout tagged in the Low SF also showed diversity in movement. One trout tagged in the North Bend segment (cutthroat) moved 8 km upstream in a two-week period during spring and then two weeks later had moved back downstream to the location at which it was released. Another trout (cutthroat) moved about 8 km downstream from where it was released and remained there for the remainder (nine months). A trout released in the Three Forks segment of the Low SF (rainbow) migrated out of the Low SF and into the Low MN during April where it remained throughout the duration (>1 year). Another of these trout (cutthroat) moved downstream into the Mainstem Snoqualmie during fall and moved upstream into the Low MF during winter where it remained until mid-March. At this time the trout then rapidly returned to the Mainstem Snoqualmie and upstream into the Low SF where it was originally released and also detected for the last time (Figure 59).

On average, coastal cutthroat moved little in spring and summer, whereas movements peaked in fall and declined slightly in winter. Hybrid or unidentified Pacific trout (Onxx) moved the greatest among all species with significant peaks in downstream movements occurring in spring and fall. Rainbow trout moved little during all months except in winter, and the one brook trout that was tagged and tracked moved more in fall (Figure 60). Gross movement (sum of upstream and downstream) was greatest for Pacific trout species tagged and released in the Low SF and rainbows moved less than coastal cutthroat and Onxx (Figure 61).

Spawning ground surveys and incubation/emergence timing

Pacific trout redds observed in the USRW showed characteristics typical of other salmonid species redds (Figure 62). The most redds were found in Clough Creek (n = 103, Low SF) followed by Roaring Creek (n = 69, Low MF). No redds were found in main-stem channels or tributaries in the Mid NF and Low MN (Table 20).

In the Kimball and Three Forks segments of the Mainstem Snoqualmie, Brockway and Three Forks* creeks and the main-stem channel of the Up MN were surveyed. The only redds found in these reaches were in Three Forks Creek*, a small tributary to the Up MN (Figure 63).

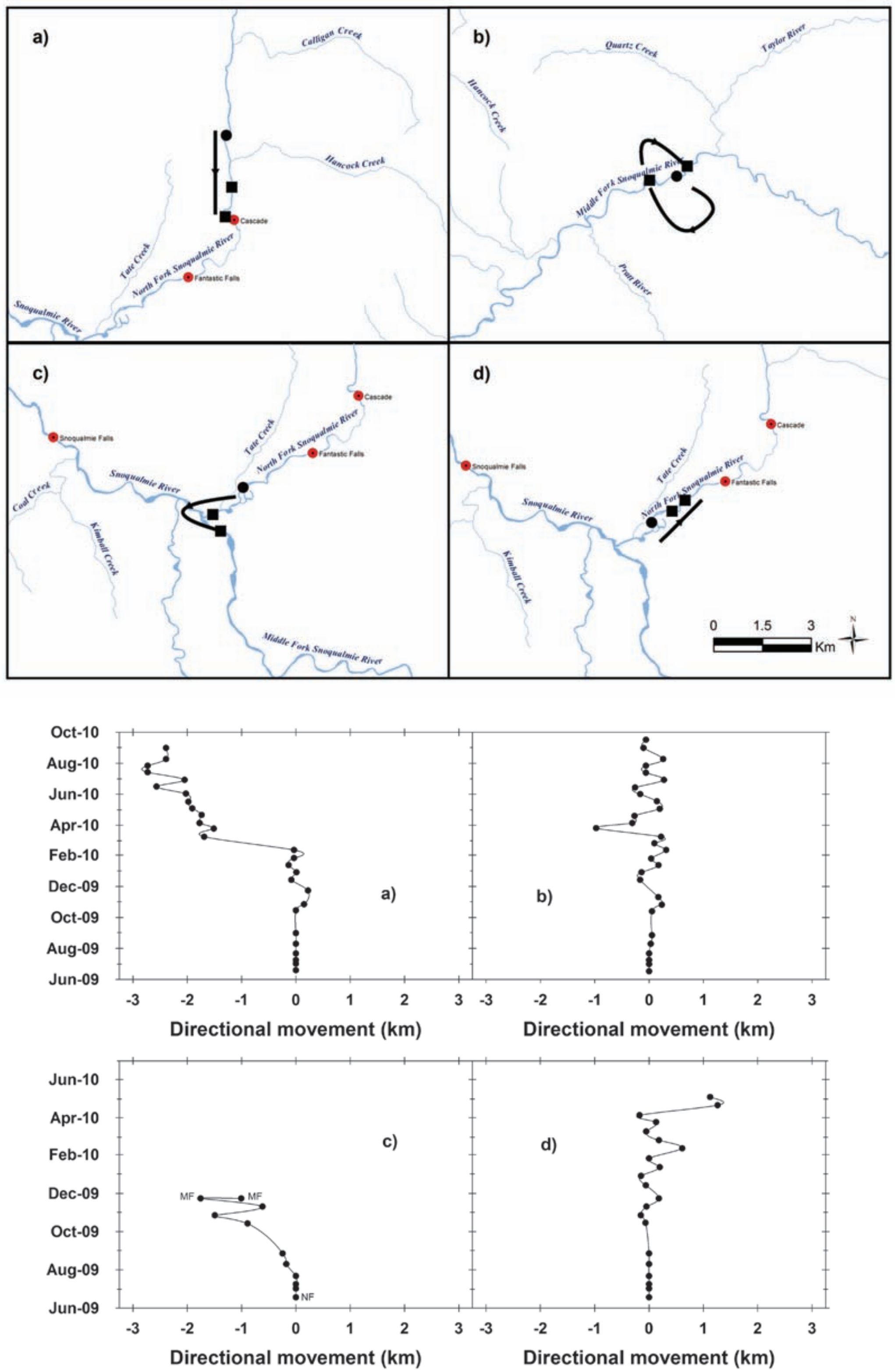


Figure 57. Aerial view (top panel) and temporal profile (bottom panel) of movement patterns by trout tagged and released in the Mid NF (a: 151.102), Mid MF (b: 151.030), and Low NF (c: 151.063, d: 151.083). Solid circles on maps indicate release locations, boxes indicate detection points, and lines with arrows correspond with directional extent of movements. Solid circles on temporal graphs indicate 2-week interval tracking events.

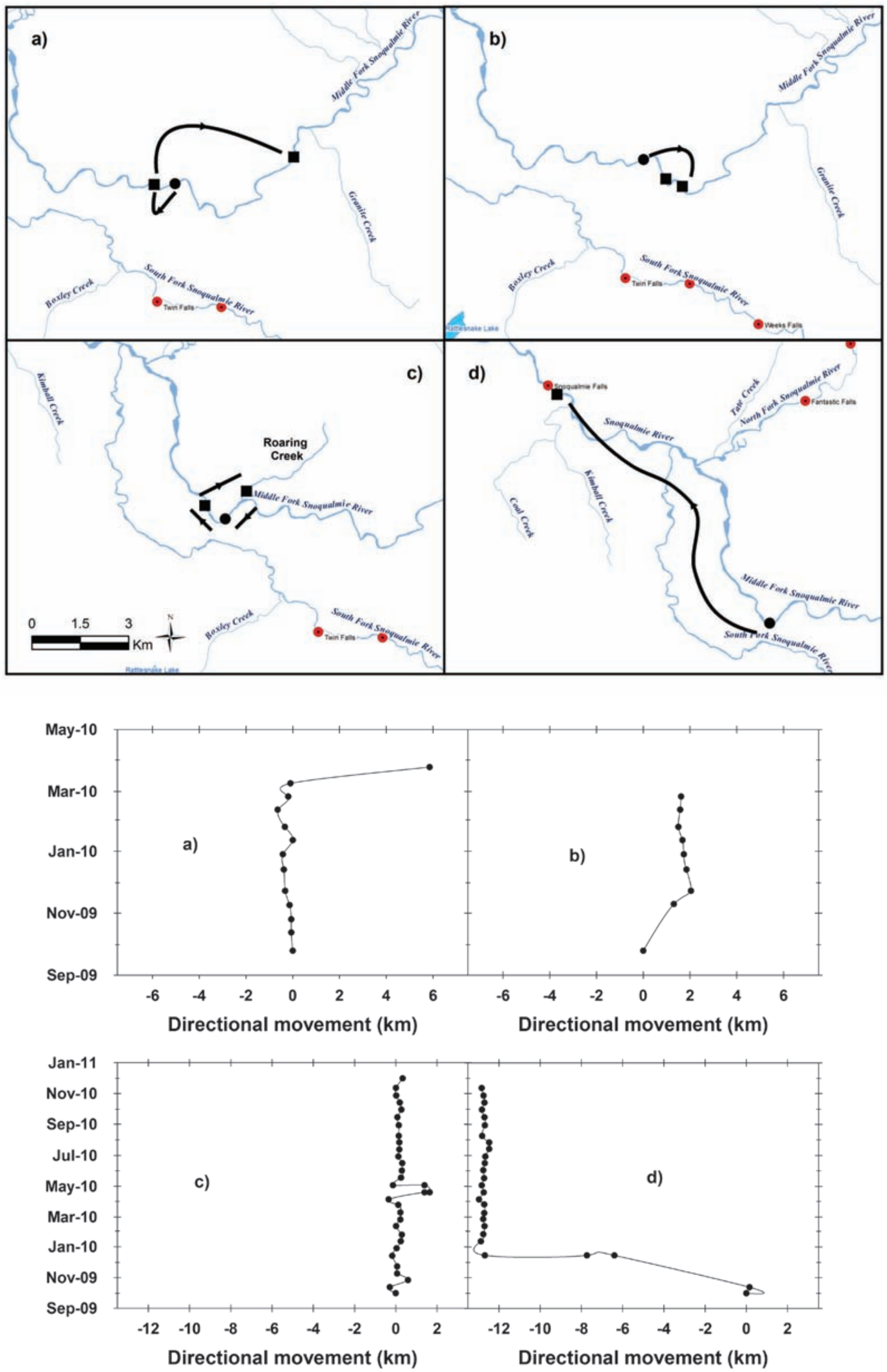


Figure 58. Aerial view (top panel) and temporal profile (bottom panel) of movement patterns by trout tagged and released in the Low MF (a: 151.230, b: 151.271, c: 151.313 and d: 151.322). Solid circles on maps indicate release locations, boxes indicate detection points, and lines with arrows correspond with directional extent of movements. Solid circles on temporal graphs indicate 2-week interval tracking events.

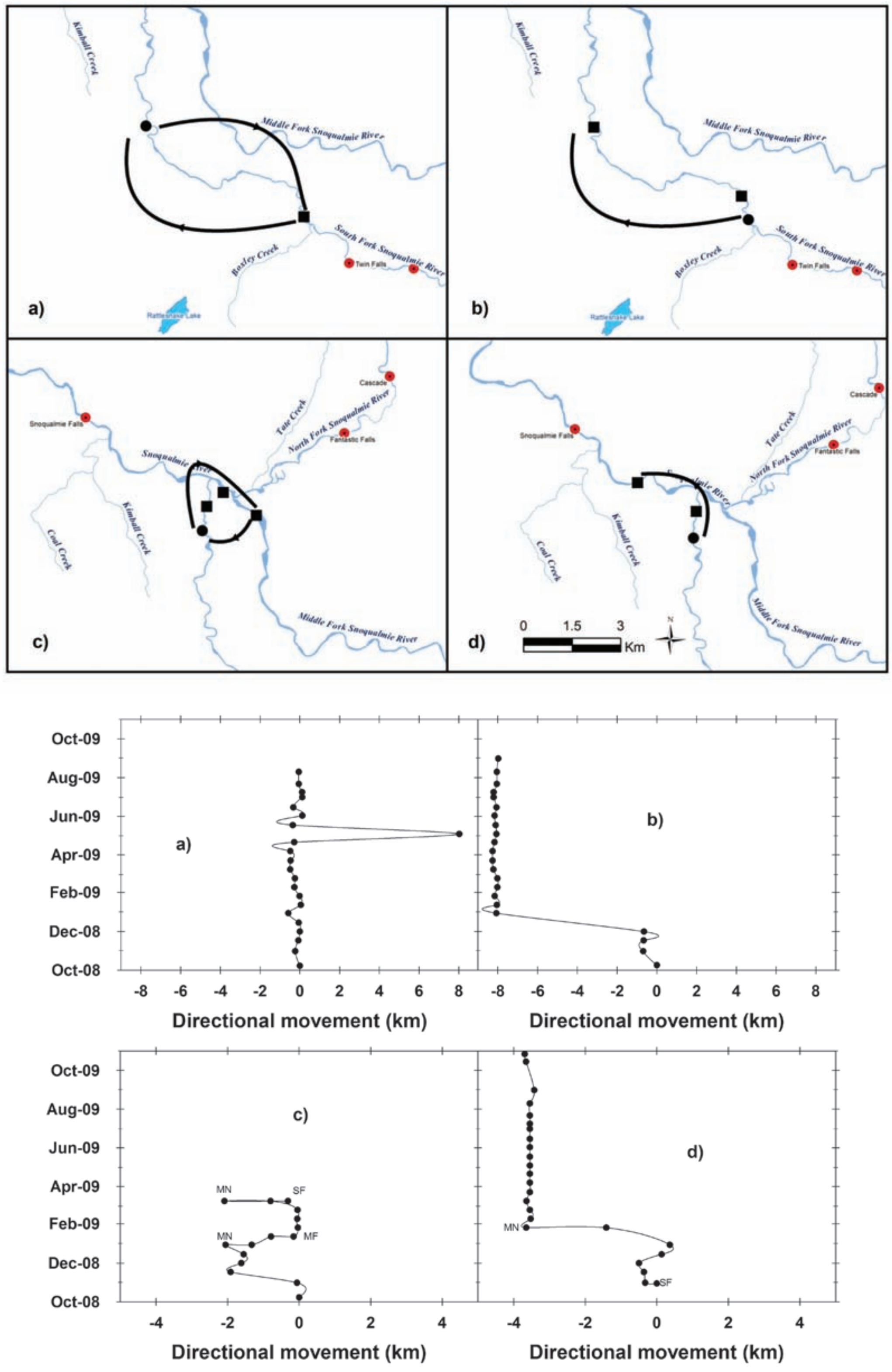


Figure 59. Aerial view (top panel) and temporal profile (bottom panel) of movement patterns by trout tagged and released in the Low SF (a: 151.013, b: 151.071, c: 151.021 and d: 151.301). Solid circles on maps indicate release locations, boxes indicate detection points, and lines with arrows correspond with directional extent of movements. Solid circles on temporal graphs indicate 2-week interval tracking events.

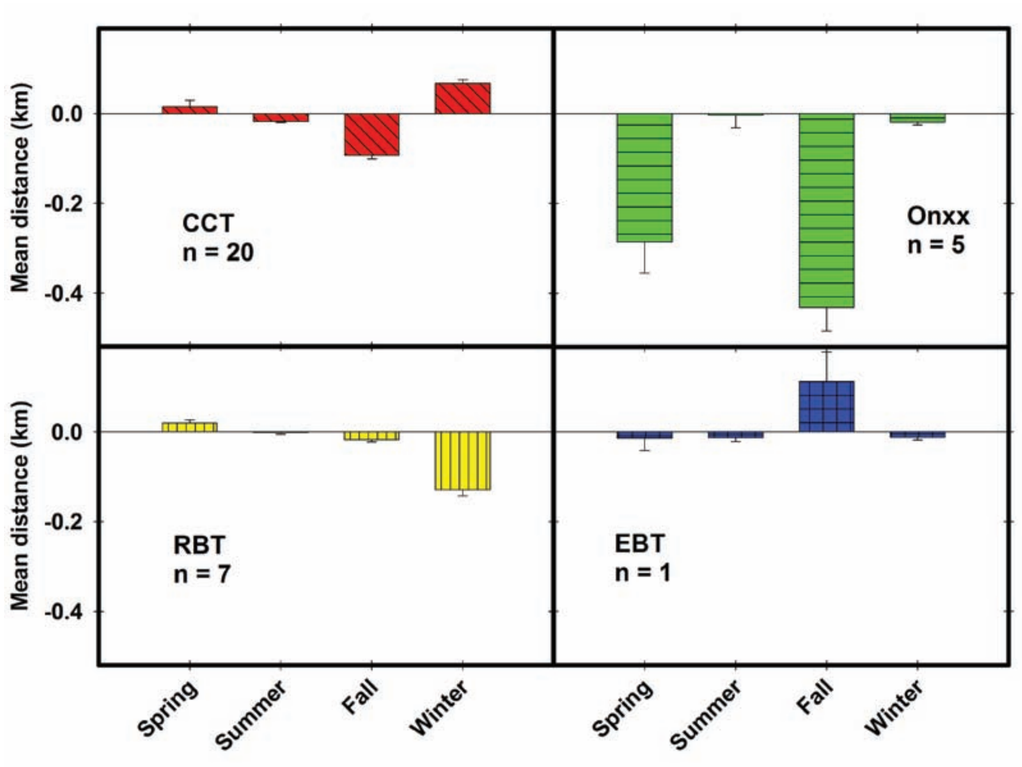


Figure 60. Mean distance (+SE) of directional movement per season for coastal cutthroat (top left), unidentified or hybrid Pacific trout (top right), rainbow trout (bottom left), and brook trout (bottom right) recorded at 2-week intervals. Sample size (*n*) indicates the number of fish analyzed.

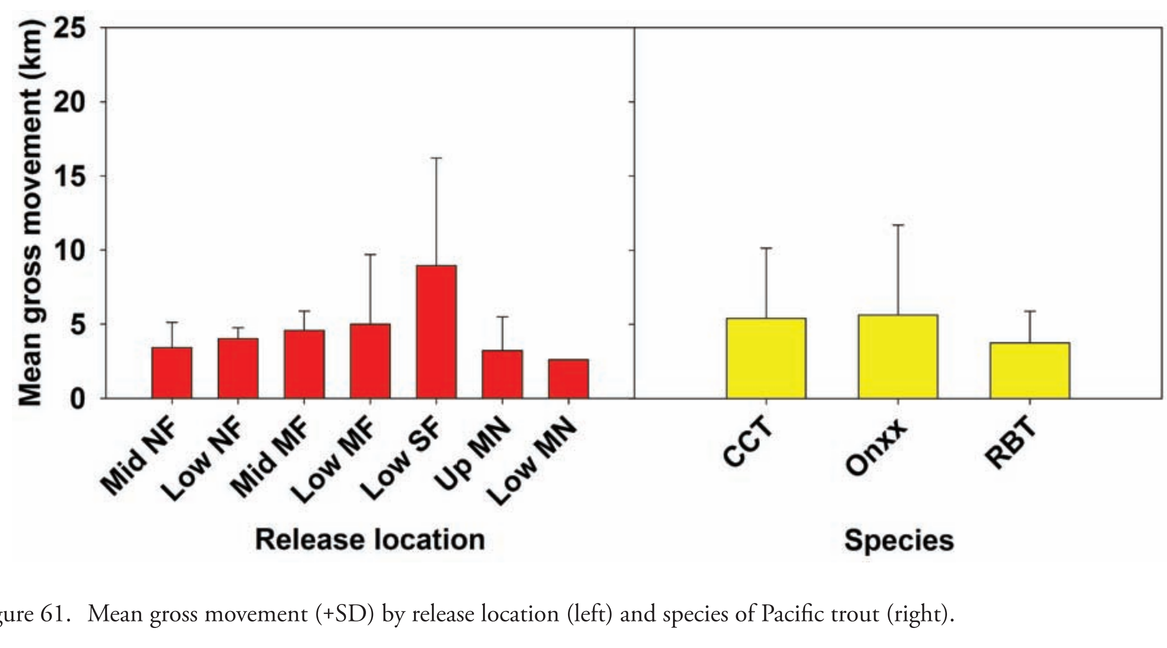


Figure 61. Mean gross movement (+SD) by release location (left) and species of Pacific trout (right).

Figure 62. Pacific trout redd found in a small tributary (Little Si Creek*) showing characteristic cleaned gravel encompassing the pit (center) and tailspill (right).

In the Three Forks and North Bend segments of the Low SF, the Circle River, Bendigo, and Playground reaches were surveyed. Redds were found in each of these reaches between February and May. One tributary to the North Bend segment (Clough Creek) was surveyed and contained the greatest number of redds found during this study (Figure 64). In the Sallal Prairie segment of the Low SF, Boxley Creek also contained a high number of redds. In the Mid SF, main-stem channels were surveyed in the Weeks Falls (Olallie Channel) and Tinkham (Hansen Creek Down) river segments. Two tributaries were also surveyed, including Mine Creek and Hansen Creek. The only redds were found during May in the Olallie Channel and Mine Creek (Figure 65).

The only main-stem channel reach in the Low MF that was surveyed was North Island Channel in the Three Forks river segment. It was surveyed only once because of highly turbid water conditions throughout most of the spawning season, and only two redds were found in this reach. In the North Bend and Sallal Prairie segments of the Low MF, two tributaries were surveyed regularly and both contained a high number of redds (Little Si Creek* in the North Bend segment and Roaring Creek in the Sallal Prairie segment). Mine Creek, a tributary in the Mt. Teneriffe segment, was surveyed, and redds were found during March and April (Figure 66). Most tributaries in the Mid MF were surveyed only intermittently due to turbid water conditions. Redds were found in all surveyed tributaries except WBC#1* and the lower Pratt River, which was surveyed only once. The main-stem channel of the Mid MF was surveyed only once due to a limited amount of gravel bars and no redds were found (Figure 67).

The only reaches surveyed in the Mid NF were Deep Creek and the main-stem channel near Spur 10, and no redds were confirmed. In the Three Forks segment of the Low NF, the main-stem channel, one floodplain channel (Fishery Creek*), and one tributary (Tate Creek) were surveyed and redds were found in all reaches. Lower Tate Creek was surveyed only once due to a lack of spawning habitat (Figure 68).

Redd frequency peaked between the middle of March and the first week of April in tributaries, but remained relatively constant in main-stem channels (Figure 69). Size of trout redds in tributaries ranged from approximately 500 to 9,000 cm², and in main-stems channels from 500 to 14,000 cm². Mean surface area of redds did not increase as a function of spawning site habitat (pool, riffle or glide), but did increase as a function of time as larger redds were found in March and April in both tributaries and main-stem channels (Figure 70). Trout used riffles for spawning more frequently than pools and glides in both tributaries and main-stems, and pools were used slightly more in main-stems than in tributaries (Figure 71). Substrate used by trout to construct redds ranged from sand to small cobble, and most dominant substrates were fine to very coarse gravel. Subdominant substrate used by trout to construct redds ranged from fine gravel to small cobble (Figure 72).

Trout incubation was estimated using data obtained from one capped redd and the temperature logger in Clough Creek. This redd was constructed by pure native Snoqualmie coastal cutthroat in a glide with mostly small gravel between approximately 17:00 on March 1, 2010 and 09:00 on March 2, 2010. Average daily temperatures experience by eggs and in-gravel alevins ranged from 8.1° to 10.5° C. Temperature units equaled approximately 762 for 15 mm fry and 892 for 20 mm fry (Table 21). Trout gonads were sampled throughout the year (n = 42), and gonad-to-body-weight ratios suggested that most Pacific trout had finished spawning by the middle of June (Figure 73).

Conclusions

Trout movement

Tagged trout exhibited a diverse suite of movement patterns in most river sections. However, there were some patterns in movement that suggested there may be a difference in the extent of movement between trout in middle or upper and lower river sections.

Trout tagged in lower river sections and released in lower river sections made the only confirmed inter-section movements, but the reason for these movements was not apparent in most cases. However, in some

Table 20. Locations, dates, and the number of Pacific trout redds counted during spawn surveys. Surveys were conducted in main-stem channel and tributary habitats.

River Section	River Segment	Stream (*Alias)	Survey date range	Number of surveys	Number of redds
Mid NF	Calligan	Deep Creek	3/5–4/1	2	0
	Black Canyon	main-stem	3/5–5/27	4	0
Low NF	Three Forks				15
		Tate Creek	2/17–5/27	7	8
		Fishery Creek*	3/8–5/27	4	2
		main-stem	2/19–4/26	5	5
Mid MF	Pratt				16
		main-stem	2/22	1	0
		Pratt River	2/22	1	0
		Bench Creek*	3/12–4/20	2	0
		Ditch Creek #1*	3/24–5/25	3	4
		Ditch Creek #2*	5/11–5/25	2	5
		WBC #1*	3/12–5/25	6	0
		Clay Creek #2*	5/11–5/25	2	2
		Big Blowout Creek*	3/12–5/25	4	3
		Green Mtn Creek*	3/24–5/26	2	2
Low MF					101
	Mt. Teneriffe	Mine Creek MF	3/12–5/21	6	7
	Sallal Prairie	Roaring Creek	2/17–5/26	8	69
	North Bend	Little Si Creek*	3/1–5/26	7	23
	Three Forks	main-stem	2/19–3/15	2	2
Mid SF					7
	Tinkham	Hansen Creek	3/9–5/10	4	0
		main-stem	3/9–5/27	5	0
	Weeks Falls	Mine Creek SF	5/25	1	6
		Firefighter Creek*	3/17	1	0
	Grouse Ridge	main-stem	3/17–5/10	3	1
Low SF					184
	Sallal Prairie	Boxley Creek	2/16–5/10	12	26
	North Bend				126
		Clough Creek	2/16–5/21	15	103
		main-stem	2/19–5/10	8	23
	Three Forks	main-stem	2/17–5/26	14	32
Up MN					6
	Three Forks	Three Forks Creek*	3/8–5/26	6	6
		main-stem	2/19–5/10	4	0
Low MN	Kimball Creek	Brockway Creek	2/17–5/27	6	0
Total					329

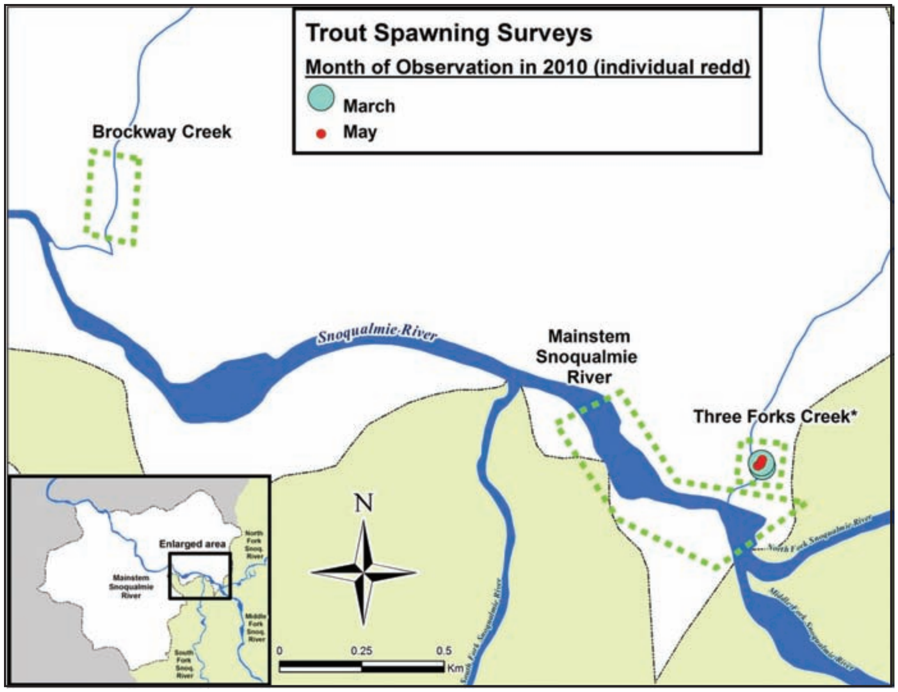


Figure 63. Temporal distribution of redds in main-stem channel and tributary habitats in the Up MN and Low MN. Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points and indicate the month of observation.

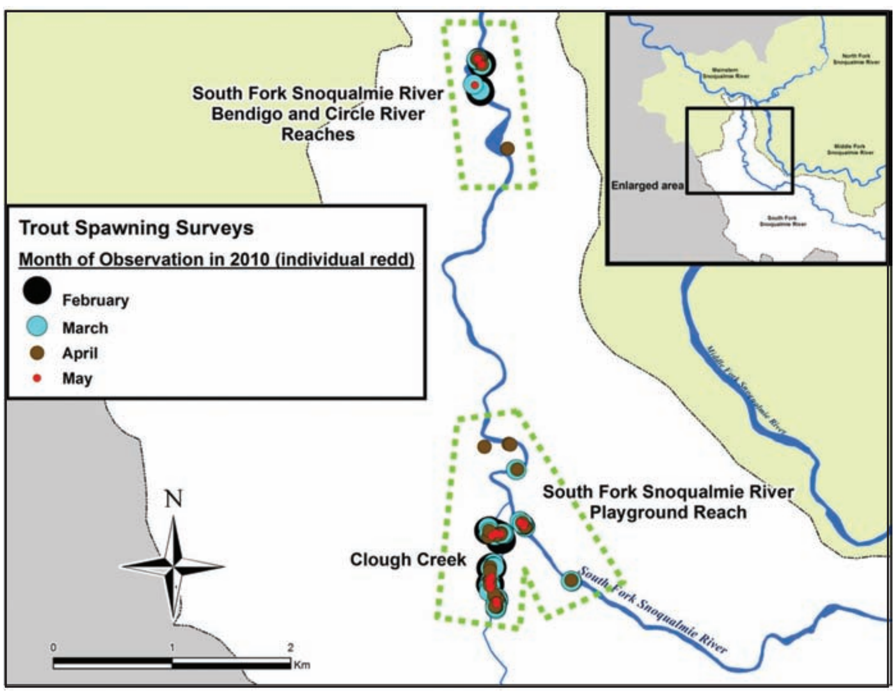


Figure 64. Temporal distribution of redds in main-stem channel and tributary habitats in the Three Forks and North Bend river segments of the Low SF. Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points, which indicate the month of observation.

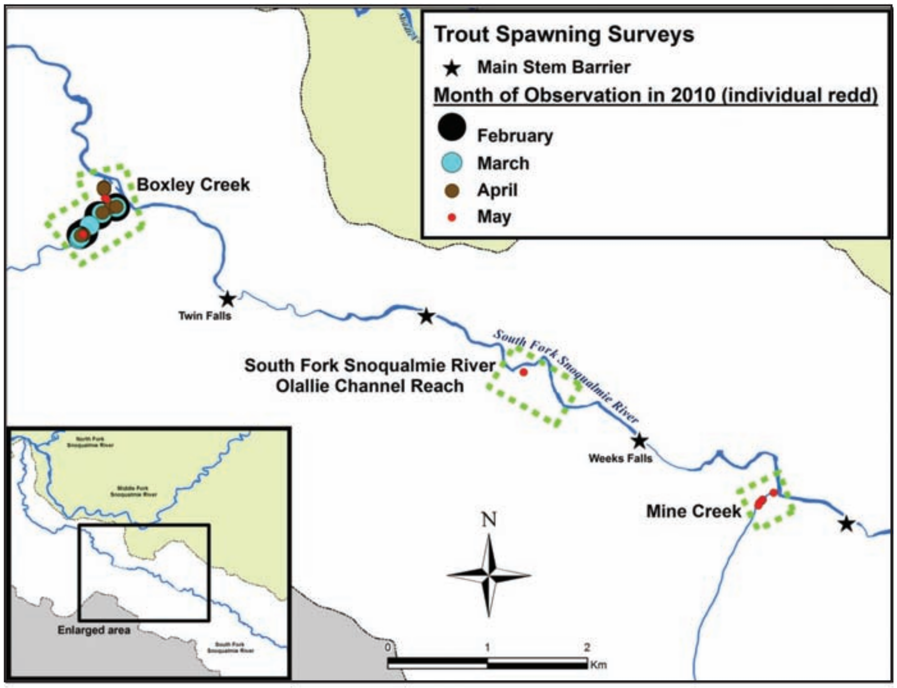


Figure 65. Temporal distribution of redds in main-stem channel and tributary habitats in the Sallal Prairie segment (Low SF) and the Grouse Ridge and Weeks Falls segments of the Mid SF. Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points, which indicate the month of observation.

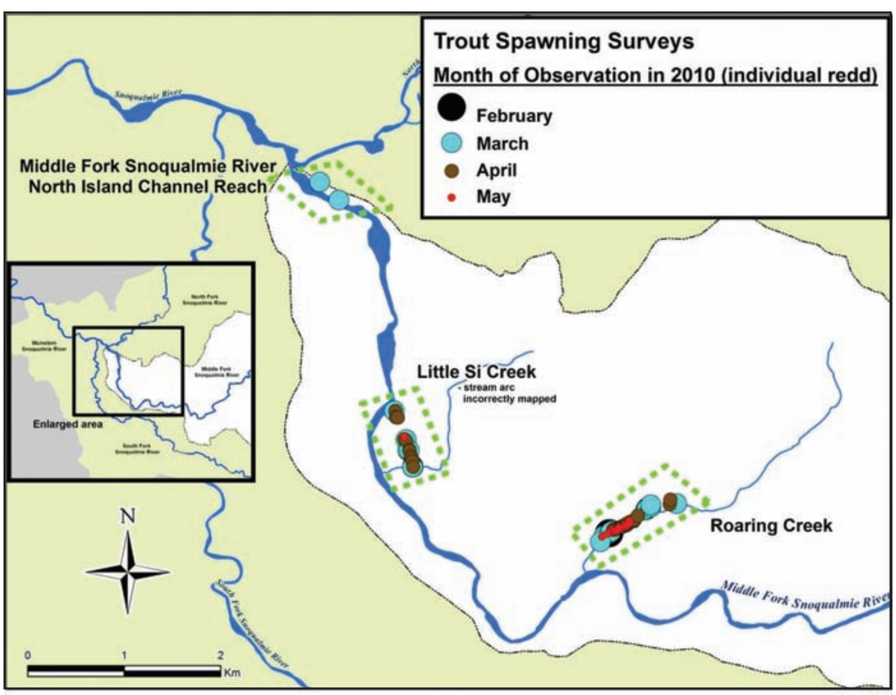


Figure 66. Temporal distribution of redds in main-stem channel and tributary habitats in the Low MF. 2Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points, which indicate the month of observation.

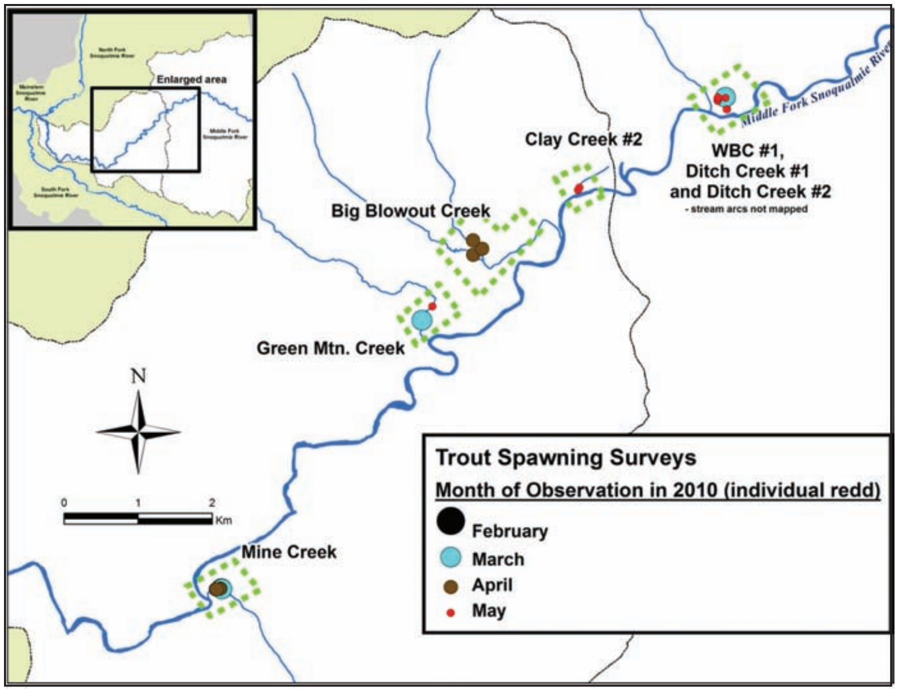


Figure 67. Temporal distribution of redds in main-stem channel and tributary habitats in the Mt. Teneriffe (Low MF) and Pratt segments (Mid MF). Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points, which indicate the month of observation.

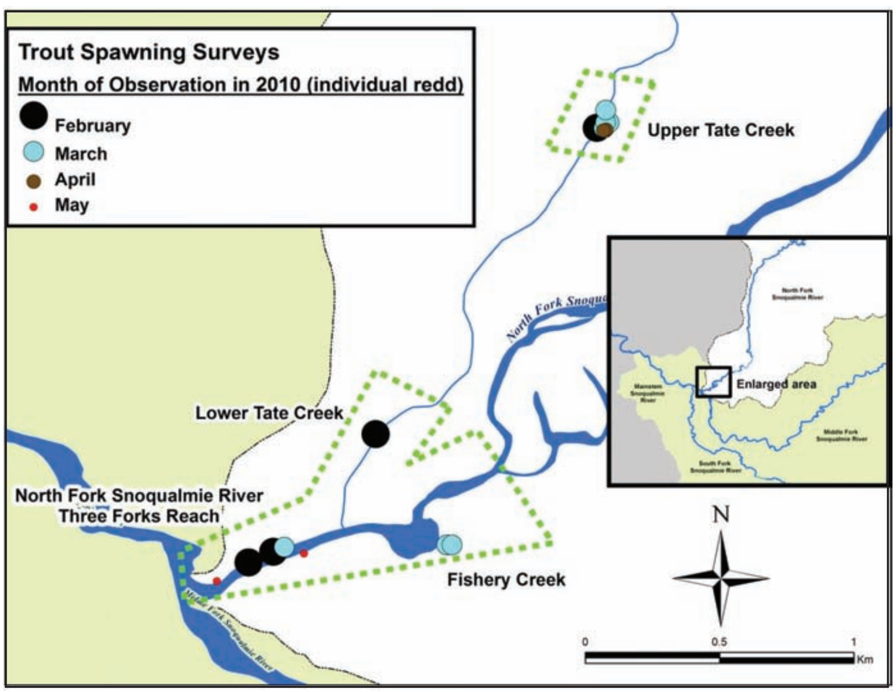


Figure 68. Temporal distribution of redds in main-stem channel and tributary habitats in the Low NF. Dashed green lines indicate the spatial range of, and name given to each survey reach. Redds are shown as size and color-coded points, which indicate the month of observation.

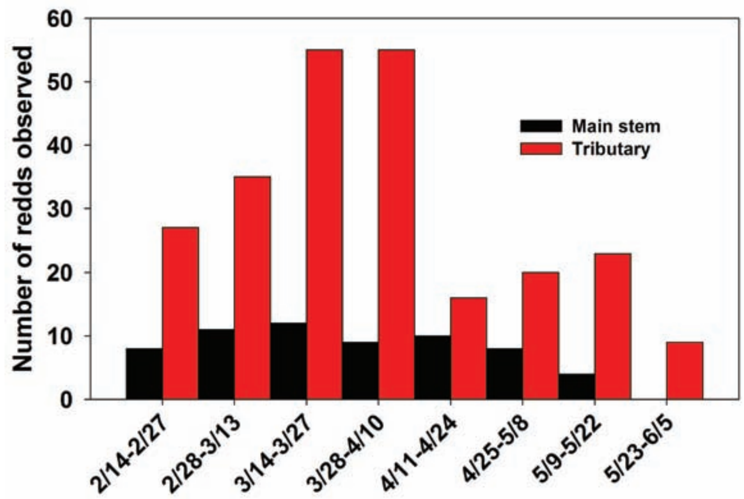


Figure 69. Temporal distribution (2-week intervals) of trout redds in main-stem channel and tributary habitats.

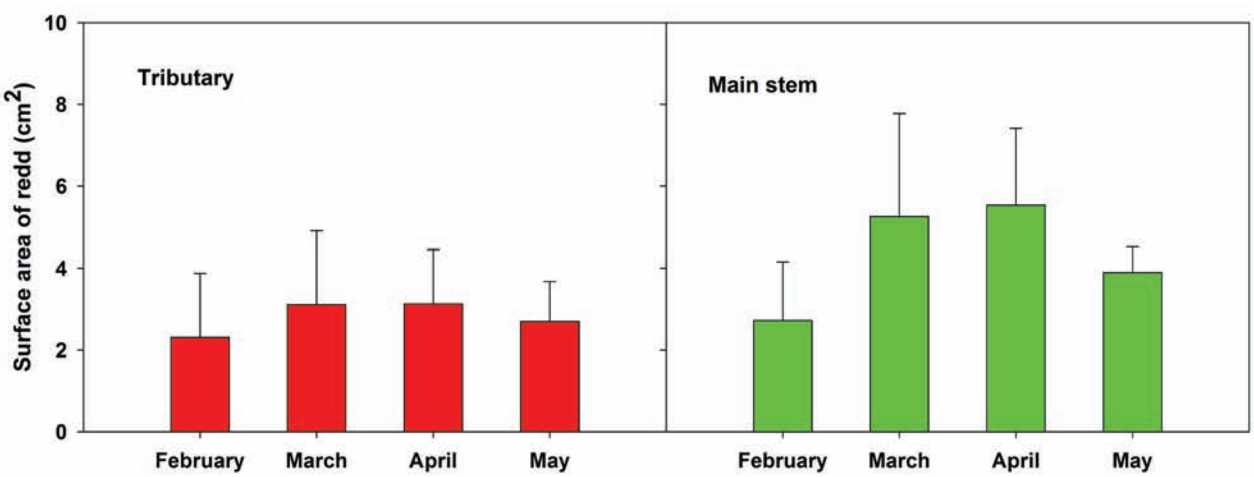


Figure 70. Surface area (in thousands of cm², +SD) of trout redds in tributary (left) and main-stem channel habitats (right) by month in 2010.

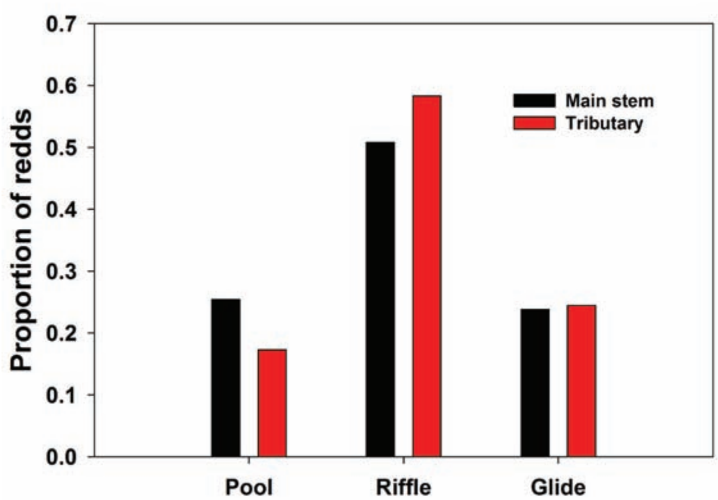


Figure 71. Proportion of trout redds found in each of three habitat types in main-stem channel and tributary spawn survey reaches.

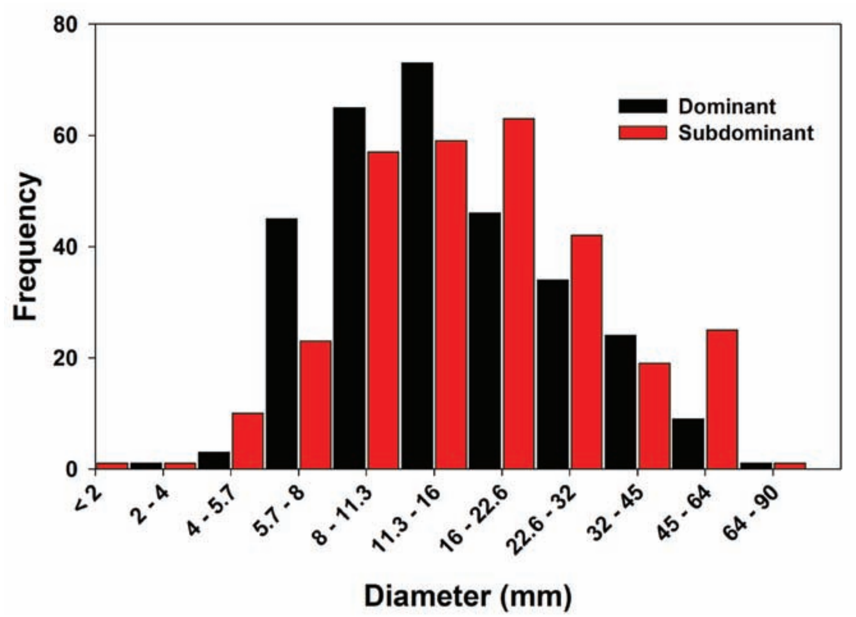


Figure 72. Substrate size (diameter range) frequency distribution for trout redds.

Table 21. Temperature units (TU) experienced by fertilized pure native coastal cutthroat trout (Snoqualmie *O. clarki*) eggs and in-gravel alevins until emergence from gravel. Data were collected from a capped redd and an adjacent temperature logger installed in Clough Creek, a tributary to the lower South Fork Snoqualmie. The redd was constructed between approximately 17:00 on March 1, 2010 and 09:00 on March 2, 2010. The first fry were captured (approx. 15 mm TL) on May 21, 2010 and the second capture (approx. 20 mm TL) occurred on June 03, 2010.

Temperature (ºC)	Days at temp (15 mm)	Days at temp (20 mm)	TU (15 mm)	TU (20 mm)
8.0	5	5	40	40
9.0	39	39	351	351
10.0	36	49	360	490
11.0	1	1	11	11
Total	**81**	**94**	**762**	**892**

cases inter-section or main-stem channel-to-tributary movements in lower river sections were possibly a result of reproductive or overwintering behavior. For example, during the spawning season, one trout in the Low MF moved upstream into a tributary (Roaring Creek) where we observed a high number of spawning trout, and then returned to the Low MF. In another instance, a trout in the Low SF moved into the Low MF where it spent a majority of the winter season, and then moved back into the Low SF to an area where newly constructed redds were concurrently found.

Similarly, some large-scale intra-section movements observed during the spawning season may have been related to spawning behavior. For example, one trout in the Low SF moved upstream 8 km over a 2-week period during the peak spawn and then over the next two weeks moved downstream to the location from which it migrated. In the Low NF, a large adult trout moved upstream over 1 km in two weeks during peak spawn and was not detected again. However, other large-scale intra-section movements did not coincide with the spawning period. For example, one trout tagged and released in the Low

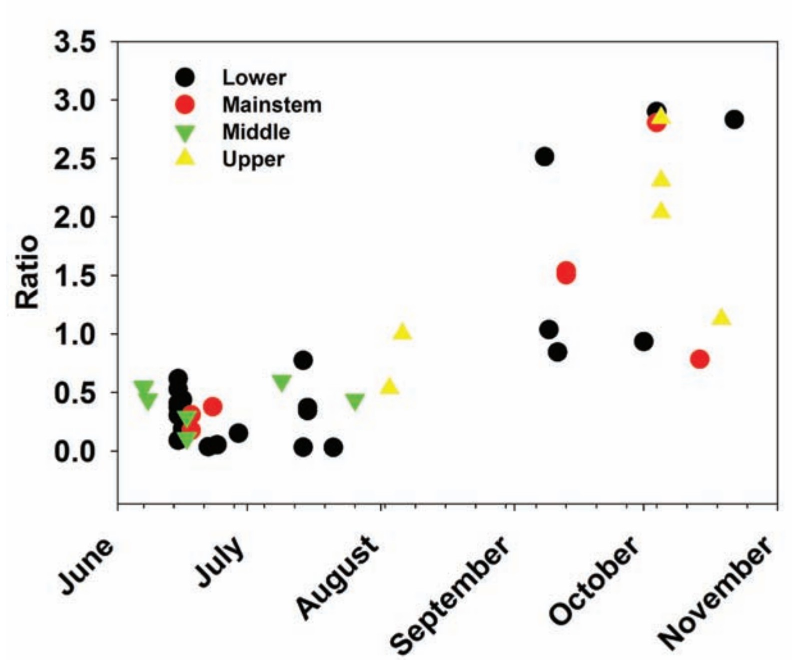


Figure 73. Gonad development (hundredths of gonad:body weight ratios) for individual age 2–5 male and female trout species (158 – 304 mm FL, mean (SE) = 227 mm ± 6 mm) during 2010. Gonads were retained from inadvertent mortalities during fish sampling. Species were pooled and included coastal cutthroat, rainbow, unidentified Pacific trout, and westslope cutthroat trout.

SF moved over 8 km downstream during fall where it remained throughout the remainder of the life of the tag transmission. The largest single movement during this study occurred in early winter where in one month a trout tagged in the Low MF moved downstream about 11 km and remained near Snoqualmie Falls throughout the life of the tag (approx. 10 months).

Five of the seven trout tagged in middle river sections made only local or very short intra-section movements. However, the two trout that moved greater distances did so during the peak spawn time period. Only two trout were tagged in an upper river section (Up SF). One trout made only local movements and the other moved a long distance downstream to the middle section (inter-section movement). The farther moving trout was not detected for a two month period (December 15 to March 23) so movement possibly took place during the spawning period. However, because of the long distance moved (>4 km) and the number of migratory barriers between the start and end point, we assumed that this trout was probably a mortality and that the fish or tag had drifted downstream passively during a flood in January 2009.

Because of relatively low sample size, it is difficult to draw clear conclusions about movement patterns of the trout population from this effort. It appeared that trout in the more isolated upper and middle river sections moved less frequently and of lesser magnitude than those in the lower river sections and the Mainstem Snoqualmie. This observation is logical as trout that do not move downstream of barriers would be selected for in isolated reaches since trout that move out would take their genetic propensity to move with them when they leave. The movement data synthesized for this study provided some interesting 'what if' scenarios that might help produce hypotheses related to restricted or non-restricted movement by resident trout (e.g., Kocik and Ferreri 1998). However, an improved study design would include a more concise set of movement questions and a smaller more localized or clearly defined population of interest.

Trout reproductive life history

Spawning distribution encompassed both main-stem channel and tributary habitats. Only one redd was found in main-stem channels of middle river sections, and upper river sections were not surveyed for spawning activity. The Low NF and Low SF both contained an abundance of spawning habitat in the form of unembedded gravel bars, and we detected unexpectedly high numbers of trout redds given the relatively small area surveyed. The Mid MF and Low MF lacked large areas of clean gravel substrates, and detection of redds was difficult because turbidity prohibited spawn surveys throughout much of the season. However, we found high numbers of trout redds in tributaries to the Low MF and more modest numbers in tributaries to the Mid MF. Although we only found modest numbers in tributaries to the Mid MF, there is more tributary and off-channel habitat in the Mid MF compared to the Low MF. Therefore, additional spawning surveys that focus in the Mid MF would benefit our understanding of the amount and extent of spawning habitat in that river section. Due to the exploratory nature of these surveys, it is difficult to draw clear conclusions regarding the abundance or lack thereof of spawning habitat in the USRW. What is apparent however, is that trout populations will benefit from an increased diversity of available spawning habitat.

The availability of a diverse suite of spawning habitats accommodates variation in reproductive life histories for trout. For example, if main-stem channels are limited in spawning habitat and nearby tributaries have adequate spawning habitat, spawning by main-stem trout would be limited by access to these tributaries and the amount of the spawning habitat in them. Conversely, an abundance of main-stem channel spawning habitat would lessen the spatial limits on spawning, and spawning density might be lower in tributaries, especially if interconnectivity and spawning habitat are marginal. Neither scenario was statistically assessed during this study, but we did observe substantial numbers of trout redds in habitat-abundant tributaries that flow into habitat-limited main-stem channels, and we tracked an adult trout that moved during peak spawn from a habitat-limited main-stem reach into a habitat-abundant tributary. We also observed high numbers of trout redds in habitat-abundant tributaries that flow into habitat-abundant main-stem channels, but no trout in habitat-abundant main-stems were tracked moving into habitat-abundant tributaries. However, trout in habitat-abundant main-stem channels did move great distances within main-stems during peak spawn, which suggests a high degree of site fidelity. Because we tracked tagged trout every two weeks it is possible that these trout did move into tributaries to spawn, but these movements were undetected. Regardless, for the trout populations in the USRW access to both tributary and main-stem channel spawning habitats can encourage a more diverse compilation of life histories, which is associated with more robust populations.

Geomorphology and spawn timing can influence use of spawning habitat and reproductive life history and behavior (Montgomery et al. 1998a). Small trout are limited to building shallow redds with small substrates, and in tributaries with the most spawning activity, dominant and subdominant substrates were small and medium gravels. Shallow redds are less vulnerable to scour if located in low-gradient tributaries, which are often buffered from seasonal high flow events (Montgomery et al. 1998a). The minimum size at sexual maturity and ripeness was 135 mm for males (Up SF) and 175 mm for females (Tate Creek, Low NF), and the most abundant size categories we observed in main-stems was small to medium adults. We did not observe trout larger than 300 mm spawning in tributaries; however, a lack of observations does not preclude the possibility of large adult presence in tributaries during spawning. Regardless, it appeared that most of the spawning activity in the densest tributaries was attributable to small and medium adults.

Most main-stem channel habitats in the middle and lower North and South forks contained an abundance of gravel. Theoretically, only larger trout would be capable of building deeper redds with larger substrates such as these, and redds built by larger trout would be more robust against scour associated with high flows during spring run-off. While we only detected one redd in the Mid MF and Low MF, these two river sections contain enough gravel in small patches to provide ample spawning habitat for a moderate number of large spawning trout. However, access to tributaries with abundant spawning habitat probably provides the best opportunities for the greatest number of individuals to spawn at least once in their lifetime, while main-stem channel habitat availability provides opportunities for the larger, more fecund individuals to spawn.

The USRW contains a wealth of easily attainable information on the reproductive behavior of resident trout in drainages of the western slopes of the Cascade Mountains. We identified locations that could be surveyed by fishery managers to monitor or identify trends in the reproductive behavior of spawning resident trout. Survey sites used in this study could be used as spawning index sites, for example Clough Creek, Roaring Creek, the Low NF, and the Low SF. It would also be beneficial to identify spawning activity in middle and upper river sections, as our surveys were limited mainly to the lower portions of the watershed. The identification of potential spawning and rearing habitat is the first step toward implementation of effective habitat enhancement, as current or potential degradation can be addressed, and protective measures can be proactively implemented in these critical habitats.

7. Angler Use

Methods

An off-site volunteer creel survey (Anderson and Thompson 1991, Pollock et al. 1994) was conducted in the USRW beginning in September 2008 and continued through December 2010. Creel survey boxes were installed at 36 access points throughout the USRW (Figure 74), and sites were selected based on proximity to parking, public use facilities, and river access on municipal, county, state, U.S. Forest Service, and private timber lands. Large signs were placed above some of the less-conspicuous boxes, and WDFW logos were placed on each box to advertise the survey (Figure 75). Creel survey questionnaires were kept in waterproof dispensers, and a notice on the creel box instructed anglers to insert completed catch cards into the box.

Angler trip and demographic information was requested on the front of the catch card including date fished, start and end time, total hours fished, location fished, number of cutthroat, rainbow, brook, other trout, and mountain whitefish >10″ or <10″ caught and released, length of retained fish, angling gear, gender, age, and residence. Instructions, definitions of abbreviations, and a space for comments and contact information were provided on the back of the catch card (Figure 76). During the low angler use period (November–April), completed catch cards were collected and boxes were restocked once a month. During the high angler use period (May–October), cards were retrieved and restocked every two weeks. Between creel box checks, some catch card dispensers were emptied of cards

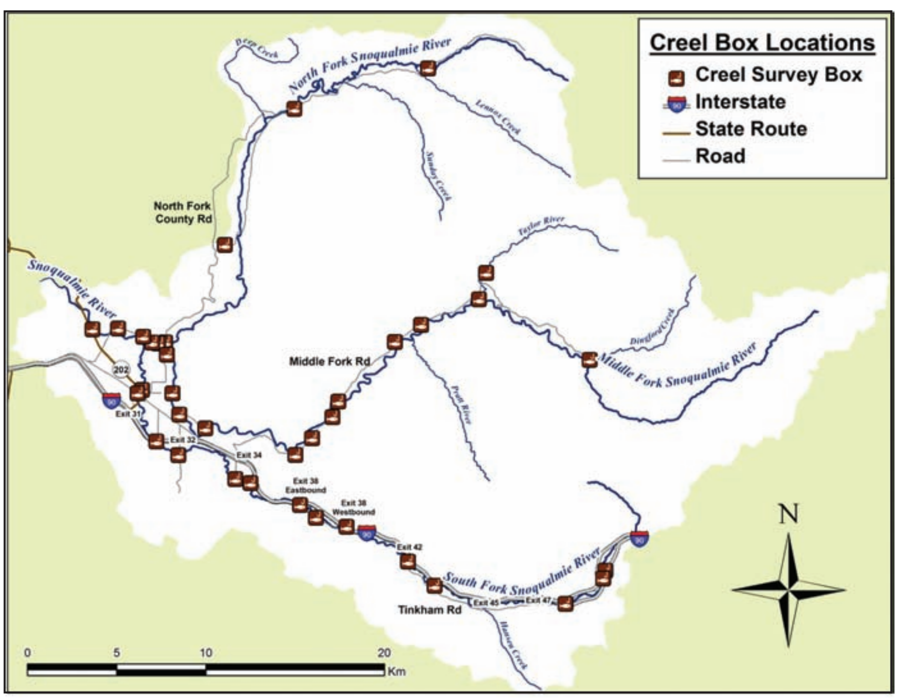
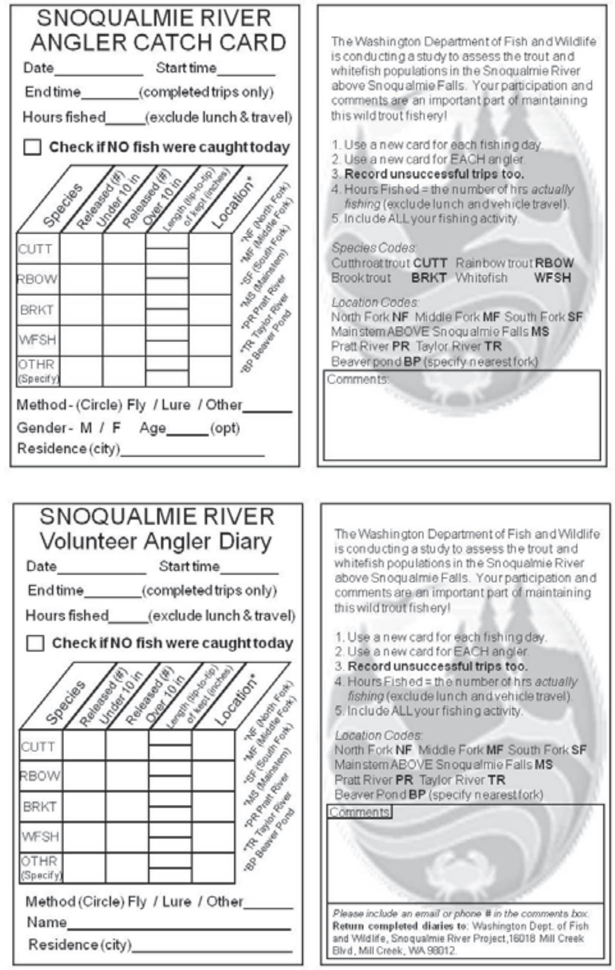


Figure 74. Locations of creel survey boxes throughout the upper Snoqualmie River watershed. Boxes were installed between September 2008 and June 2009.

Figure 75. Volunteer creel survey box installed in the Mt. Teneriffe segment of the Low MF on the Middle Fork Road.



SNOQUALMIE RIVER
ANGLER CATCH CARD

Date________ Start time________
End time________(completed trips only)
Hours fished_____(exclude lunch & travel)
☐ **Check if NO fish were caught today**

Species	Released (#) Under 10 in	Released (#) Over 10 in	Length (tip-to-tip) of kept (inches)	Location*
CUTT				
RBOW				
BRKT				
WFSH				
OTHR (Specify)				

*NF (North Fork) *MF (Middle Fork) *SF (South Fork) *MS (Mainstem) *PR Pratt River *TR Taylor River *BP Beaver Pond

Method - (Circle) Fly / Lure / Other______
Gender - M / F Age_____(opt)
Residence (city)______________

The Washington Department of Fish and Wildlife is conducting a study to assess the trout and whitefish populations in the Snoqualmie River above Snoqualmie Falls. Your participation and comments are an important part of maintaining this wild trout fishery!

1. Use a new card for each fishing day.
2. Use a new card for EACH angler.
3. **Record unsuccessful trips too.**
4. Hours Fished = the number of hrs *actually fishing* (exclude lunch and vehicle travel).
5. Include ALL your fishing activity.

Species Codes:
Cutthroat trout **CUTT** Rainbow trout **RBOW**
Brook trout **BRKT** Whitefish **WFSH**

Location Codes:
North Fork **NF** Middle Fork **MF** South Fork **SF**
Mainstem ABOVE Snoqualmie Falls **MS**
Pratt River **PR** Taylor River **TR**
Beaver pond **BP** (specify nearest fork)

Comments:

SNOQUALMIE RIVER
Volunteer Angler Diary

Date________ Start time________
End time________(completed trips only)
Hours fished_____(exclude lunch & travel)
☐ **Check if NO fish were caught today**

Species	Released (#) Under 10 in	Released (#) Over 10 in	Length (tip-to-tip) of kept (inches)	Location*
CUTT				
RBOW				
BRKT				
WFSH				
OTHR (Specify)				

*NF (North Fork) *MF (Middle Fork) *SF (South Fork) *MS (Mainstem) *PR Pratt River *TR Taylor River *BP Beaver Pond

Method (Circle) Fly / Lure / Other______
Name______________
Residence (city)______________

The Washington Department of Fish and Wildlife is conducting a study to assess the trout and whitefish populations in the Snoqualmie River above Snoqualmie Falls. Your participation and comments are an important part of maintaining this wild trout fishery!

1. Use a new card for each fishing day.
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5. Include ALL your fishing activity.

Location Codes:
North Fork **NF** Middle Fork **MF** South Fork **SF**
Mainstem ABOVE Snoqualmie Falls **MS**
Pratt River **PR** Taylor River **TR**
Beaver Pond **BP** (specify nearest fork)

Comments

Please include an email or phone # in the comments box.
Return completed diaries to: Washington Dept. of Fish and Wildlife, Snoqualmie River Project,16018 Mill Creek Blvd, Mill Creek, WA 98012.

Figure 76. Angler catch card (top) and volunteer angler diary card (bottom).

and remained empty for non-quantified amounts of time. During creel box checks, each properly completed card was labeled with the date of retrieval and the creel box location from where it was collected.

Volunteer angler diary cards were used to assess fishery use by more specialized anglers (i.e., regular upper Snoqualmie anglers) and were distributed to 12 businesses in the Puget Sound region, including sporting goods, tackle, and fly shops. Diaries were circulated in packets of ten and made available to anglers through self-serve countertop displays, through fly fishing clubs, and were sent to individuals who requested them. A downloadable version of the diary was posted on a popular local fly fishing website (*www.washingtonflyfishing.com*).

Data analysis

Due to the high amount of sampling bias inherent to off-site voluntary survey methods (see Pollock et al. 1994), data were not used to produce precise estimates of effort or harvest. Instead, data were used to calculate mean effort and catch for each river segment, and those values were plotted to show how they varied spatially and temporally. Catch was calculated as catch-per-unit-of-effort (CPUE, number of fish caught per hour), and catch rates from this study were compared with catch rates from historic USRW creel studies to examine long-term trends in catch rates. Also, because project staff used angling to sample larger trout, catch rates for staff were compared with creel survey participant catch rates for both large and small trout.

We also explored how increases in the number of fish caught and released could affect trout abundance given the observed proportional differences in the number of trout caught and released among river segments (i.e., spatial effect of angler catch rates). Catch-and-release hooking mortality rates from similar fisheries (Schill et al. 1986, Pauley and Thomas 1993) were incorporated with creel survey participant catch and release data. The number of trout reportedly caught and released from each river section was multiplied by the mortality rate to estimate the number of fish lost to catch and release hooking mortality. The number of fish lost to hooking mortality was then subtracted from trout abundance estimates for each river section, the difference resulting in the number of fish that were either never caught or that survived being caught and released. The number of trout reportedly caught in each river section was then increased by factors of 1, 5, 10 and 50 to explore the spatial effect of incremental increases in catch and release on the abundance of trout in the USRW.

Results

Volunteer participation rates

The Mid SF, Low NF and Low MF contained the highest rates of participation per creel box (number of survey cards fully completed and returned to boxes). Only one box was installed in the Low NF river section, but use was high as it was located at the only direct public access point for the Low NF (Table 22). The greatest reported monthly effort occurred in the Mid SF during July and August followed by the Low MF in August. The Mid SF and Low MF also experienced the overall greatest fishing pressure throughout the study. The lowest overall reported effort occurred in the Up NF, Up MF, and Low MN (Table 23). There was no road access to the Up NF between January 2009 and June 2010, and in the Up MF from January 2009 to the end of the study. Mean trip length for all river sections pooled was 2.5 hours. Combining the number of completed catch and diary cards with an arbitrary value of $40.00 per trip the annual value of the fishery was estimated at $17,373.

Angler demographics and catch rates

The majority of participating anglers were male; however, female participation increased in the Low MN, Up MF and Up SF. Most anglers were residents of non-local towns and cities (local: Snoqualmie Valley) followed by residents of Seattle and local residents of the Snoqualmie Valley from Fall City to North Bend. Out-of-state anglers participated in all river sections but the Low MN, Up MF, and Up NF; however, access by all anglers was limited in the Up NF and Up MF. Local participants comprised the majority of creel survey participants in the Up MN and Low MN and decreased as a function of distance upstream in each fork (Figure 77). Overall, a majority of creel survey participants used artificial flies distantly followed by lures or a combination of the two methods. However, anglers in the Low MN used lures more frequently than flies. Some creel survey participants reported the use of bait, so conservative non-

Table 22. Creel survey box installation distribution and participation statistics at creel boxes among river sections. *Completed diaries contained information on the location that was fished (i.e., river section) and were returned via creel boxes, fly shops, and postal mail.

River Section	Number of creel boxes	Completed catch cards	*Completed diaries	Mean number of completed surveys per box
Up NF	1	5	0	5
Mid NF	2	32	0	16
Low NF	1	51	0	51
Up MF	1	9	0	9
Mid MF	4	144	1	36
Low MF	7	328	8	48
Up SF	3	51	5	19
Mid SF	5	317	19	67
Low SF	6	239	14	42
Up MN	4	64	2	17
Low MN	2	14	0	7
Totals	**36**	**1,254**	**49**	

Table 23. Total effort (hours fished per month) reported by anglers in river sections between September 2008 and December 2010.

River Section	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Total
Up NF	0	0	0	0	0	0	2	22	0	0	0	0	**24**
Mid NF	0	0	2	3	3	8	50	11	7	4	0	0	**87**
Low NF	0	0	2	1	0	13	38	24	16	30	0	0	**124**
Up MF	0	0	0	0	0	0	0	0	25	0	0	0	**25**
Mid MF	0	0	9	4	16	37	130	167	58	7	6	0	**434**
Low MF	0	19	16	13	32	84	158	267	138	87	5	5	**823**
Up SF	0	0	0	0	0	21	15	77	5	1	0	0	**117**
Mid SF	0	2	3	12	25	82	328	275	88	40	2	0	**856**
Low SF	2	5	13	30	41	87	182	84	51	32	1	7	**536**
Up MN	0	0	3	2	17	8	48	28	15	11	0	0	**130**
Low MN	0	0	10	0	0	0	14	5	9	3	0	0	**41**
Total	**2**	**26**	**57**	**64**	**133**	**339**	**966**	**960**	**410**	**214**	**13**	**12**	**3,196**

compliance rates were calculated for each river section (Figure 78). The highest rates of admitted non-compliance occurred in the Up SF (12.7%), Mid NF (10.3%), and Low MN (8.3%), whereas non-compliance rates in the Low MF, Low SF and Mid SF fell below 1%. Bob Pfeifer, personal communication, implied that non-compliance was historically prevalent, potentially skewing the abundance and size structure of trout in the USRW. A complementary creel survey targeted at all anglers is needed to estimate the current number of trout caught, released, harvested, and the frequency of non-compliance in the USRW.

Catch rates increased dramatically during summer months, but variability in success was high among anglers. The anomalous peak in CPUE for January reflected only two catch cards, one of which reported two trout being caught in one hour, whereas the other angler caught no fish (Figure 79). Cutthroat trout were the most frequently reported species of trout caught by creel survey participants followed closely by rainbows (Table 24).

In the North Fork, most angling effort was distributed in the highly accessible Three Forks and Big Creek Falls segments, and catch rates for trout <10" were relatively high in the Illinois Creek segment of the Up NF and the Black Canyon segment of the Low NF. Trout >10" were more frequently caught in the Three Forks and Illinois Creek segments of the North Fork (Figure 80). Again, creel results in the Mid NF and Up NF were probably affected by road closures that severely limited access to these river sections during a majority of the duration of the survey.

In the Middle Fork, the easily accessed Mt. Teneriffe and Pratt segments received the most effort, and the lowest catch rates were also reported in these two segments. Catch rates increased in segments where access was difficult, and the highest catch rates for large trout occurred in the North Bend and Sallal Prairie segments (Figure 81). Again, creel results in the upper portions of the Mid MF and all of the Up MF were probably affected by road closures that severely limited access to these river sections during a majority of the duration of the survey.

The South Fork experienced the most consistent and evenly distributed angler effort among the forks. The Three Forks segment of the South Fork was not well represented in the creel survey because there is a lack of public access in this segment. Catch-per-unit-effort was relatively stable at between one and two trout <10" per hour except in the Commonwealth segment, where anglers reported catching over five trout <10" and 0.75 trout >10" per hour (Figure 82).

Effort reported for the Low MN was low especially in the mostly inaccessible (except by boat) Kimball segment. Regardless, catch rates were higher for both size classes of trout in the Kimball segment compared to the more easily accessible and more intensely fished Three Forks segment (Figure 83).

Historical catch rate data compiled by Pfeifer (1985) were compared with the current study to assess inter-decadal angler catch rate trends. Catch rates in the North Fork improved only slightly between 1984 and 2010, but

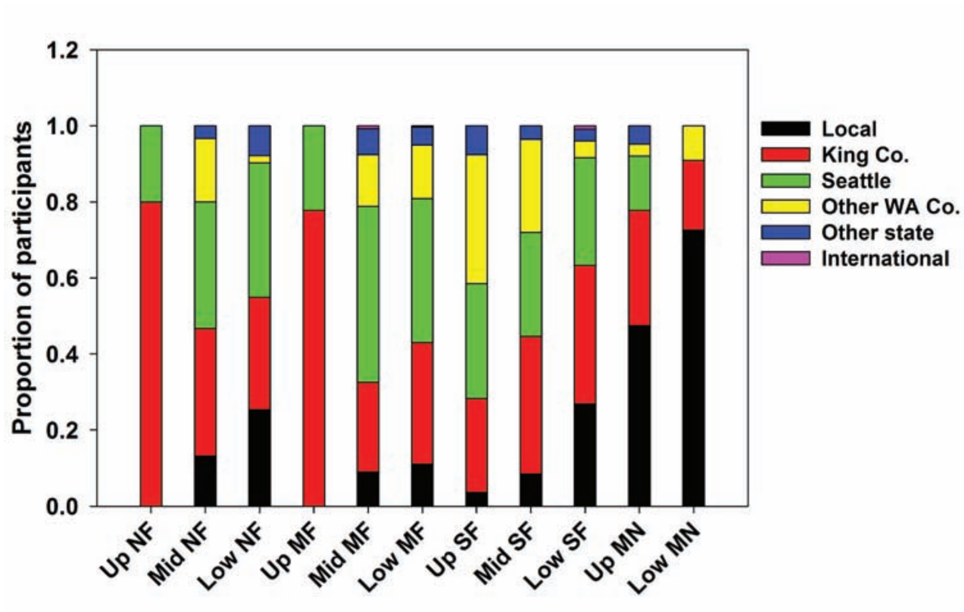

Figure 77. Residence composition of creel survey participants among river sections.

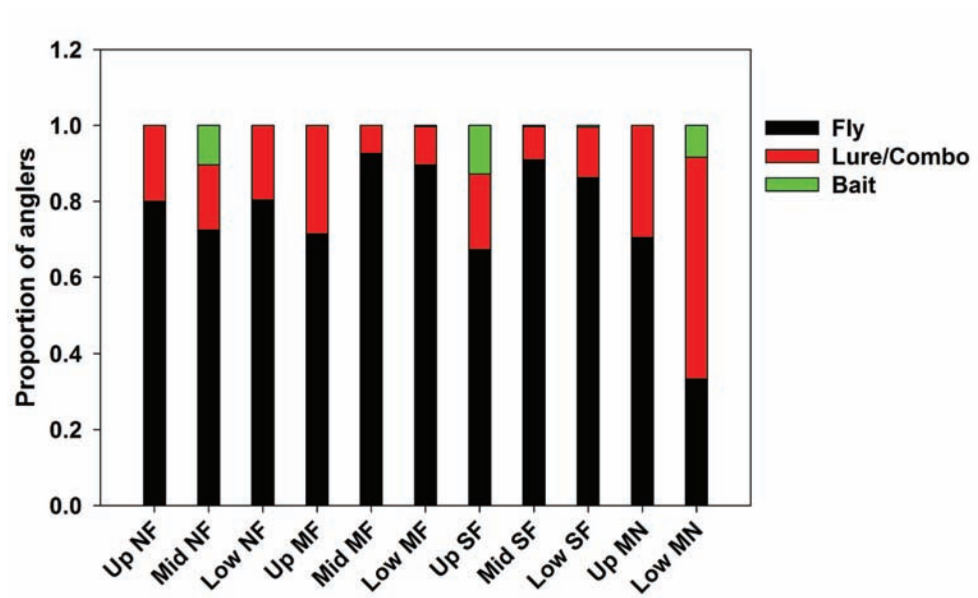

Figure 78. Method of angling used by creel survey participants among river sections.

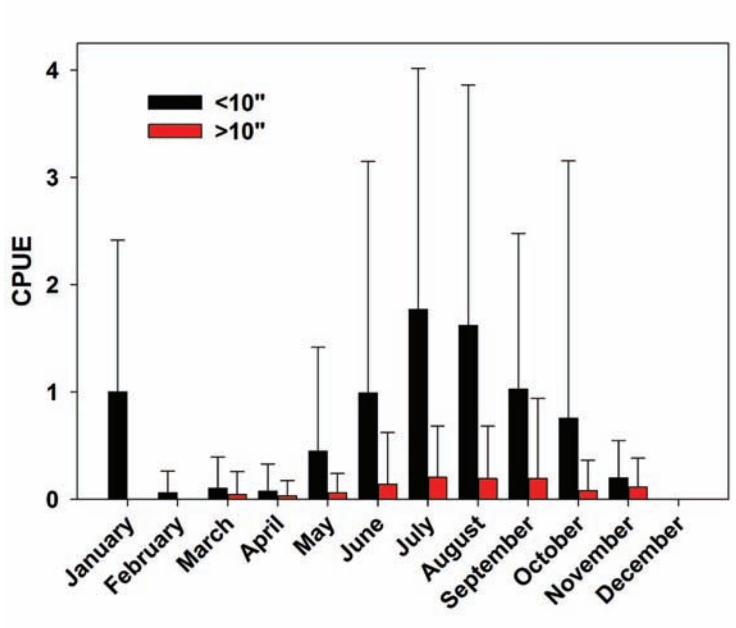

Figure 79. Mean (±SD) monthly CPUE for large (>10") and small (<10") trout as reported by volunteer creel survey participants between September 2008 and December 2010.

Table 24. Catch composition as reported by creel survey participants among river sections.

River Section	Cutthroat	Rainbow	Brook	Unidentified	Whitefish
Up NF	43	0	12	0	0
Mid NF	8	66	6	0	0
Low NF	116	31	2	0	0
Up MF	28	0	0	0	0
Mid MF	362	147	8	30	1
Low MF	563	321	17	6	12
Up SF	192	54	16	0	0
Mid SF	496	872	242	64	5
Low SF	403	348	22	9	2
Up MN	97	43	9	0	0
Low MN	16	14	0	0	0
Total	**2,324**	**1,896**	**334**	**109**	**20**

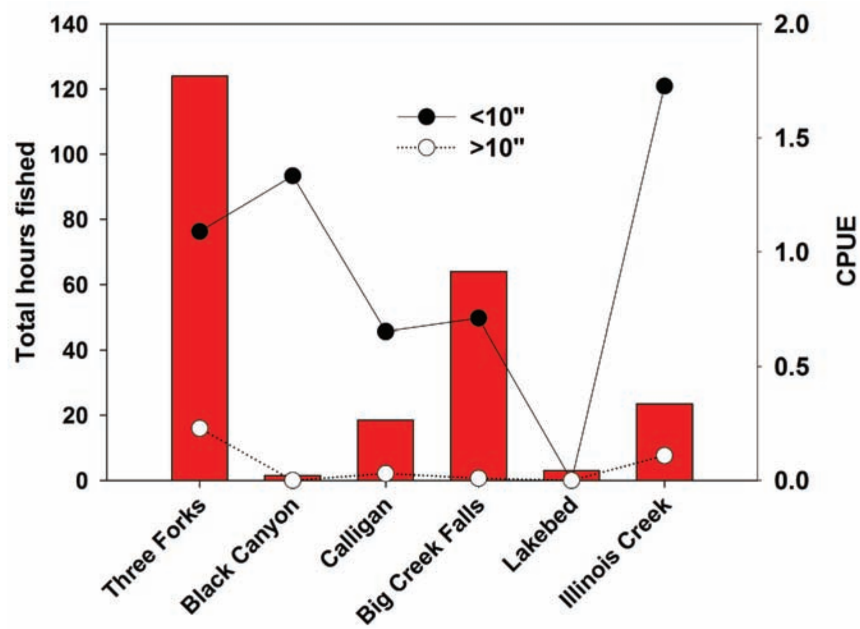

Figure 80. Effort (bars) and catch rates (solid and hollow circles) for creel survey participants among river segments in the North Fork Snoqualmie River.

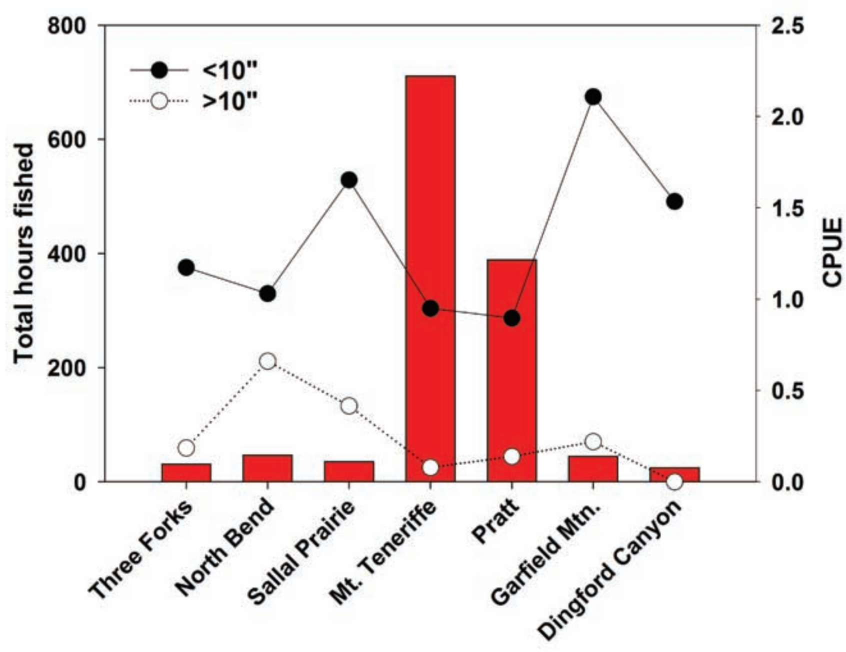

Figure 81. Effort (bars) and catch rates (solid and hollow circles) for creel survey participants among river segments in the Middle Fork Snoqualmie River.

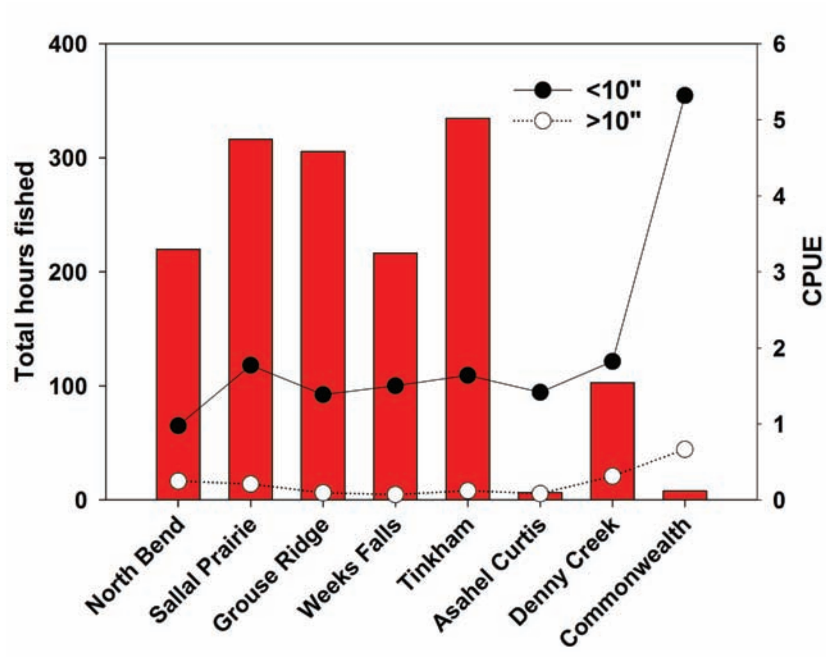

Figure 82. Effort (bars) and catch rates (solid and hollow circles) for creel survey participants among river segments in the South Fork Snoqualmie River.

increased by nearly 1 fish per hour in the South Fork and nearly 1.5 fish per hour in the Middle Fork (Figure 84). Different creel survey methods were used for most surveys so comparisons should be made cautiously. While all angling methods were available to project staff, most large trout were caught on unscented artificial lures or flies. Biologist catch rates for trout >10" were substantially higher than creel survey participant catch rates for the same size group in most river sections (Figure 85).

Hooking mortality scenarios

For hooking mortality scenarios, a 10% mortality rate was chosen because it was intermediate between the reported high of 16% (Pauley and Thomas 1993) and the reported low of 3% (Schill et al. 1986). Most trout populations in the USRW remained robust under all but the most drastic increases in angler catch. Deficits in trout abundance (i.e., all fish died from catch and release mortality) were not reached until catch increased to a rate of 50:1, and were only experienced for trout <10" in the Low MF, Mid SF, and Up MN, and Low MN. For trout >10" the only deficits in trout occurred when catch increased to 50:1 in the Up SF and Mid SF. Larger trout were reportedly not caught in high numbers, which helped to buffer the less-populated large trout from catch and release mortality, even when catch increased by 20:1 in other river sections (Table 25). While unlikely to reach even a tenfold increase in catch in the near future, the Mid SF's proximity to Interstate 90 and ease of access might suggest that an increase in use is highly likely over time. Due to the combination of seasonally high angler use and the low abundance of trout calculated in abundance estimates, trout in the Mid SF would appear to be the most sensitive to increases in mortality caused by fishing pressure.

Conclusions

Volunteer creel surveys are the least labor intensive and the most cost effective method of gathering large amounts of demographic and catch data useful for comparing fishery performance trends over time (Pollock et al. 1994). Anglers are enabled to participate in resource management by assisting in the monitoring of a fishery, and completed volunteer surveys may be more accurate than other methods (Mosindy and Duffy 2007). Volunteer creel data were found to be comparable in accuracy to data obtained by roving creel surveys on Great Bear Lake at a fraction of the cost (Anderson and Thompson, 1991). However, cost effectiveness comes at the expense of highly biased and uncalibrated estimators (Pollock et al. 1994). For example, anglers may exaggerate their catch, may not understand questions on the survey, may fail to fill out a survey, misidentify fish species, and misreport lengths (Pollock et al. 1994). Also, we noted that many catch cards were removed and were never returned. Furthermore, because of logisti-

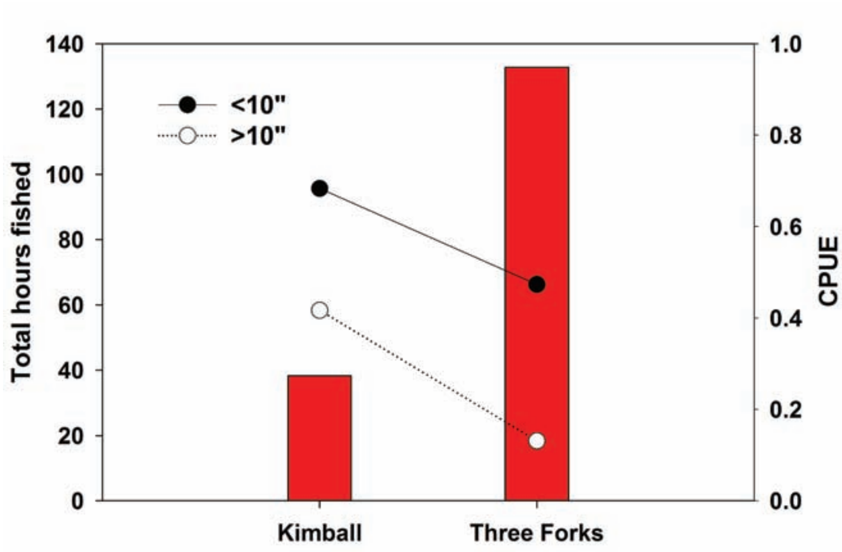

Figure 83. Effort (bars) and catch rates (solid and hollow circles) for creel survey participants among river segments in the Mainstem Snoqualmie River.

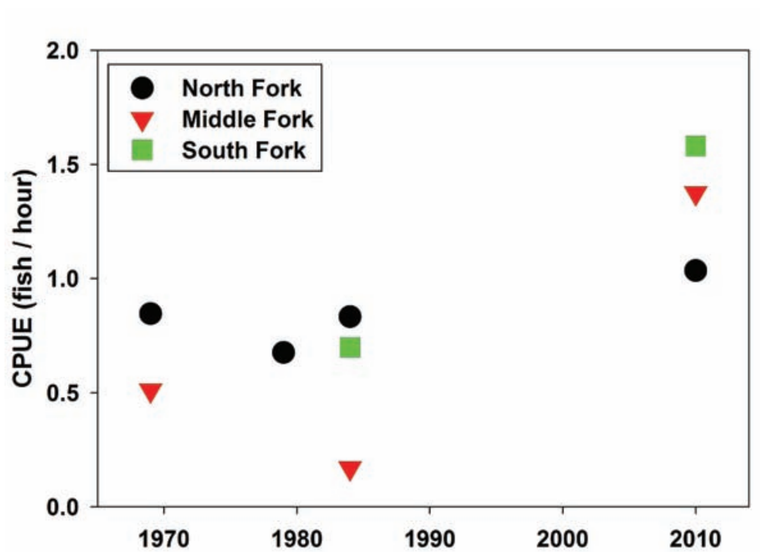

Figure 84. Comparison of angler catch rates in the North, Middle, and South forks of the Snoqualmie River from years 1969, 1979, 1984, and 2010 (average of 2008 and 2010). Different survey methods were used between the years so extrapolation should be made with caution.

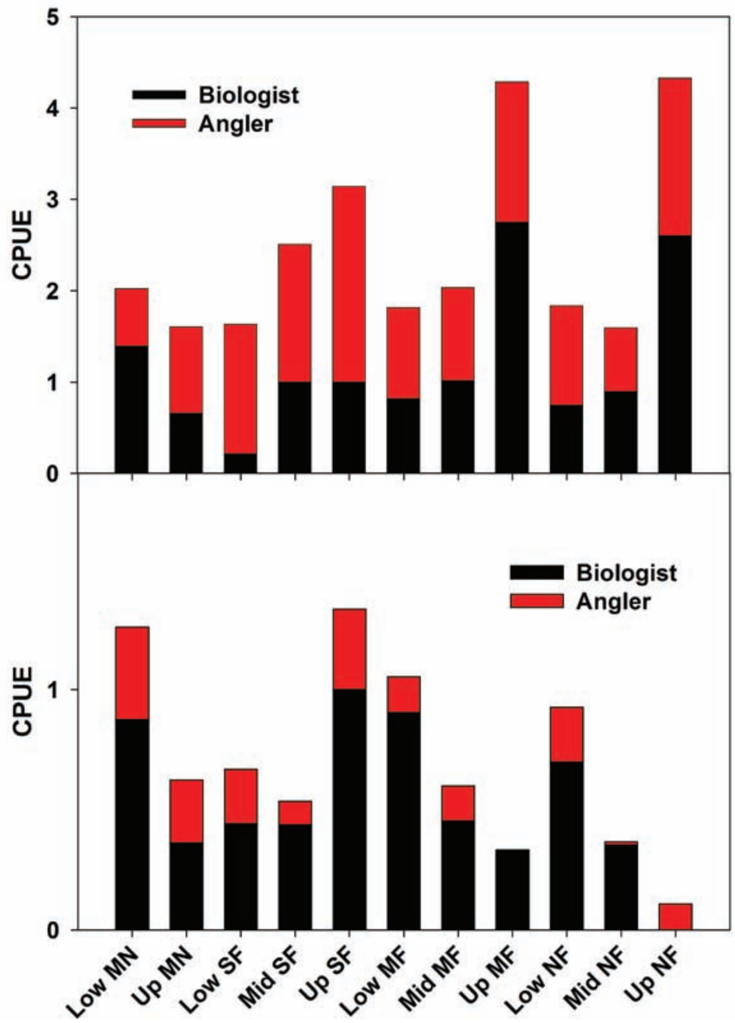

Figure 85. Catch rate comparisons between biologist anglers and creel survey participant anglers for trout <10" (top) and trout >10" (bottom).

cal constraints placed on checking creel boxes daily, catch card dispensers were empty for extended periods, which probably diminished the potential for maximum angler participation. Secondary calibration creel surveys that use random sampling of the angling population (e.g., roving survey) should be conducted by professional fishery managers concurrent with a volunteer survey to produce more reliable estimates of the numbers of trout being caught, released, and harvested in the USRW. With careful consideration for its quantitative and statistical shortcomings the volunteer creel survey conducted for this study provided updated reference points for important aspects of the game fish fishery in the USRW.

Catch and release mortality scenarios revealed interesting "what if" scenarios that could be useful in a fishery like the USRW. Because of its close proximity to the Seattle metro area, the amount of angling pressure in the USRW might be expected to maintain or increase. For fishery managers, there is value in understanding if some parts of a fish population might be more vulnerable to increased fishing pressure. There are a number of factors influencing catch and release mortality rates, including gear type, water temperature, and stress on fish from being handled. Unfortunately, the conclusions of most mortality studies aren't always consistent on the effects of these factors. Wydoski (1980) found that trout caught on flies had a lower mortality rate than those caught on lures while Mongillo (1984) reported no difference. Klein (1965) and Dotson (1982) recorded increased mortalities with trout caught at higher water temperatures while Marnell and Hunsaker (1970) found no difference.

A more thorough development of assessing hooking

Table 25. Trout abundance estimates for small (**Sm**$_N$) and large (**Lg**$_N$) Onxx, and abundance of each size group after being exposed to increasing amounts of catch and release (CR) CR*1, CR*5, CR*10, and CR*50. Trout abundance deficits are highlighted in bold (deficit: trout population = 0).

River Section	Sm_N	CR*1	CR*5	CR*10	CR*50
Up NF	265	261	245	225	65
Mid NF	1,249	1,243	1,220	1,190	954
Low NF	936	929	900	863	571
Up MF	1,005	1,002	991	977	865
Mid MF	3,343	3,320	3,229	3,114	2,198
Low MF	2,620	2,548	2,261	1,902	**-970**
Up SF	803	790	736	668	128
Mid SF	2,906	2,828	2,516	2,125	**-999**
Low SF	3,822	3,785	3,635	3,448	1,952
Up MN	172	166	144	115	**-113**
Low MN	78	76	67	55	**-37**

River Section	Lg_N	CR*1	CR*5	CR*10	CR*50
Up NF	32	32	31	29	17
Mid NF	448	448	447	446	438
Low NF	270	269	266	261	225
Up MF	45	45	45	45	45
Mid MF	817	815	805	793	697
Low MF	2,269	2,259	2,218	2,166	1,754
Up SF	35	33	24	13	**-75**
Mid SF	213	207	183	152	**-92**
Low SF	1,183	1,176	1,150	1,117	853
Up MN	95	94	89	83	35
Low MN	64	64	62	59	39

mortality would incorporate natural mortality as well. If the correct mortality rates are applied and the volunteer survey is calibrated, more statistically concise catch and release mortality scenarios can help managers accurately identify locations in the watershed that may be more vulnerable to exploitation because the magnitude of the catch and release frequency effect is scaled to local trout abundance, size structure, natural mortality, seasonal use, and the number of trout being caught.

The USRW is an important fishery resource for King County anglers, who provided 80% of the total completed surveys. The population in King County has grown significantly since the last creel survey in the 1980s, and with the growing popularity of trout fishing we expect the amount of anglers fishing the USRW to increase. Given sparing resources the methods used to provide this baseline for angler use could be developed to monitor trends in the use of this and similar fisheries.

8. Habitat Enhancement and Public Outreach

Habitat enhancement and public outreach are not research tasks per se, but implementation of enhancement and outreach activities was initiated at the end of this project as an application of the information gathered during research tasks.

Habitat enhancement

Identification of habitat enhancement needs

Water typing. All water bodies in the State of Washington are designated as particular land management types by the WDNR—for example, fish bearing, non-fish bearing, or shorelines (WDNR Forest Practices water typing). Water type designations were created to inform landowners and managers about water, riparian, and forestry resources and to enable protective measures against potentially deleterious land use practices. Stream enhancement, restoration, and protection prioritizations are often based on water body type designations. For example, a portion of stream containing fish requires a wider riparian buffer relative to non-fish bearing portions, and fish need to be able to move upstream through road crossings such as culverts during various life stages (Kahler and Quinn 1998; Hoffman and Dunham 2007). Thus, fish-type streams that lack appropriate riparian cover or that contain perched culverts blocking migration are often targeted for restoration projects.

The WDNR interactive water-typing map was examined to identify mis-classified tributaries (typed as non-fish where fish probably occurred). The lower 400 m of three conspicuously mis-typed tributaries were surveyed to assess habitat conditions and fish species composition and size structure. Habitat and fish data were submitted to the WDFW water-type liaison to initiate the needed changes. In addition to being incorrectly typed as non-fish bearing, two of these tributaries were mis-mapped in the statewide WDNR GIS hydro layer. Incorrectly mapped streams can lead to inaccurate inventories of water type designations, which can influence land-use restrictions and the prioritization of restoration needs. More accurate maps were submitted to initiate an update of stream locations in the WDNR GIS hydro layer.

Critical habitat. Surveys of fish use in tributaries and mainstem channel habitats conducted under the Plan yielded information to assist public agencies, restoration organizations, and private landowners with prioritizing and implementing effective enhancement projects across the USRW. Watershed-scale ecological principles backed by intensive, standardized survey data led to the identification of acute habitat enhancement project sites and provided a baseline of biological and physical information for those charged with managing land and water resources in the USRW.

USRW habitat enhancement group

Habitat enhancement and restoration projects have been conducted in the USRW, but there are no groups that coordinate habitat information or monitor results of restoration projects. Important projects such as noxious weed removal/native re-planting (Walker 2006) and culvert replacements have been implemented, but biological response in these habitats remains unknown, and a consolidated inventory of such work apparently does not exist. Projects may not have been targeted at fish biology (Schrank and Rahel 2004), and the value of each project to the enhancement of the fishery or the aquatic habitat remains unknown. Thus scarce resources have probably been allocated to projects without scale to the watershed as a whole and of unknown consequence to fish biology (Whol et al. 2005; Hoffman and Dunham 2007; Dufour and Hervé 2009).

Resources from this project were allocated to collecting and analyzing baseline fishery resource information, which is the first step in identifying habitat enhancement needs (Whol et al. 2005; Budy and Schaller 2007; Schiff et al. 2010). To initiate a sustainable stewardship program, all habitat enhancement activities in the USRW should be adopted by a committee or group of stakeholders, including non-profit or local governmental agencies and angling businesses and organizations. These groups can use data obtained during the Plan field studies to improve or protect aquatic habitats where needed. Organizing restoration efforts in this manner would be the most cost-effective, progressive, and sustainable approach to addressing habitat enhancement needs in the USRW.

The formation of the USRW habitat enhancement committee was proposed to key individuals involved with governmental and non-profit habitat restoration and enhancement groups in the Snoqualmie River valley. This group would assume responsibility for furthering landowner relations, developing enhancement or restoration plans, obtaining funding for projects, and implementing and monitoring restoration projects at sites identified by Plan biologists or other agency personnel. Local businesses may become involved in habitat enhancement activities and would be a beneficial component to bridge the public-private gap in the USRW. Enhancement sites encompass all forms of land ownership from public (e.g., U.S. Forest Service) to commercial (e.g., Hancock Forest Management, Snoqualmie Forest) to homeowner. Because homeowner land is widespread throughout lower portions of the watershed, it will be imperative to educate and gain the trust and support of landowners toward building a healthier watershed. Furthermore, stewardship incentives should be made available for landowners if possible.

Public outreach and education

Starting in the mid 1990's urban growth areas in the USRW experienced tremendous growth in both residential population and development. Inherent to this growth has been an influx in the diversity of the socioeconomic background of households in the USRW. Public services and education have likewise experienced growth in the form of increased development of public utilities and public schools. The combination of increased diversity, public facilities, and resource usage has created an environment that is ripe for increasing public awareness of the potential value of the wild game fish resources in the USRW. On a larger scale, economic and recreational opportunities in part drive the continued population increase in the Puget Sound area as a whole. Coincidentally, demand for regional recreational opportunities should increase and drive up the potential monetary returns on a local scale. To sustain the quality and value of the recreational resources in the USRW it is imperative to increase the public's understanding of the tangible value inherent to these resources.

Three steps were taken to improve awareness and the quality of the game fish resources in the USRW. First, kiosk signage was installed at strategic locations intended to artistically educate resource users about the importance of preserving healthy, natural aquatic resources. Second, existing fishery regulation signage was restored and new fishery signage was installed at creel box installation sites. Signage was targeted toward fishery users to inform them of river section delineations and gear restrictions among river sections. Signage also demonstrates a pervasive interest and involvement in the fishery by WDFW, PSE, and other potential partners. Thirdly, funds that were not spent on research tasks were set aside for contribution to habitat restoration in the USRW. Priority habitat restoration actions (replacement of culverts, placement of LWD, channel restoration, etc.) were listed throughout this document to guide restoration groups toward implementing the most effectual restoration projects.

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10. Glossary

Acronyms

FERC	Federal Energy Regulatory Commission
LWD	large wooody debris
PSE	Puget Sound Energy
USFS	United States Forest Service
USRW	Upper Snoqualmie River Watershed
WDFW	Washington Department of Fish and Wildlife
WDNR	Washington Department of Natural Resources
WSDOT	Washington State Department of Transportation

Abbreviations

Coastal cutthroat trout	CCT or *O. clarki*
Rainbow trout	RBT or *O. mykiss*
Westslope cutthroat trout	WCT or *O. clarki lewisi*
Unidentified or hybrid Pacific trout species	Onxx
Eastern brook trout	EBT
Mountain whitefish	MWF
Largescale sucker	SUCKER
Upper North Fork	Up NF
Middle North Fork	Mid NF
Lower North Fork	Low NF
Upper Middle Fork	Up MF
Middle Middle Fork	Mid MF
Lower Middle Fork	Low MF
Upper South Fork	Up SF
Middle South Fork	Mid SF
Lower South Fork	Low SF
Upper Mainstem	Up MN
Lower Mainstem	Low MN

11. Appendices

Appendix Table 1. Mean (±1SE) wetted width (m) by river section and habitat type for the total survey range in each river section. Data were collected during extensive habitat surveys (n/a = no habitat).

River Section	All units	Pools	Riffles	Glides	Cascades
Up NF	10.16 ± 0.08	9.67 ± 0.45	8.65 ± 0.44	10.36 ± 0.37	11.03 ± 0.19
Mid NF	15.88 ± 0.02	15.17 ± 0.07	16.17 ± 0.03	16.10 ± 0.05	13.92 ± 0.32
Low NF	15.39 ± 0.04	16.37 ± 0.44	15.71 ± 0.08	15.17 ± 0.10	9.91 ± 0.73
Up MF	10.97 ± 0.03	9.51 ± 0.14	11.65 ± 0.06	10.67 ± 0.11	10.17 ± 0.25
Mid MF	24.68 ± 0.02	25.63 ± 0.08	25.47 ± 0.04	22.25 ± 0.08	23.39 ± 0.54
Low MF	37.86 ± 0.03	33.47 ± 0.15	40.67 ± 0.07	36.25 ± 0.12	33.17 ± 0.64
Up SF	8.52 ± 0.02	7.31 ± 0.05	9.80 ± 0.05	10.24 ± 0.32	5.77 ± 0.08
Mid SF	12.58 ± 0.02	12.39 ± 0.07	11.88 ± 0.04	15.22 ± 0.06	4.97 ± 0.12
Low SF	19.04 ± 0.02	19.20 ± 0.13	17.16 ± 0.04	20.36 ± 0.03	9.14 ± 0.00
Up MN	32.95 ± 0.24	37.51 ± 0.54	26.67 ± 0.55	38.10 ± 0.20	n/a
Low MN	39.19 ± 0.38	49.70 ± 0.51	22.39 ± 0.41	42.86 ± 1.52	n/a
Total	20.48 ± 0.00	20.34 ± 0.02	21.23 ± 0.01	20.75 ± 0.01	13.53 ± 0.07

Appendix Table 2. Mean (±1SE) active width (m) by river section and habitat type for the total survey range in each river section. Data were collected during extensive habitat surveys (n/a = no habitat).

River Section	All units	Pools	Riffles	Glides	Cascades
Up NF	23.02 ± 0.13	20.68 ± 1.09	25.22 ± 0.59	27.28 ± 0.55	20.61 ± 0.23
Mid NF	29.06 ± 0.02	26.67 ± 0.08	29.56 ± 0.04	29.89 ± 0.07	26.88 ± 0.40
Low NF	30.58 ± 0.09	29.72 ± 0.58	31.33 ± 0.17	30.84 ± 0.30	20.42 ± 1.93
Up MF	71.89 ± 0.39	80.72 ± 2.36	68.52 ± 0.68	84.90 ± 2.41	50.56 ± 2.88
Mid MF	47.44 ± 0.04	45.50 ± 0.11	49.40 ± 0.10	44.87 ± 0.20	48.83 ± 0.96
Low MF	62.38 ± 0.06	54.77 ± 0.26	63.84 ± 0.13	64.10 ± 0.22	64.95 ± 1.40
Up SF	11.90 ± 0.02	10.14 ± 0.06	14.14 ± 0.05	12.13 ± 0.15	9.10 ± 0.11
Mid SF	30.28 ± 0.05	31.62 ± 0.24	31.55 ± 0.12	29.84 ± 0.12	17.89 ± 0.62
Low SF	31.00 ± 0.03	35.80 ± 0.28	30.30 ± 0.10	30.23 ± 0.05	25.91 ± 1.08
Up MN	87.07 ± 0.62	88.86 ± 2.03	74.30 ± 0.95	109.73 ± 0.41	n/a
Low MN	90.42 ± 0.58	83.14 ± 0.98	92.14 ± 1.45	104.01 ± 4.14	n/a
Total	40.49 ± 0.01	39.80 ± 0.05	42.57 ± 0.02	39.67 ± 0.03	30.40 ± 0.16

Appendix Table 3. Mean (±1SE) main stem depth (m) by river section and habitat type in habitat units that were snorkeled during extensive habitat surveys (n/a = no habitat or no units sampled for depth).

River Section	All units	Pools	Riffles	Glides	Cascades
Up NF	0.33 ± 0.002	0.37 ± 0.012	0.23 ± 0.022	0.32 ± 0.009	0.34 ± 0.004
Mid NF	0.57 ± 0.001	0.93 ± 0.005	0.40 ± 0.001	0.60 ± 0.002	0.30 ± 0.000
Low NF	0.69 ± 0.004	1.28 ± 0.007	0.49 ± 0.006	0.79 ± 0.009	0.30 ± 0.000
Up MF	0.57 ± 0.002	0.81 ± 0.008	0.44 ± 0.003	0.59 ± 0.005	n/a
Mid MF	0.84 ± 0.001	1.54 ± 0.006	0.50 ± 0.001	0.77 ± 0.003	n/a
Low MF	0.97 ± 0.002	1.90 ± 0.010	0.66 ± 0.001	0.91 ± 0.003	0.37 ± 0.100
Up SF	0.61 ± 0.003	0.79 ± 0.004	0.37 ± 0.002	0.75 ± 0.036	0.30 ± 0.009
Mid SF	0.55 ± 0.001	0.91 ± 0.008	0.39 ± 0.001	0.47 ± 0.002	n/a
Low SF	0.74 ± 0.001	1.24 ± 0.011	0.46 ± 0.001	0.79 ± 0.001	n/a
Up MN	1.11 ± 0.021	2.04 ± 0.039	0.57 ± 0.015	0.69 ± 0.010	n/a
Low MN	1.91 ± 0.035	2.87 ± 0.066	0.72 ± 0.015	1.50 ± 0.098	n/a
Total	0.74 ± 0.000	1.29 ± 0.001	0.49 ± 0.000	0.72 ± 0.000	0.33 ± 0.005

Appendix Table 4. Total snorkel survey counts of Onxx trout by length group (total length; mm) per habitat unit type in the upper Snoqualmie River watershed (nd = no units of this type were surveyed, n/a = no unit types within total survey range). The Onxx trout category used for snorkel surveys included coastal cutthroat, rainbow, unidentified Pacific, and hybrid Pacific trout.

	Pools					Riffles					Glides					Cascades					
River Section	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	Total Count
Up NF	11	31	4	0	0	1	1	0	0	0	0	0	0	0	0	64	157	28	0	0	297
Mid NF	61	226	117	30	10	139	555	170	37	8	106	162	53	17	5	0	0	1	0	0	1,697
Low NF	99	187	48	18	6	98	231	68	9	4	100	217	93	17	7	0	4	0	0	0	1,206
Up MF	119	237	18	1	0	75	168	8	1	0	142	263	15	2	0	nd	nd	nd	nd	nd	1,049
Mid MF	568	958	274	60	14	366	700	215	63	6	246	505	141	36	8	nd	nd	nd	nd	nd	4,160
Low MF	140	545	378	188	59	318	1052	647	323	83	124	419	334	191	50	7	15	12	2	0	4,887
Up SF	131	90	8	0	0	107	50	0	0	0	47	34	3	0	0	17	19	0	0	0	506
Mid SF	517	331	61	10	1	673	493	89	6	1	536	354	41	4	0	nd	nd	nd	nd	nd	3,117
Low SF	221	431	169	49	8	495	613	141	42	8	756	1306	610	130	26	nd	nd	nd	nd	nd	5,005
Up MN	35	72	45	22	6	31	25	14	5	0	3	6	2	1	0	n/a	n/a	n/a	n/a	n/a	267
Low MN	13	35	20	11	5	5	22	10	1	1	0	3	5	8	3	n/a	n/a	n/a	n/a	n/a	142

Appendix Table 5. Total snorkel survey counts of westslope cutthroat trout by length group (total length; mm) per habitat unit type in the upper Snoqualmie River watershed (nd = no units of this type were surveyed, n/a = no unit types within total survey range).

River Section	Pools					Riffles					Glides					Cascades					Total Count
	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	
Up NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mid NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Low NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Up MF	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	nd	nd	nd	nd	nd	1
Mid MF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	nd	nd	nd	nd	nd	0
Low MF	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	2
Up SF	64	93	16	0	0	31	37	2	0	0	25	52	5	0	0	0	6	1	0	0	332
Mid SF	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	nd	nd	nd	nd	nd	2
Low SF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	nd	nd	nd	nd	nd	0
Up MN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	n/a	n/a	n/a	0
Low MN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	n/a	n/a	n/a	0

Appendix Table 6. Total snorkel survey counts of brook trout by length group (total length; mm) per habitat unit type in the upper Snoqualmie River watershed (nd = no units of this type were surveyed, n/a = no unit types within total survey range).

	Pools					Riffles					Glides					Cascades					
River Section	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	100-149	150-229	230-299	300-379	380+	Total Count
Up NF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mid NF	6	4	1	1	0	3	1	1	0	0	8	5	1	2	0	0	0	0	0	0	33
Low NF	0	0	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	3
Up MF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	nd	nd	nd	nd	nd	0
Mid MF	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	nd	nd	nd	nd	nd	1
Low MF	0	0	1	0	0	1	2	0	0	0	0	1	1	0	0	0	0	0	0	0	6
Up SF	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Mid SF	89	43	19	1	0	31	32	12	2	0	61	24	8	0	0	nd	nd	nd	nd	nd	322
Low SF	1	0	0	0	0	0	3	2	1	0	1	6	1	0	0	nd	nd	nd	nd	nd	15
Up MN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	n/a	n/a	n/a	0
Low MN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	n/a	n/a	n/a	n/a	n/a	0

Appendix Table 7. Ratios of the total number of habitat units that were snorkeled versus the total number of habitat units (n_h/N_h) within the survey range in river sections of the upper Snoqualmie River watershed.

River Section	Pools	Riffles	Glides	Cascades
Up NF	6/6	4/10	9/9	4/7
Mid NF	56/56	143/163	94/94	1/21
Low NF	6/6	28/28	16/16	1/3
Up MF	26/26	54/89	31/31	0/17
Mid MF	55/55	132/176	63/63	0/23
Low MF	28/28	88/118	46/46	4/20
Up SF	41/41	46/84	27/29	10/39
Mid SF	54/54	84/131	74/75	0/23
Low SF	22/22	49/58	47/48	0/2
Up MN	4/4	5/5	2/2	0/0
Low MN	7/7	5/6	3/3	0/0

Appendix Table 8. The total surface area snorkeled (left) and not snorkeled (right) by habitat type within the total survey range in river sections of the upper Snoqualmie River watershed. Total surface area was calculated by combining surface area values calculated for each habitat unit within the total survey range. Surface area for individual habitat unit = mean width (m) * total length (m).

River Section	$A_{snorkeled}$ (m²)				$A_{not\ snorkeled}$ (m²)				Total area (m²)
	Pool	Riffle	Glide	Cascade	Pool	Riffle	Glide	Cascade	
Up NF	1,552	1,115	3,539	12,012	0	1,666	0	408	20,292
Mid NF	71,455	203,198	127,009	301	0	6,144	0	5,576	413,683
Low NF	5,646	34,949	25,542	293	0	0	0	649	67,079
Up MF	7,230	36,286	15,014	0	0	15,802	0	7,142	81,474
Mid MF	153,010	217,330	148,575	0	0	49,097	0	17,236	585,248
Low MF	114,207	299,999	218,807	8,950	0	62,458	0	24,471	728,893
Up SF	8,144	23,727	9,329	1,944	0	20,511	511	6,098	70,262
Mid SF	38,652	87,216	90,992	0	0	22,805	1,622	5,656	246,942
Low SF	29,016	84,863	163,522	0	0	3,035	0	1,061	281,497
Up MN	42,843	13,670	8,547	0	0	0	0	0	65,060
Low MN	168,178	12,616	28,415	0	0	1,234	0	0	210,443

Appendix Table 9. Log_e transformed trout abundance estimates. Fish counts from snorkel surveys were portioned into age groups based on age-length group probability matrices and then transformed (log_e) for use in linear catch curve regressions. Ages were estimated from scales and corroborated with otoliths.

River Section	Scale Age	CCT/Onxx	RBT
Up NF	2	5.0	-
	3	4.7	-
	4	2.8	-
	5	2.8	-
Mid NF	2	4.9	6.7
	3	3.7	6.2
	4	4.8	5.0
	5	3.7	3.7
	6	2.4	2.4
Low NF	1	5.3	
	2	4.4	5.5
	3	4.6	5.7
	4	3.6	5.1
	5	1.7	2.5
	6	1.7	1.7
Up MF	2	6.1	-
	3	6.2	-
	4	4.7	-
	5	2.2	-
Mid MF	2	7.6	-
	3	7.1	-
	4	5.8	-
	5	4.5	-
	6	3.6	-
Low MF	2	7.9	-
	3	7.7	-
	4	6.1	-
	5	5.9	-

Appendix Table 9 (continued).

River Section	Scale Age	CCT/Onxx	RBT	WCT	EBT
Up SF	2	5.4	-	5.7	-
	3	5.6	-	4.8	-
	4	4.6	-	4.8	-
Mid SF	1	-	6.9	-	5.3
	2	6.2	6.3	-	5.0
	3	5.9	6.0	-	2.7
	4	4.5	4.9	-	-
	5	-	3.5	-	-
Low SF	1	7.4			
	2	7.3	-	-	-
	3	6.6	-	-	-
	4	4.7	-	-	-
	5	2.7	-	-	-
Up MN	2	4.6	-	-	-
	3	4.4	-	-	-
	4	2.3	-	-	-
Low MN	2	4.3	-	-	-
	3	3.5	-	-	-
	4	3.5	-	-	-

Appendix Table 10. Mean seasonal gravimetric proportions of diet items among river sections for coastal cutthroat and undetermined Pacific trout species, rainbow trout, westslope cutthroat trout, eastern brook trout, sculpin species, and mountain whitefish (Dipt. = dipteral, Chiron. = chironomid, Trico. = tricoptera, Pleco. = plecoptera, Ephem. = ephemeroptera, Other Aq. Inverts = odonata and unidentified, Coleop. = coleopteran, Hymenop. = hymenoptera, Hemip. = hemiptera, Arachn. = arachnida, Arthro. = arthropod, Gastro. = gastropod, Other Terr. = other terrestrial invertebrates, Fish, Cray., Amph., Eggs = salmonids, sculpin, dace, and unidentified prey fish, crayfish, amphibians, unidentified fish eggs, and trout eggs).

Species	River Section	Season	*n*	Dipt.	Chiron.	Trico.	Pleco.	Ephem.	Other Aq. Inverts	Coleop.	Hymenop.	Hemip.	Lepidop.	Arachn.	Arthro.	Gastro.	Other Terr.	Fish, Cray., Amph., Eggs
Coastal cutthroat - Onxx	Up NF	Spring	23	0.13	0.08	0.19	0.13	0.27	0.10	0.03	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.00
		Summer	27	0.03	0.01	0.21	0.12	0.25	0.08	0.07	0.07	0.01	0.02	0.04	0.00	0.00	0.00	0.09
		Fall	16	0.04	0.03	0.23	0.07	0.24	0.16	0.03	0.07	0.04	0.03	0.05	0.03	0.00	0.00	0.00
	Mid NF	Spring	11	0.12	0.03	0.23	0.04	0.23	0.06	0.10	0.01	0.00	0.03	0.01	0.00	0.02	0.02	0.10
		Summer	5	0.07	0.02	0.07	0.06	0.15	0.17	0.14	0.11	0.06	0.02	0.10	0.00	0.00	0.02	0.01
		Fall	2	0.16	0.00	0.26	0.04	0.18	0.16	0.00	0.06	0.05	0.00	0.09	0.00	0.00	0.00	0.00
		Winter	1	0.00	0.00	0.36	0.00	0.47	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00
	Low NF	Spring	9	0.10	0.09	0.20	0.05	0.18	0.08	0.10	0.03	0.01	0.05	0.00	0.04	0.00	0.02	0.04
		Summer	9	0.05	0.14	0.19	0.10	0.09	0.21	0.10	0.03	0.03	0.02	0.02	0.02	0.00	0.00	0.00
		Fall	17	0.04	0.03	0.12	0.11	0.14	0.17	0.04	0.04	0.06	0.14	0.06	0.03	0.00	0.01	0.00
		Winter	8	0.06	0.01	0.20	0.13	0.40	0.00	0.00	0.00	0.00	0.17	0.03	0.00	0.00	0.00	0.00
	Up MF	Summer	35	0.09	0.03	0.17	0.05	0.24	0.14	0.05	0.04	0.05	0.05	0.02	0.00	0.00	0.02	0.04
		Fall	27	0.06	0.05	0.21	0.09	0.22	0.04	0.04	0.05	0.08	0.03	0.08	0.05	0.00	0.00	0.00
	Mid MF	Spring	35	0.10	0.04	0.25	0.09	0.20	0.07	0.06	0.03	0.04	0.05	0.04	0.00	0.00	0.00	0.02
		Summer	36	0.08	0.06	0.13	0.04	0.14	0.14	0.06	0.21	0.06	0.03	0.02	0.00	0.01	0.01	0.00
		Fall	32	0.11	0.02	0.12	0.16	0.21	0.10	0.08	0.02	0.05	0.04	0.06	0.02	0.01	0.00	0.00
		Winter	19	0.03	0.02	0.25	0.23	0.30	0.01	0.02	0.00	0.03	0.09	0.01	0.00	0.00	0.00	0.00
	Low MF	Spring	33	0.11	0.09	0.18	0.11	0.30	0.04	0.03	0.04	0.03	0.01	0.03	0.00	0.01	0.00	0.02
		Summer	42	0.10	0.06	0.15	0.05	0.20	0.17	0.03	0.10	0.04	0.01	0.03	0.01	0.00	0.03	0.04
		Fall	31	0.06	0.10	0.20	0.15	0.30	0.05	0.00	0.04	0.03	0.00	0.05	0.00	0.00	0.02	0.01
		Winter	22	0.05	0.04	0.30	0.13	0.42	0.00	0.00	0.00	0.03	0.01	0.00	0.02	0.00	0.00	0.00
	Up SF	Spring	22	0.06	0.04	0.22	0.07	0.22	0.13	0.05	0.13	0.01	0.04	0.02	0.00	0.00	0.01	0.00
		Summer	3	0.01	0.10	0.08	0.01	0.20	0.05	0.01	0.09	0.35	0.05	0.00	0.04	0.00	0.00	0.00
		Fall	2	0.00	0.00	0.79	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	5	0.00	0.00	0.13	0.31	0.22	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table 10 (continued).

Species	River Section	Season	*n*	Dipt.	Chiron.	Trico.	Pleco.	Ephem.	Other Aq. Inverts	Coleop.	Hymenop.	Hemip.	Lepidop.	Arachn.	Arthro.	Gastro.	Other Terr.	Fish, Cray., Amph., Eggs
	Mid SF	Spring	18	0.08	0.03	0.10	0.14	0.31	0.09	0.06	0.06	0.04	0.04	0.02	0.00	0.00	0.01	0.02
		Summer	20	0.10	0.04	0.21	0.05	0.23	0.13	0.01	0.03	0.02	0.03	0.03	0.01	0.00	0.02	0.10
		Fall	6	0.00	0.04	0.31	0.06	0.12	0.32	0.09	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.00
		Winter	12	0.01	0.00	0.03	0.12	0.24	0.55	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low SF	Spring	34	0.10	0.01	0.15	0.07	0.17	0.14	0.04	0.06	0.04	0.03	0.01	0.09	0.03	0.02	0.04
		Summer	39	0.09	0.07	0.15	0.05	0.23	0.16	0.02	0.05	0.04	0.01	0.02	0.00	0.01	0.01	0.08
		Fall	55	0.08	0.05	0.24	0.15	0.09	0.29	0.01	0.02	0.01	0.02	0.00	0.00	0.00	0.02	0.02
		Winter	32	0.02	0.04	0.38	0.08	0.17	0.20	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.02	0.01
	Up MN	Spring	27	0.14	0.05	0.20	0.14	0.15	0.09	0.05	0.04	0.05	0.01	0.02	0.03	0.01	0.02	0.01
		Summer	27	0.12	0.10	0.13	0.06	0.15	0.20	0.05	0.05	0.08	0.02	0.01	0.01	0.00	0.01	0.02
		Fall	26	0.00	0.20	0.34	0.05	0.18	0.13	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.04
		Winter	5	0.05	0.00	0.34	0.07	0.24	0.07	0.06	0.00	0.01	0.00	0.00	0.00	0.00	0.14	0.01
	Low MN	Spring	21	0.14	0.05	0.20	0.07	0.26	0.04	0.02	0.01	0.03	0.02	0.02	0.05	0.01	0.00	0.06
		Summer	23	0.03	0.07	0.21	0.09	0.10	0.13	0.07	0.05	0.15	0.01	0.01	0.00	0.03	0.01	0.03
		Fall	19	0.08	0.01	0.22	0.13	0.07	0.10	0.05	0.11	0.14	0.00	0.04	0.01	0.01	0.01	0.01
		Winter	2	0.00	0.00	0.08	0.30	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42
Rainbow trout	Mid NF	Spring	21	0.06	0.03	0.16	0.06	0.40	0.05	0.03	0.05	0.03	0.03	0.02	0.03	0.00	0.01	0.00
		Summer	31	0.07	0.06	0.10	0.07	0.22	0.14	0.08	0.14	0.01	0.01	0.05	0.00	0.00	0.04	0.00
		Fall	30	0.12	0.02	0.26	0.09	0.24	0.05	0.01	0.03	0.05	0.03	0.03	0.00	0.00	0.02	0.04
		Winter	14	0.03	0.02	0.34	0.06	0.40	0.02	0.00	0.00	0.00	0.12	0.00	0.02	0.00	0.00	0.00
	Low NF	Spring	26	0.06	0.02	0.27	0.13	0.19	0.09	0.08	0.03	0.02	0.04	0.02	0.01	0.01	0.01	0.02
		Summer	30	0.08	0.12	0.19	0.07	0.19	0.09	0.06	0.05	0.03	0.04	0.02	0.01	0.00	0.02	0.00
		Fall	11	0.06	0.03	0.19	0.20	0.26	0.08	0.04	0.01	0.02	0.06	0.01	0.00	0.00	0.01	0.02
		Winter	16	0.02	0.00	0.41	0.15	0.27	0.00	0.00	0.00	0.00	0.14	0.00	0.01	0.00	0.00	0.00
	Up SF	Summer	2	0.13	0.15	0.11	0.09	0.09	0.17	0.06	0.00	0.11	0.07	0.03	0.00	0.00	0.00	0.00
		Fall	1	0.00	0.00	0.67	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table 10 (continued).

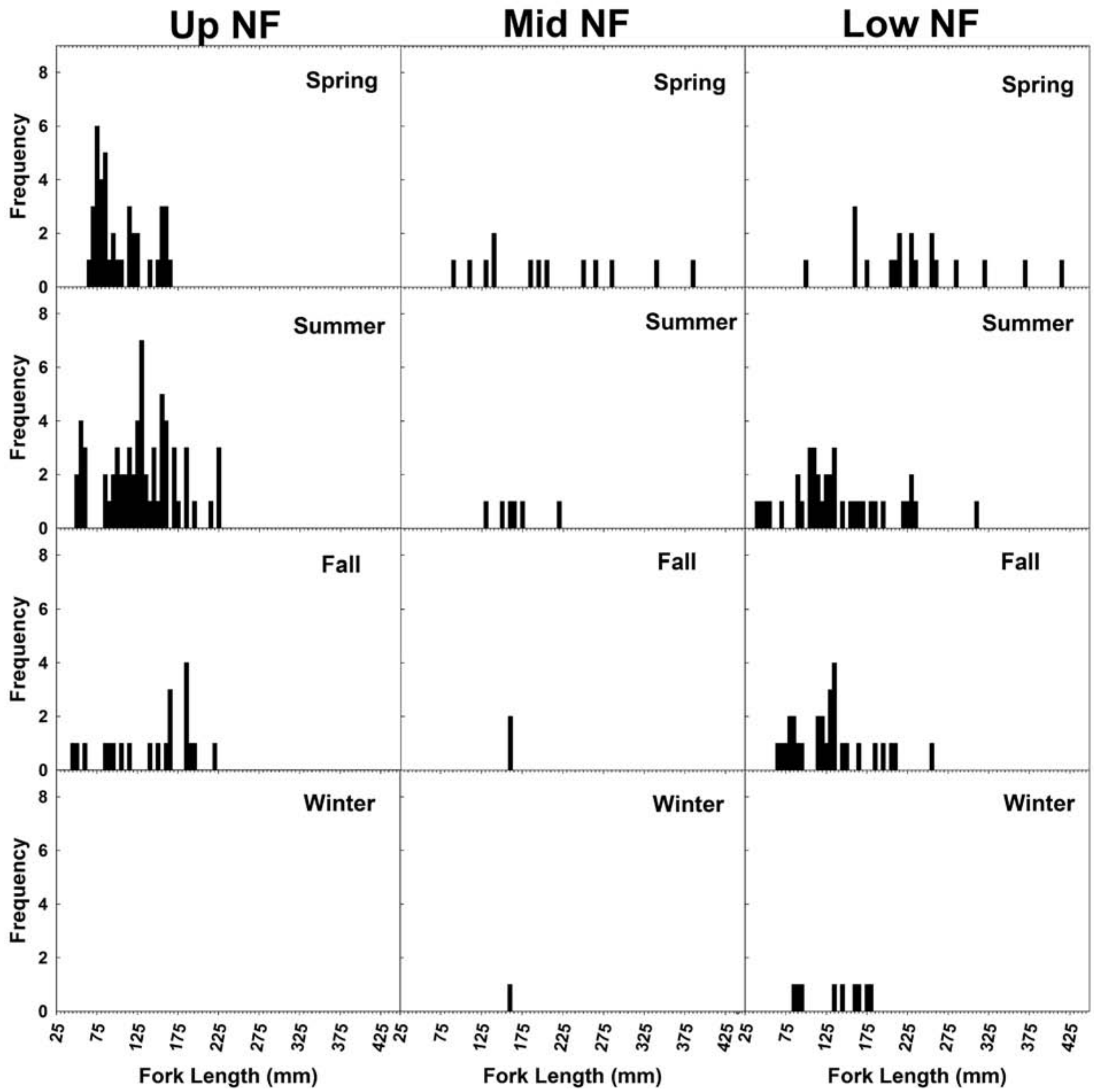
Species	River Section	Season	*n*	Dipt.	Chiron.	Trico.	Pleco.	Ephem.	Other Aq. Inverts	Coleop.	Hymenop.	Hemip.	Lepidop.	Arachn.	Arthro.	Gastro.	Other Terr.	Fish, Cray., Amph., Eggs
	Mid SF	Spring	8	0.17	0.03	0.06	0.10	0.19	0.10	0.04	0.07	0.00	0.08	0.00	0.00	0.13	0.04	0.00
		Summer	15	0.09	0.07	0.13	0.17	0.22	0.20	0.03	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.01
		Fall	24	0.02	0.06	0.16	0.02	0.04	0.23	0.11	0.11	0.14	0.06	0.02	0.00	0.00	0.00	0.03
		Winter	30	0.01	0.02	0.12	0.17	0.30	0.33	0.03	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
	Low SF	Spring	3	0.05	0.04	0.19	0.09	0.09	0.18	0.01	0.08	0.00	0.10	0.05	0.10	0.00	0.01	0.01
		Summer	1	0.20	0.35	0.14	0.00	0.11	0.15	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
		Fall	13	0.01	0.05	0.34	0.08	0.11	0.32	0.04	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.00
		Winter	9	0.00	0.04	0.52	0.00	0.13	0.26	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Up MN	Spring	1	0.19	0.00	0.27	0.12	0.05	0.03	0.00	0.05	0.17	0.12	0.00	0.00	0.00	0.00	0.00
		Summer	2	0.06	0.06	0.17	0.21	0.15	0.16	0.16	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.00
West-slope cutthroat trout	Up SF	Spring	5	0.09	0.06	0.12	0.16	0.26	0.03	0.10	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.06
		Summer	23	0.11	0.02	0.11	0.16	0.17	0.13	0.05	0.14	0.07	0.02	0.02	0.00	0.00	0.01	0.00
		Fall	18	0.07	0.04	0.32	0.01	0.17	0.22	0.00	0.10	0.05	0.00	0.00	0.01	0.00	0.00	0.00
		Winter	13	0.00	0.28	0.17	0.18	0.12	0.19	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Eastern brook trout	Mid NF	Spring	1	0.06	0.00	0.11	0.00	0.17	0.07	0.14	0.15	0.00	0.05	0.26	0.00	0.00	0.00	0.00
		Summer	1	0.04	0.00	0.00	0.00	0.26	0.00	0.22	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.04
		Winter	3	0.34	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19
	Mid SF	Spring	6	0.03	0.05	0.32	0.00	0.17	0.19	0.08	0.01	0.01	0.02	0.00	0.05	0.00	0.00	0.09
		Summer	10	0.09	0.04	0.22	0.01	0.01	0.18	0.02	0.03	0.01	0.05	0.14	0.03	0.00	0.08	0.08
		Fall	11	0.10	0.00	0.39	0.00	0.01	0.10	0.05	0.05	0.00	0.00	0.03	0.02	0.00	0.00	0.25
		Winter	3	0.00	0.00	0.33	0.00	0.00	0.33	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sculpin species	Up NF	Spring	1	0.09	0.00	0.27	0.18	0.00	0.36	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00
		Summer	2	0.00	0.00	0.45	0.05	0.35	0.00	0.00	0.10	0.00	0.00	0.05	0.00	0.00	0.00	0.00
		Fall	2	0.00	0.00	0.22	0.00	0.19	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mid NF	Spring	1	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	4	0.03	0.19	0.69	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Fall	3	0.00	0.00	0.59	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27

Appendix Table 10 (continued).

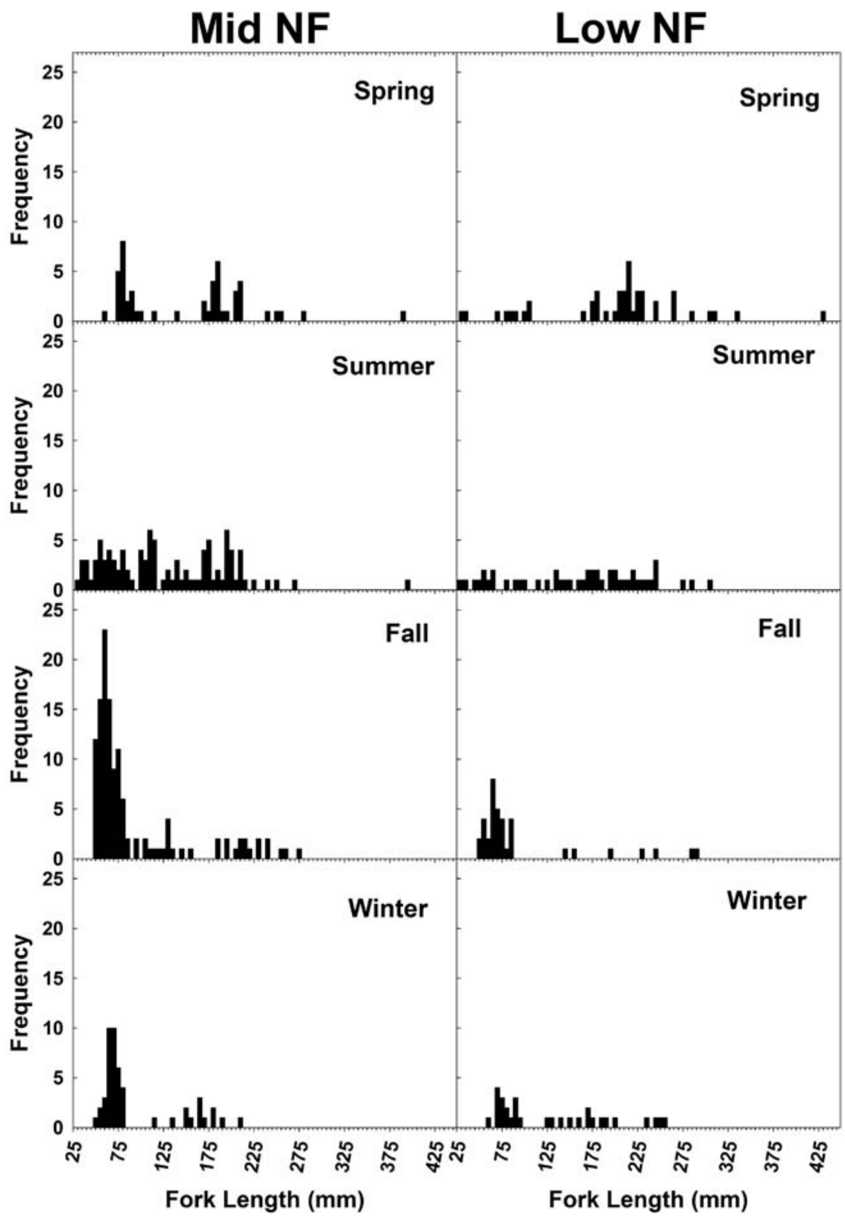
Species	River Section	Season	*n*	Dipt.	Chiron.	Trico.	Pleco.	Ephem.	Other Aq. Inverts	Coleop.	Hymenop.	Hemip.	Lepidop.	Arachn.	Arthro.	Gastro.	Other Terr.	Fish, Cray., Amph., Eggs
	Low NF	Spring	1	0.00	0.00	0.12	0.36	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	8	0.07	0.10	0.20	0.34	0.11	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
		Fall	6	0.00	0.00	0.31	0.33	0.19	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	1	0.00	0.00	0.26	0.23	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Up MF	Summer	2	0.00	0.00	0.08	0.22	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28
	Mid MF	Spring	4	0.00	0.23	0.35	0.11	0.17	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	2	0.00	0.00	0.08	0.00	0.38	0.50	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Fall	4	0.12	0.00	0.63	0.14	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	2	0.00	0.00	0.03	0.10	0.23	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.63
	Low MF	Spring	3	0.19	0.06	0.05	0.38	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	2	0.00	0.00	0.50	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24
		Fall	4	0.00	0.02	0.94	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	2	0.00	0.09	0.42	0.13	0.30	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
	Up SF	Spring	8	0.01	0.02	0.21	0.12	0.49	0.06	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00
		Fall	5	0.00	0.00	0.36	0.24	0.08	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	7	0.00	0.40	0.16	0.04	0.17	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mid SF	Spring	8	0.03	0.02	0.51	0.13	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	2	0.00	0.17	0.35	0.17	0.13	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.13
		Fall	3	0.00	0.00	0.17	0.00	0.09	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	6	0.00	0.48	0.09	0.06	0.21	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low SF	Spring	4	0.08	0.34	0.12	0.06	0.21	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
		Summer	2	0.06	0.00	0.16	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.16	0.00	0.24
		Fall	8	0.05	0.00	0.32	0.07	0.21	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	8	0.03	0.30	0.14	0.13	0.22	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Up MN	Summer	2	0.00	0.05	0.31	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
		Fall	2	0.00	0.00	0.27	0.29	0.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	1	0.00	0.00	0.18	0.64	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix Table 10 (continued).

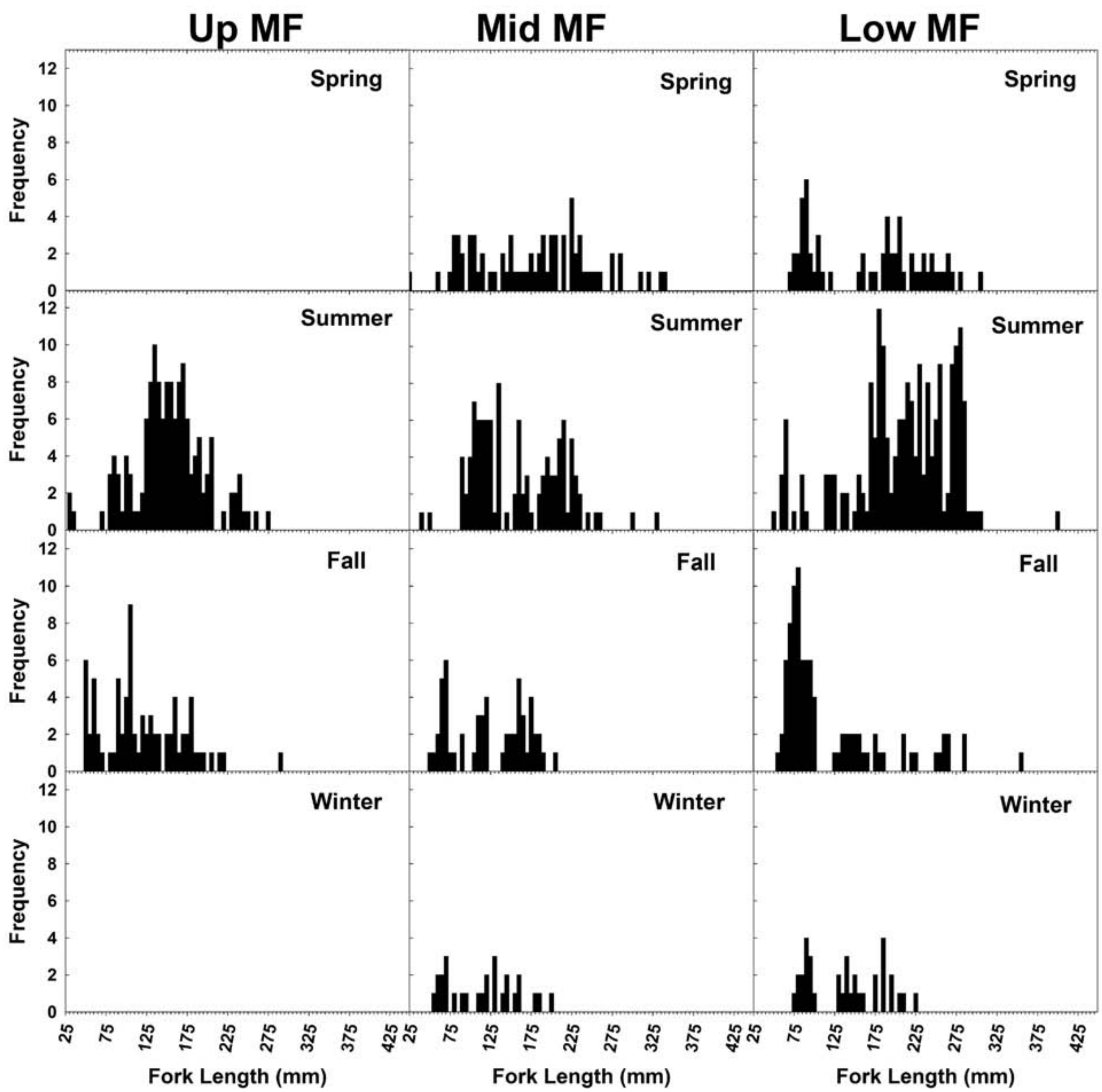
Species	River Section	Season	*n*	Dipt.	Chiron.	Trico.	Pleco.	Ephem.	Other Aq. Inverts	Coleop.	Hymenop.	Hemip.	Lepidop.	Arachn.	Arthro.	Gastro.	Other Terr.	Fish, Cray., Amph., Eggs
Mountain whitefish	Low NF	Spring	2	0.00	0.11	0.20	0.08	0.41	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.17	0.00
	Mid MF	Spring	2	0.11	0.10	0.18	0.05	0.41	0.00	0.10	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00
		Summer	1	0.40	0.00	0.26	0.00	0.21	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	5	0.02	0.02	0.14	0.46	0.27	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00
	Low MF	Summer	1	0.09	0.28	0.10	0.16	0.03	0.30	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
		Fall	2	0.15	0.00	0.30	0.03	0.17	0.04	0.00	0.00	0.22	0.00	0.09	0.00	0.00	0.00	0.00
		Winter	3	0.17	0.02	0.40	0.13	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Low SF	Spring	22	0.21	0.14	0.34	0.04	0.19	0.01	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00
		Summer	1	0.08	0.20	0.08	0.00	0.13	0.25	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00
		Winter	1	0.00	0.00	0.33	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Up MN	Summer	1	0.16	0.10	0.09	0.00	0.00	0.56	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00



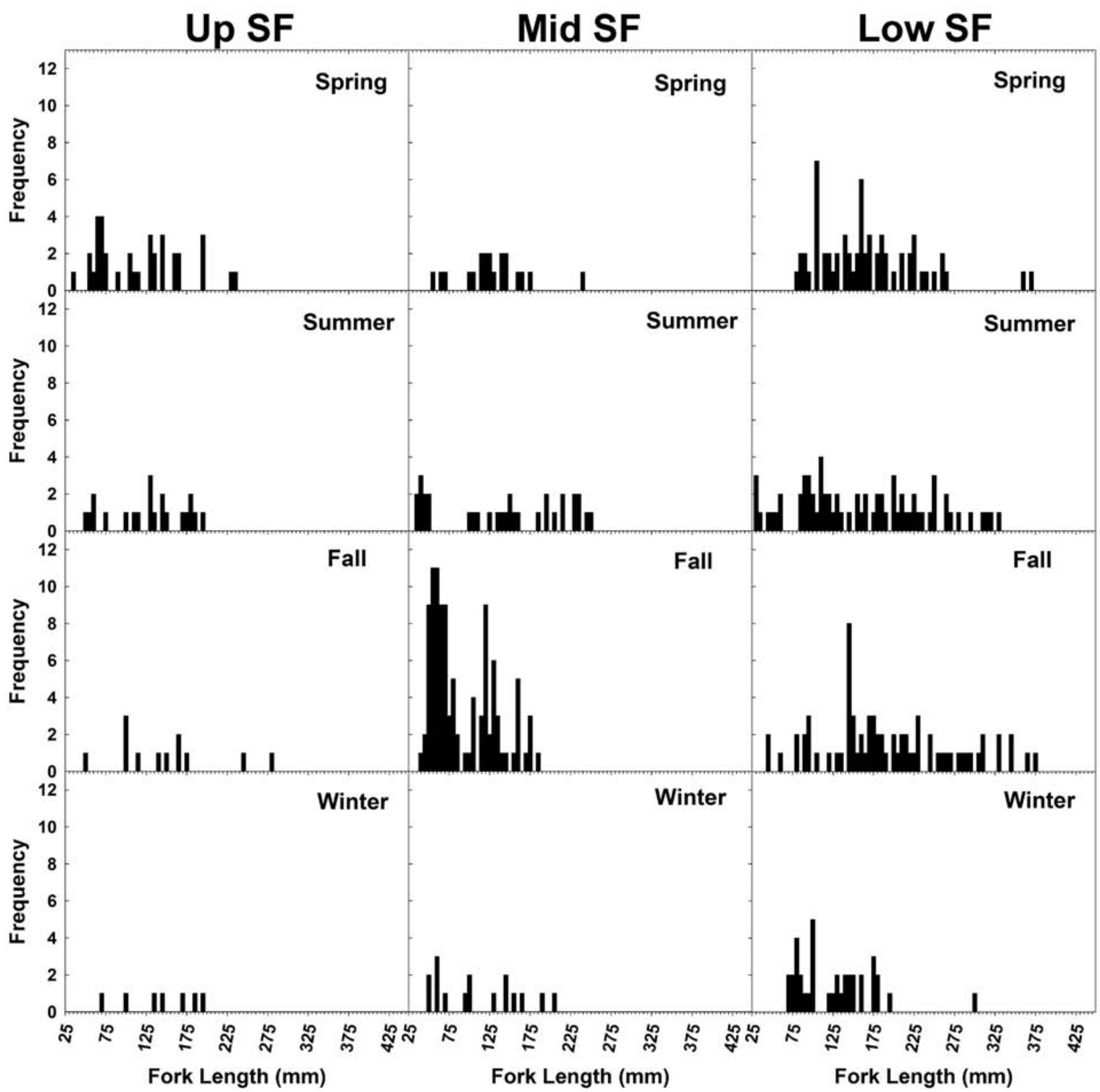
Appendix Figure 1. Length frequencies of coastal cutthroat and unidentified Pacific trout species captured seasonally from river sections in the North Fork Snoqualmie River. Fish were captured in various reaches between June 2009 and October 2010 using single-pass backpack electrofishing and angling. The Up NF was not sampled during winter.



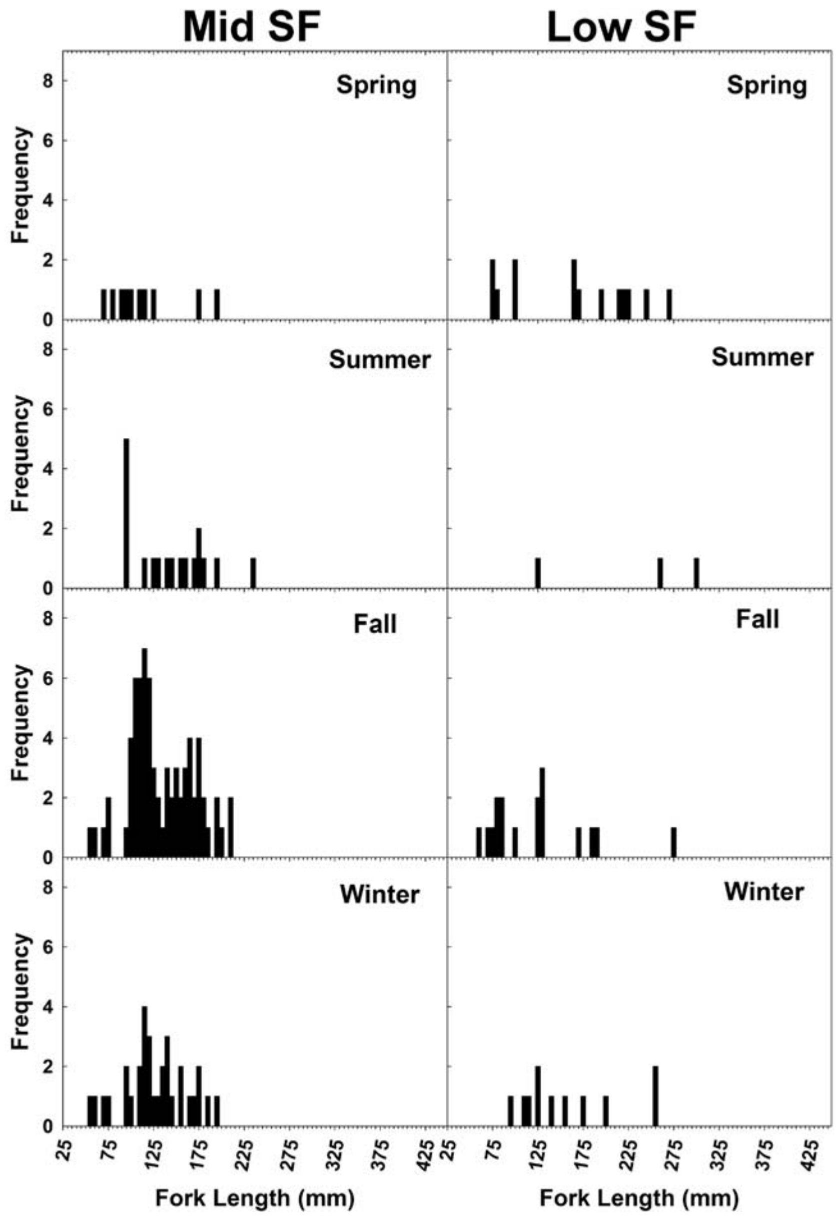
Appendix Figure 2. Length frequencies of rainbow captured seasonally from river sections in the North Fork Snoqualmie River. Fish were captured in various reaches between June 2009 and October 2010 using single-pass backpack electrofishing and angling. Rainbow trout were not captured in the Up NF.



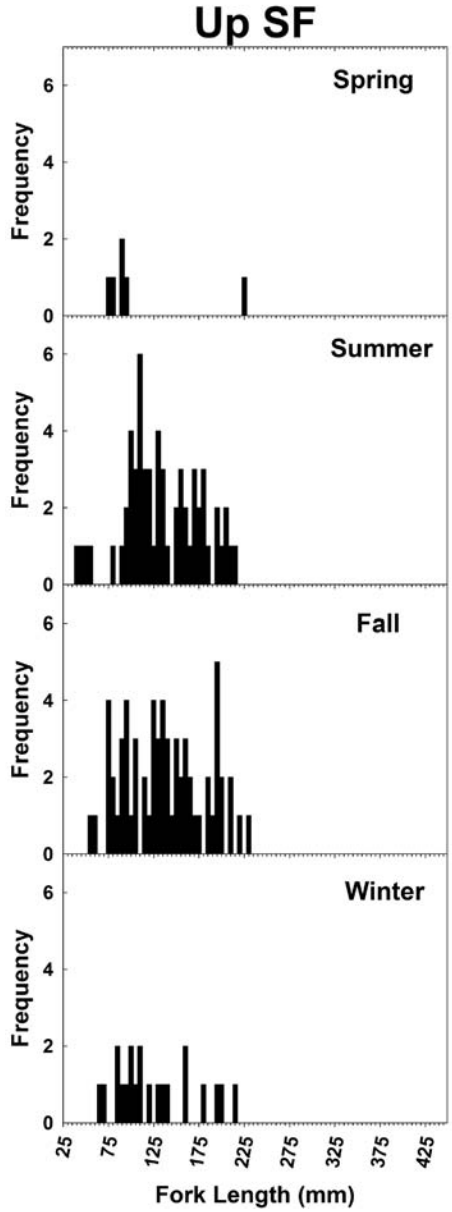
Appendix Figure 3. Length frequencies of coastal cutthroat and unidentified Pacific trout captured seasonally from river sections in the Middle Fork Snoqualmie River. Fish were captured in various reaches between June 2009 and October 2010 using single-pass backpack electrofishing and angling. The Up MF was not sampled during spring and winter.



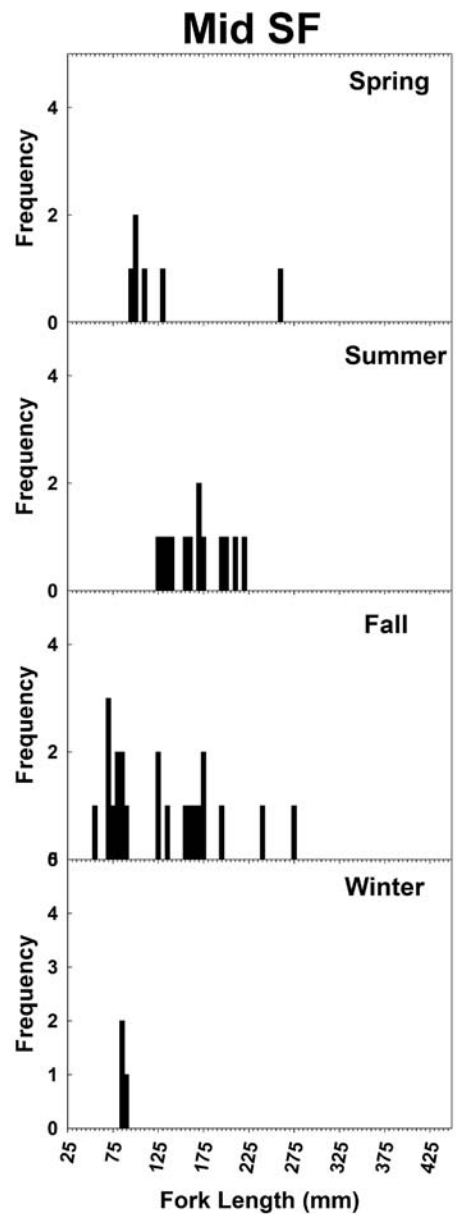
Appendix Figure 4. Length frequencies of coastal cutthroat and unidentified Pacific trout captured seasonally from river sections in the South Fork Snoqualmie River. Fish were captured in various reaches between October 2008 and October 2010 using single-pass backpack electrofishing, boat electrofishing, and angling.



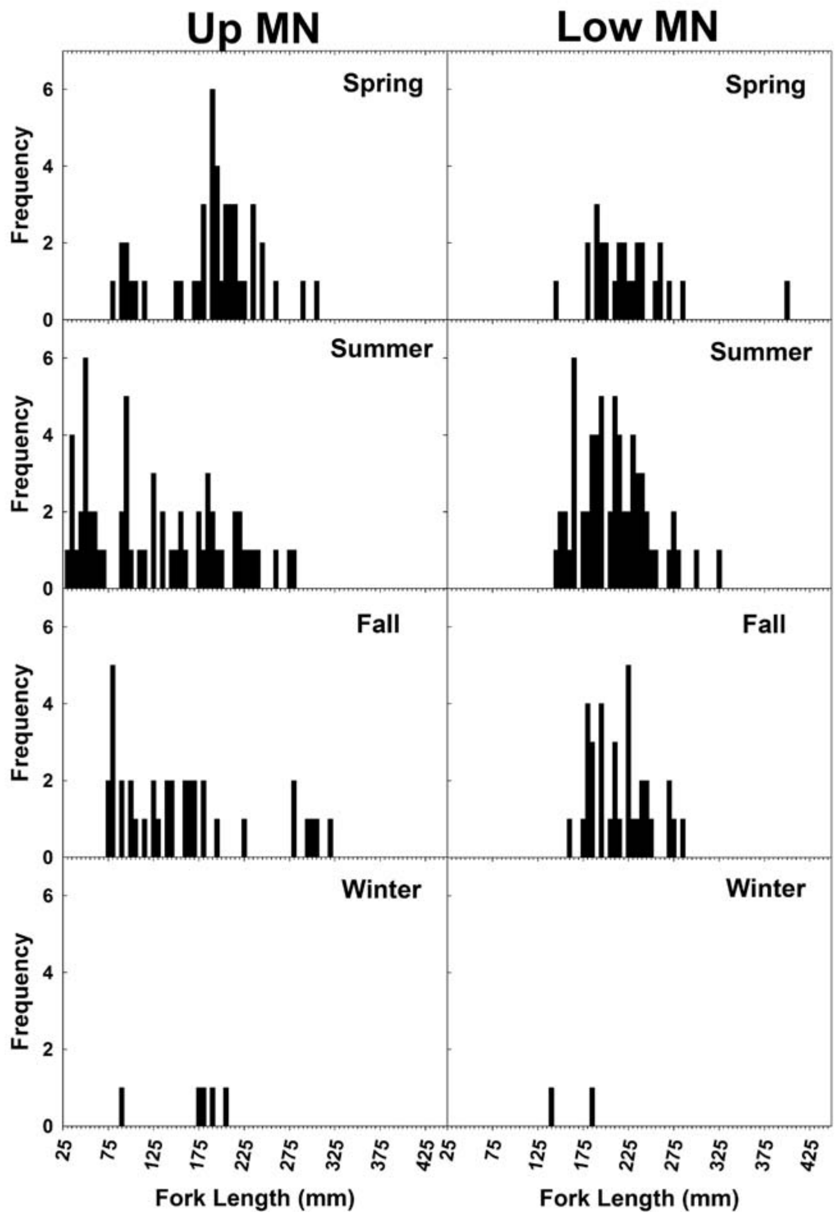
Appendix Figure 5. Length frequencies of rainbow trout captured seasonally from river sections in the South Fork Snoqualmie River. Fish were captured in various reaches between October 2008 and October 2010 using single-pass backpack electrofishing, boat electrofishing, and angling.



Appendix Figure 6. Length frequencies of westslope cutthroat trout captured seasonally from river sections in the upper South Fork Snoqualmie River (Up SF). Fish were captured in various reaches between October 2008 and October 2010 using single-pass backpack electrofishing and angling. Among all river sections in the upper Snoqualmie River watershed, only the Up SF contained substantial numbers of westslope cutthroat trout.



Appendix Figure 7. Length frequencies of brook trout captured seasonally from river sections in the middle South Fork Snoqualmie River (Mid SF). Fish were captured in various reaches between October 2008 and October 2010 using single-pass backpack electrofishing and angling. Among all river sections in the upper Snoqualmie River watershed, only the Mid SF contained substantial numbers of brook trout.



Appendix Figure 8. Length frequencies of coastal cutthroat trout and unidentified Pacific trout species captured seasonally from the upper (Up MN) and lower (Low MN) mainstem Snoqualmie River above Snoqualmie Falls. Fish were captured in various reaches between July 2009 and September 2010 using single-pass backpack electrofishing and angling. Rainbow trout were not captured in substantial numbers in the mainstem.

Genetic composition of Pacific trout species in relation to landscape features in the upper Snoqualmie River watershed, WA

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Abstract

The upper Snoqualmie River watershed (USRW) is located above an 82 m vertical barrier to anadromous fishes. Main stem rivers and tributaries in the USRW contain wild populations of coastal and westslope cutthroat trout, rainbow trout, and hybrids among these species. Releases of hatchery-raised strains of Pacific trout were widespread throughout the watershed between 1930's and 1990's and continue in alpine lakes that drain into tributaries and main stem rivers. Trout identified in the field as rainbow, coastal cutthroat, westslope cutthroat, and hybrids were sampled in main stem and tributary habitats in the USRW and analyzed to describe the various species and lineages inhabiting the watershed and the magnitude of introgression by hatchery strains of Pacific trout. Fish were genotyped at seven microsatellite DNA loci and 96 single nucleotide polymorphism loci (SNPs) and results differentiated between putative native and hatchery strains of coastal and westslope cutthroat, rainbow and hybrids between all of these species. Hybrids were composed of first generation types (F1) and descendants of hybrids (beyond F1 or introgressed). Many samples contained a mixture of native and hatchery strains indicating that hatchery-raised trout have introgressed into the populations and even dominate the genetic structure in discrete segments of the watershed. Dominant lineages (native or hatchery ancestry) were generally homogenous within each fork but varied between the forks, indicating that some native subpopulations were probably more vulnerable to displacement by hatchery-raised species or the area was unoccupied prior to hatchery introductions. Current spatial distribution of the genetic composition of Pacific trout revealed possible causal mechanisms of the distribution of salmonids during and after the last glacial recession (c. 10,000 to 15,000 years before present).

Introduction

The Snoqualmie River Game Fish Enhancement Plan (Plan) is a comprehensive inventory and ecological study of the fishery resources in the upper Snoqualmie River watershed (USRW). The USRW consists of all waters draining the Snoqualmie River basin upstream of the Snoqualmie Falls Hydroelectric Project at Snoqualmie Falls, which is owned and operated by Puget Sound Energy (PSE). In 2004 the Federal Energy Regulatory Commission (FERC) issued a new license for the hydroelectric project. Article 413 of the license required PSE to file a final Plan to the FERC for approval and allocate funds to implement the Plan. PSE developed the final Plan in consultation with the Washington Department of Fish and Wildlife (WDFW) and submitted it to the FERC (Puget Sound Energy 2005). The Plan was approved by the FERC in December 2006 and in 2007 PSE contracted WDFW to conduct the Plan (Thompson et al. 2011).

One of the goals of the Plan was to determine trout species composition and distribution in the watershed. Pacific trout species known to inhabit the USRW include coastal cutthroat (CCT: *Oncorhynchus clarki clarki*), rainbow (RBT: *O. mykiss*), westslope cutthroat (WCT: *O. clarki lewisi*), and hybrids among these species (Onxx). Bull trout (*Salvelinus confluentus*) is the only char species endemic to the inland Central Puget Sound region, but none were found during this study (Thompson et al. 2011). Over the years anglers have reported sightings of bull trout in the USRW; however, none were observed during a previous study designed specifically to detect their presence in the USRW (Berge and Mavros 2001).

Coastal cutthroat and rainbow trout are the most likely native trout species in the USRW, as westslope are known to be native only in drainages east of the Cascade Mountains. Various species of hatchery-raised trout (CCT, RBT, and WCT) were released into water bodies of the USRW between the 1930's and 1990's (Table 1). It is likely that additional trout were stocked prior to 1930 (Bob Pfeifer, personal communication). Plants of hatchery-raised CCT and RBT continue presently, but are limited to alpine lakes or water bodies that do not connect directly with main stem rivers (Table 1). Coastal cutthroat are the most abundant species of Pacific trout in the USRW followed by RBT, and Onxx. Accurate field differentiation between CCT, RBT, and Onxx is difficult in discrete segments of the USRW (Thompson et al. 2011). Genetic analysis of individuals sampled throughout the watershed can help field biologists describe species composition and can help identify the extent of introgression or hybridization with putative native species. Analysis of genetic samples collected on a landscape scale can help managers identify where various lineages (native or hatchery) occur so appropriate management actions can be prioritized in specific reaches.

The objectives of this study were to identify the various Pacific trout species and to describe species and lineage composition of Pacific trout on a large spatial scale in the USRW. Genetic samples were spatially distributed among main stem rivers and tributaries in the USRW to facilitate a watershed-scale understanding of species composition.

Study Area

Upper Snoqualmie River Watershed

The USRW is composed of the headwater portions of the Snoqualmie River above Snoqualmie Falls, an 82 m vertical barrier that limits anadromous fish distribution to the lower watershed. The Snoqualmie River below Snoqualmie Falls converges with the Skykomish River near the city of Monroe to form the Snohomish River, the second largest river system flowing into the Puget Sound (Figure 1). Major river systems of the USRW include the North, Middle and South forks, and the mainstem of the Snoqualmie River above Snoqualmie Falls. Each of the Snoqualmie forks originates on the west slopes of the Cascade Mountains, flowing in a general westerly direction through varied landscapes until they converge as the mainstem Snoqualmie River. The mainstem Snoqualmie continues downstream for about 6 km before plunging over Snoqualmie Falls (Figure 2).

The headwater portions of each fork originate high on the Cascade Crest in the Alpine Lakes Wilderness Area. In a landscape sculpted by alpine glaciers (c. 20,000 ybp), headwaters consist of confined, turbulent, high gradient habitats with geologic barriers that isolate fish into sub-populations (Figure 2). Downstream of headwaters the steep stream channels converge with more moderate gradient terraced u-shaped montane valley bottoms. Gradient is heterogeneous along montane valley bottoms as low gradient segments yield to exposed bedrock or boulder-cascade reaches that isolate fish (e.g., Big Creek Falls in the North Fork and Weeks Falls in the South Fork). Each fork is low to moderate gradient downstream of the most major geologic barriers (Black Canyon in the North Fork, Twin Falls in the South Fork, and Dingford Canyon in the Middle Fork).

Prior to the most recent glaciation (c. 14,000 ybp) the upper Cedar River basin drained into the Snoqualmie basin. However, the Cedar River was diverted south and the major geologic barriers in each fork of the Snoqualmie were formed after the most recent encroachment and retreat of the Vashon Lobe of the Cordilleran Ice Sheet, as glacial moraines (e.g., Grouse Ridge) were formed creating lakes behind large 'earthen dams' and bedrock outcroppings (e.g., Twin Falls) were exposed. The Vashon Lobe blocked the pathway of the Snoqualmie River and a large ice-marginal lake occupied the lower portion of the basin just upstream of Snoqualmie Falls as the Vashon Lobe slowly retreated. This lake received streamflows from most, if not all, northern and central Puget Sound basins (Skagit, Stillaguamish, Skykomish, etc.) as they converged with and flowed south along the eastern border of the ice sheet. The original outlet for the ice marginal lake was through the Cedar Channel near Rattlesnake Lake, but as the Vashon Lobe retreated the lake level dropped and the Snoqualmie River carved a new channel that flowed over Snoqualmie Falls (Figure 2).

Each fork and the mainstem Snoqualmie River were divided into river segments (Figure 3). River segments corresponded with discrete channel types (sediment transport or deposition), geography, trout abundance, and trout species composition (Thompson et al. 2011). Sample reaches were located within river segments and spatially explicit trout genetic composition was analyzed by comparing trout genetics between river segments.

Materials and Methods

Data collection

Sample reaches were distributed across river segments (Figure 3) and fish were sampled randomly from length groups in sample reaches (0–99, 100–149, 150–229, 230–299, 300–379, 380+ mm total length - TL). Size of sample reach ranged between 50 m and 8 km in length and from shallow margins to the entire wetted width depending on habitat size. Fish were captured between June 2009 and October 2010 using one of two methods: 1) single pass backpack electrofishing without blocknets (*sensu* Bateman et al. 2005); or 2) wade- or float-based angling. Wade-based angling was used in conjunction with backpack electrofishing in reaches containing habitats too deep for effective backpack shocking. Captured fish were held in containers of cold, fresh, aerated water with cover to reduce stress. Fish were anesthetized using 6 ml of 10g:1 L solution MS 222 in 7.5 L of fresh water, and were identified to species, measured for total and fork lengths (mm), and weighed (0.1 g). Lower caudal fin samples were distributed proportionally among length frequency groups, and egg and alevin samples were retained during spawning surveys in main stems and tributaries during winter and spring of 2010. Tissue samples for DNA extraction were placed directly in vials containing 95% ethanol. Samples were grouped into two collections with WDFW codes 09IJ and 09IK but field collections were not segregated by these codes consistently (field identifications presented in Table 7). Most of the cutthroat trout were in collection 09IJ and most of the rainbow trout were in collection 09IK, but each collection contained both species types. To help us distinguish descendants of introduced hatchery cutthroat trout from possible native cutthroat trout we included samples of two of the hatchery cutthroat trout collections [Lake Whatcom broodstock (coastal cutthroat trout) housed at Tokul Creek Hatchery (WDFW code 01NZ); Twin Lakes broodstock (westslope cutthroat trout) housed at Twin Lakes Hatchery (WDFW code 99GB)] as well as a native coastal cutthroat trout collection from Cedar River in South Puget Sound (WDFW code 05BB).

To further identify trout origins, we compared the USRW trout to archived trout data from WDFW. The archived data had five microsatellite loci in common with contemporary data. Analyses were conducted to pursue signals indicating that some of the Snoqualmie trout samples may have had ancestry in hatchery rainbow trout broodstocks that were not represented in the baseline samples (listed above) that had been genotyped with microsatellites and SNPs. The archived data included rainbow trout from the Puget Sound basin (Puyallup, Cedar, Green rivers and Chester Morse Lake) and hatchery rainbow trout broodstocks planted throughout Washington State (Eells Springs, South Tacoma, Goldendale, and Spokane hatcheries). The archived data also included coastal cutthroat trout from Puget Sound (Bear and Minter creeks and a collection from Lake Washington) and westslope cutthroat trout from Pend Oreille basin (Sullivan Lake, Sullivan and Gold creeks).

Laboratory analyses

Genomic DNA was extracted from tissue samples using Clone-tech® extraction kits. Trout samples were genotyped at seven microsatellite loci (One-108, Ots-103, Omy-77, Ots-1, Ots-3M, Ogo-3, and Omm-1138) which had large differences in allelic distributions between cutthroat trout and rainbow trout in Marshall et al. (2006). Microsatellite alleles were PCR-amplified using fluorescently labeled primers. PCRs were conducted in 96 well plates in 10 µl volumes employing 1 µl template with final concentrations of 1.5 mM $MgCl_{2,}$ 200µM of each dNTP, and 1X Promega PCR buffer. The following microsatellite loci were used at the following concentrations (concentration in µM after locus name): One-108 [0.075], Ots-103 [0.037], Omy-77 [0.075], Ots-1 [0.08], Ots-3M [0.05], Ogo-3 [0.07], and Omm-1138 [0.08]). After initial two minute denature at 94°, there were 3 cycles consisting of 94° denaturing for 30 seconds, 60° annealing for 30 seconds, at 72° extension for 60 seconds. These were followed by 30 cycles with the same parameters but the annealing temperature was dropped to 50° and then there was a final 10-minute extension at 72°. Samples were run on an ABI 3730 automated DNA Analyzer and alleles were sized (to base pairs) and binned using an internal lane size standard (GS500Liz from Applied Biosystems) and GeneMapper software (Applied Biosystems).

Trout samples were also genotyped at 96 single nucleotide polymorphism loci (SNPs, see Table 2 for list) through PCR and visualized on Fluidigm EP1 integrated fluidic circuits (chips). Twenty of the SNP loci were developed to discriminate among trout species and 76 of the SNP loci have been used to identify population structure and other genetic attributes of rainbow trout in Puget Sound. Protocols followed Fluidigm's recommendations for TaqMan SNP assays as follows: assay loading mixture contains 1X Assay Loading Reagent (Fluidigm), 2.5X ROX Reference Dye (Invetrogen) and 10X custom TaqMan Assay (Applied Biosystems); sample loading mixture contains 1X TaqMan Universal PCR Master Mix (Applied Biosystems), 0.05X AmpliTaq Gold DNA polymerase (Applied Biosystems), 1X GT sampling loading reagent (Fluidigm) and 2.1 µL template DNA. Four µL assay loading mix and 5 µL sample loading mix were pipetted onto the chip and loaded by the IFC loader (Fluidigm). PCR was conducted on a Fluidigm thermal cycler using a two step profile. Initial mix thermal profile was 70°C for 30min, 25°C for 5 min, 52.3° for 10 sec, 50.1°C for 1 min 50sec, 98°C for 5 sec, 96°C for 9 min 55 sec, 96°C for 15 sec, 58.6°C for 8 sec, and 60.1°C for 43 sec. Amplification thermal profile was 40 cycles of 58.6°C for 10 sec, 96°C for 5 sec, 58.6°C for 8 sec and 60.1°C for 43 sec with a final hold at 20°C. The TaqMan assays were visualized on the Fluidigm EP1 machine using the BioMark data collection software and analyzed using Fluidigm SNP genotyping analysis software. All data were scored by two researchers.

Statistical analyses

Since the WDFW Molecular Genetics Lab is transitioning from using microsatellite loci to using SNP loci for genetic analyses, we used the program ARLEQUIN3.5 (Schneider et al. 2000) to generate several genetic statistics to assist our comparisons of the loci. We used ARLEQUIN to calculate the amount of genetic variance among collections at each locus, to estimate whether the variance was significant and to identify loci that had a lower or higher amount of genetic variance than expected (balancing or directional selection at loci, respectively) using the F_{ST} outlier test. Most of our statistics assume loci are selectively neutral: a locus under balancing selection would have less divergence among populations than expected, often due to heterozygote advantage or frequency-dependent selection and a locus under directional selection would have more divergence among populations than expected, often due to selective differences among sampling locations. We used a hierarchical analysis of molecular variance (AMOVA, Excoffier et al. 1992) to calculate the amount of genetic variance among collections, among individuals within collections and within individuals using three permutations of the dataset: just the microsatellite loci, just the SNP loci and with both locus sets combined.

Trout from the USRW were assessed to determine their species identity and their status; pure, hybrid or introgressed (hybrid beyond the first generation). In addition to species identification and genetic status, we identified whether trout were descendants of introduced out-of-basin hatchery cutthroat trout or rainbow trout or if mixture was between cutthroat trout variants or between cutthroat trout and rainbow trout or included some component of hatchery rainbow trout. We used the Bayesian analysis implemented in the program STRUCTURE2.3 (Pritchard et al. 2000) to estimate individual genetic ancestry and identify putative hybrids and introgressed individuals. STRUCTURE sorts individuals (or portions of individuals if they are hybrids) into a number of hypothetical clusters (K) or groups in order to achieve Hardy-Weinberg equilibrium and linkage equilibrium (or minimize disequilibrium) in the clusters or groups – individuals that are genetically similar to each other group together in a cluster and the clustering can be broad scale (eg. species level) or fine scale (population level). Hybrid or introgressed individuals will have ancestry in two or more genetic clusters. The program outputs a likelihood value for the number of clusters or genetic groups, given the dataset. The likelihood value reaches a maximum or asymptote when the program has detected the maximum number of genetic clusters it can identify in the dataset. We set the number of clusters or possible populations at 2–7: at K = 2 we hypothesized that the dataset would divide into a cutthroat trout and a rainbow trout group and at higher K values the dataset would divide into cutthroat trout and rainbow trout subspecies and populations.

We used the program GENETIX (Belkhir et al. 2004) to view differences among individual samples and collections and to view possible interspecific hybrids. GENETIX performs a factorial correspondence analysis (FCA), which generates axes that describe the maximum genetic variation among individuals and plots individuals along these axes according to their genotype. Individuals that are genetically similar plot near each other and individuals that are genetically different plot distantly from each other. Hybridization or introgression is hypothesized when individuals from one species plot within or towards the region occupied by the other species or genetic group (eg. hatchery cluster). This program also provides insights into individuals categorized phenotypically as one species that are genetically more similar to a different species since they will plot near genetically similar individuals regardless of phenotype.

Because of the long history of hatchery rainbow trout planting and a lack of detailed information on hatchery broodstocks we conducted a secondary analysis with a subset of the microsatellite data (five loci) generated for this project. In the secondary analysis we compared the genotypic subset to archived WDFW data that included four hatchery rainbow trout broodstocks (Spokane, Goldendale, Eells Springs, South Tacoma) and native Puget Sound rainbow trout (Green, Cedar, Puyallup rivers and Chester Morse Lake) and cutthroat trout (Cedar, Bear, Minter creeks) populations. The archived data had five microsatellite loci per individual in common with the contemporary data and provided insights that were unavailable using only contemporary data. We conducted the same STRUCTURE and FCA analyses with the five loci in common.

Results

Genotyping success varied among individuals and markers. Nine individuals collected in the Snoqualmie basin failed at most loci and were excluded from analyses – failures are usually a result of degraded DNA from decayed tissues or too little DNA from too small of a sample. The microsatellite loci all worked in 80% or greater of the samples. For the SNP markers, 11 loci generated no data and 9 loci produced data for less than half the samples (See Table 3). These SNPs were excluded from further consideration. Genetic variance among collections ranged from a high of 86% at species ID locus ASpI005 to -0.5% at species ID locus ASp1012 (Table 4). Negative values indicate that most of the genetic variance is among individuals and there is little to no variance among collections—the locus has little or no utility for distinguishing among populations or species. While most trout were fixed for a single allele at this locus (there are usually two alleles at a SNP locus), the alternate allele was fixed in the westslope cutthroat trout broodstock collection from Twin Lakes Hatchery (Appendix I). In most of the other species ID SNPs allele frequencies were different between cutthroat trout and rainbow trout collections (see Appendix I). Since many genetic statistics assume that loci are neutral, we tested for neutrality in these new SNP loci and the microsatellite loci. Four markers generated signals of variance that was less than (One-108) or greater than (AOmy015, ASp1004, ASp1005, and ASp1009) expected, suggesting these loci may be under balancing or directional selection, respectively (Figure 3). Selected loci are ones where heterozygous individuals may be favored and survive to reproduce (balancing selection) such that both alleles are at nearly equal frequencies. For loci under directional selection alternate alleles are favored under different selection regimes or environmental conditions such that one allele is at a high frequency in one environment and the alternate allele is at a high frequency in a different environment.

The AMOVA found high genetic variance among collections and among individuals with all combinations of the genotypic data: with microsatellite loci only, with SNP loci only and with the two marker types combined (Table 5). Genetic variance among collections was highest using only SNP loci, likely due to the high allele frequency differences at the species ID SNPs. Genetic variance among individuals was also highest using only SNP loci, possibly also driven by the species ID SNPs. Genetic variance within individuals was lower for SNPs. This was expected since SNPs have two alleles per locus as opposed to over 30 alleles at some microsatellite loci and the species ID SNPs are expected to be nearly or completely fixed in single-species collections. Examining the partitioning of genetic variance (among populations, within populations and within individuals) allows us to identify patterns of genetic variation (eg. if there is significant genetic variance between fish collected from two tributaries that tells us that there is non-random gene flow among the tributaries and that there is geographic structure to the genetic variation).

The STRUCTURE analysis identified cutthroat trout and rainbow trout in the USRW trout samples, as well as some hybrids or introgressed individuals (Figure 3a and Figure 3b). In this analysis, the user tells the program to divide the data set into a number of genetic groups. The program sorts through the data, without knowledge of the origin of the sample, and groups the data into clusters that minimize Hardy-Weinberg disequilibrium and linkage disequilibrium (Hardy-Weinberg and linkage equilibrium are genetic characteristics of unmixed groups). Thus, individuals (or portions of an individual if they are introgressed) that are collected in a single location may be classified into different genetic groups if their ancestry is from different genetic groups. For this study, we were interested in genetic identities of trout of unknown origin, so we included trout of known origin that may have been planted in the basin (hatchery cutthroat trout) or may share recent common ancestry with native Snoqualmie basin trout (Cedar River cutthroat trout) to explore which genetic group individual USRW trout were most similar to. We used the program as a hierarchical analysis that looked at genetic identity from the species level to the population level.

For this study, we first had the program divide the data into two groups and these groups corresponded to a cutthroat trout group and a rainbow trout group (Figure 3a at K = 2). In that figure, each individual fish is represented by a bar of color, blue corresponds to cutthroat trout ancestry and tan to rainbow trout ancestry. If an individual is of single ancestry, it will have a single color in its color bar. If an individual is of mixed ancestry it will have two colors in its color bar, with the proportion of each color corresponding to the percentage of ancestry in the two groups, here cutthroat trout and rainbow trout. The reader can see that samples collected as phenotypic cutthroat trout and rainbow trout in the USRW were mostly genetically cutthroat trout and rainbow trout, respectively (see Table 7 for phenotypic and genetic identification). However, some individuals identified phenotypically as one species identified genetically as the other species and several individuals appeared to have mixed ancestry. This is also seen in the cutthroat trout collection from the Cedar River where a few rainbow trout (tan color bars among the blue) were known to have been included in that collection.

At K = 3 (Figure 3a), the cutthroat trout cluster subdivided into coastal (blue) and westlope (green) cutthroat trout clusters. With this increased definition, a few of the individuals identified genetically as cutthroat trout in the Snoqualmie rainbow trout collection now identify as cutthroat trout with westslope ancestry (green individuals within the Snoqualmie rainbow trout collection). So the resolution of the analysis is at the species and subspecies level.

At K = 4 (Figure 3a), the coastal cutthroat trout cluster subdivided into the Puget Sound coastal cutthroat trout (blue) and coastal cutthroat trout from USRW (purple). We suspect that the coastal cutthroat trout cluster identified in the USRW collection (purple in Figure 3a) is a native coastal cutthroat trout population. The USRW is above a barrier falls and native trout above the falls were expected to be genetically divergent from other coastal cutthroat trout from Puget Sound since there has been no gene flow across the barrier falls. However, some of the Snoqualmie cutthroat trout had ancestry in the Puget Sound coastal cutthroat trout cluster (blue individuals) suggesting that they were descendants of hatchery cutthroat trout (Lake Whatcom broodstock) planted in the basin (see discussion below). Most of the cutthroat trout identified in the USRW rainbow trout collection shared their ancestry with the Snoqualmie cutthroat trout (purple individuals in the USRW rainbow trout collection) and a few were hatchery cutthroat trout origin (blue individuals). Now the resolution of the analysis reaches to the population level for cutthroat trout.

At K = 5 (Figure 3a), the Puget Sound coastal cutthroat trout cluster subdivided into North (Lake Whatcom -blue) and South (Cedar River - red) Puget Sound cutthroat trout and the USRW cutthroat trout (SnoqOcl in Figure 3a) remained in its own cluster (purple). Some of the Puget Sound cutthroat trout identified at K = 4 in the USRW cutthroat trout and rainbow trout collections are more similar to the south Puget Sound cutthroat trout. This may indicate that two hatchery cutthroat trout broodstocks were planted in the USRW or that there are two native cutthroat trout populations in the USRW.

At K = 6 (Figure 3a and Figure 3b), the rainbow trout cluster subdivided into two clusters that we labeled "Snoqualmie 1 and Snoqualmie 2", tan and orange, respectively. We suspected that one of these clusters might be native rainbow trout and the other might be derived from hatchery rainbow trout planted in the basin. In Figure 3b we break down the K = 6 plot into its clusters to more easily see the distributions of ancestries in each collection. Each different color represents a different genetic group (cluster) identified by the analysis and these are named by the most common known member of the genetic group; eg. the first cluster (identified by blue color) is occupied by Lake Whatcom cutthroat trout, a known cutthroat trout broodstock stocked in the USRW, and several trout from the USRW. The USRW trout were of unknown ancestry and we hypothesized that these were derived from Lake Whatcom broodstock since the analysis grouped them in the cluster occupied by Lake Whatcom cutthroat trout and this broodstock had been planted in the basin. This breakdown into individual clusters allows the viewer to easily see whether fish are of one type—have pure ancestry (one color in color bar)—or if they are mixed ancestry (more than one color). One can also see that there are some USRW individuals in the Lake Whatcom Ocl cluster, a few more individuals in the Cedar Ocl cluster, three individuals in the Twin Lakes Ocl cluster (note: these particular fish had been field-identified as westslope cutthroat trout), but that most USRW trout cluster in their own cutthroat trout (SnoqOcl) and rainbow trout (SnoqOmy1, SnoqOmy2) clusters. This breakdown plot also shows more clearly the division among the rainbow trout collected in the USRW (SnoqOmy1 and SnoqOmy2).

We explored further the two rainbow trout groups identified in the USRW rainbow trout collection, and considered the possibility that the USRW rainbow trout had native and hatchery ancestry. We conducted a second STRUCTURE analysis in which we included archived data from hatchery rainbow trout that may have been planted in the basin as well as some native rainbow trout from Puget Sound (results not shown). This data was from several years ago with a mostly different suite of microsatellite loci. There were five loci in common with the contemporary data such that the analysis had less power to resolve genetic differences at the population level, but was still informative for the origins of the rainbow trout in the USRW. This analysis yielded insights into the identity of the two Snoqualmie rainbow trout groups: the "SnoqOmy1" rainbow trout group in Figures 4a and 4b shared ancestry with hatchery rainbow trout, in particular the broodstock from Goldendale Hatchery, suggesting that they were derived from hatchery rainbow trout. Marshall et al. (2006) similarly found that rainbow trout in the upper Cedar River from Chester Morse Lake were derived from exotic hatchery rainbow trout. The rainbow trout broodstock housed at Tokul Creek Hatchery since 1974 were "Mt. Whitney" strain that had been reared at Goldendale Hatchery during their history (Crawford 1979). The "SnoqOmy2" rainbow trout group in Figures 4a and 4b shared ancestry with native rainbow trout from the Cedar River, suggesting that they were native rainbow trout.

We used the STRUCTURE results to identify genetic origins of individual USRW trout (Table 6). Genetic identities are tabulated with field data in Table 7. Several USRW cutthroat trout and some isolated trout collected as rainbow trout clustered with the Cedar River cutthroat trout in the STRUCTURE analysis and were identified as "Cedar cutthroat" in Table 6 and Table 7. These may be cutthroat trout from a hatchery broodstock that had been planted in both Cedar and Snoqualmie rivers or another native cutthroat trout population founded from common ancestors. However, only Lake Whatcom-origin coastal cutthroat trout broodstock are recorded for Tokul Creek Hatchery (Crawford 1979), which was a main source of hatchery cutthroat trout planted in USRW. Crawford (1979) describes another coastal cutthroat trout broodstock developed for introduction in Puget Sound tributaries that had origins in the Stillaguamish and Nooksack rivers. This broodstock would likely be genetically more closely related to Lake Whatcom broodstock from North Puget Sound (rather than the Cedar River cutthroat trout if they are a native population) and there are no records of planting this other broodstock in USRW. (Note: the STRUCTURE analysis was conducted also including cutthroat trout collections from Minter and Bear creeks and Lake Washington, all from South Puget Sound. The Cedar River cutthroat trout [and some of the Snoqualmie cutthroat trout] grouped with these populations. This suggests either that the "Cedar" cutthroat trout are a native South Puget Sound cutthroat trout population or (less likely) that the same hatchery cutthroat trout were introduced in all these basins.) At this time we lack details on hatchery broodstocks planted in USRW (current information is mostly limited to numbers of hatchery fish without identifying broodstock) to examine the relationship between Cedar and Snoqualmie cutthroat trout and merely present these ideas based on the data available to this study.

The STRUCTURE analysis also suggested that several fish from USRW had mixed ancestry. The mixtures included several combinations such as a mix of hatchery and wild cutthroat trout (eg. Lake Whatcom Ocl and Snoqualmie Ocl), a mix of species with native ancestry (eg. Snoqualmie Ocl and Snoqualmie Omy2), or a mix of species and hatchery and wild ancestries (eg. Lake Whatcom Ocl and Snoqualmie Omy2).

The factorial correspondence analysis (FCA) from GENETIX supported the results from the STRUCTURE analyses. Individual fish plot in the genetic space created by axes that explain the most genetic variance in the data set. The first axis has the greatest genetic variance and cutthroat trout and rainbow trout separate along that axis (Figure 4). The separation is somewhat difficult to see since there is a continuum of distribution for the USRW trout. This continuum is due to mixing within the USRW collections in that some rainbow trout were identified as cutthroat trout or included in the collection that was predominantly cutthroat trout and *vice versa*. There was also genetic mixing within individuals since STRUCTURE suggested that several individuals from both USRW collections were hybrids or introgressed (had ancestry from both species). The cutthroat trout separate along the second axis and three individuals from the USRW rainbow trout collection plot with the westslope cutthroat trout from Twin Lakes Hatchery. STRUCTURE also identified these individuals as Twin Lakes Hatchery origin and these fish were identified in the field as westslope cutthroat trout.

We saw no evidence in the FCA for golden trout (*Oncorhynchu aguabonita*) among the USRW trout. In this type of analysis, fish with very different genetic profiles, such as golden trout or brook trout (*Salvilinus fontinalis*), would separate from all other fish in the plot. However, all fish clustered with either the rainbow trout or the cutthroat trout, suggesting that there were no golden trout or fish with partial golden trout ancestry.

We conducted the FCA with the archived WDFW data (five microsatellite loci) described above to gain more insights into genetic relationships and the ancestry of the USRW trout. Figure 5a shows the FCA with a plot of only the collection centers (the genetic information is collapsed into the center of the genetic distribution for each collection). In Figure 5a, the USRW 09IJ (mainly cutthroat trout) collection center is associated with other coastal cutthroat trout collection centers and the USRW 09IK (mainly rainbow trout but at least 30% cutthroat trout) collection center is between the coastal cutthroat trout and the rainbow trout. This placement reflects the mix of rainbow trout and cutthroat trout in the USRW 09IK trout collection suggested in the STRUCTURE analysis. Figure 5b and Figure 5c show the individual USRW 09IJ and 09IK trout, respectively, plotted in relation to the collection centers. This makes it easier to see that there was a mix of species in both USRW collections, especially in the 09IK collection.

Longitudinal and inter-basin patterns in species composition:

North Fork Snoqualmie River

In the upper North Fork a majority of the trout lineage matched pure Lake Whatcom hatchery coastal cutthroat (85%). In the Lakebed segment only three trout were sampled, but each contained different genetic backgrounds. None were pure native ancestry, but one matched native *O. mykiss* genetic ancestry. From the downstream border of the Lakebed segment downstream to the confluence with the Middle Fork a majority of samples matched hatchery-lineage rainbow trout (69%). However, the presence of pure native Snoqualmie coastal cutthroat trout (Snoq. *O. clarki*) increased in the Three Forks segment near the confluence with the Middle Fork (Figures 6 and 7).

Middle Fork Snoqualmie River

In the upper Middle Fork only four trout were sampled in the Hardscrabble reach, but all were mixed native and hatchery trout genetic ancestry (Table 7). Downstream of Hardscrabble to the confluence with the North Fork the majority of trout matched pure native coastal cutthroat trout genetic lineage (76%, Snoq. *O. clarki*; Figures 6 and 7).

South Fork Snoqualmie River

Samples from the Denny Creek segment of the upper South Fork (n = 4) were all pure or hybridized westslope cutthroat genetic lineage, suggesting they were derived from planted hatchery fish. No samples obtained in the upper and middle South Fork matched pure native Snoq. *O. clarki*. Conversely, most matched a pure genetic lineage of native Cedar *O. clarki* (29%), Cedar *O. mykiss* (29%) or hybridized Cedar *O. clarki* /*O. mykiss* (20%). The Asahel Curtis segment of the upper South Fork and Tinkham segment of the middle South Fork contained the highest proportions of pure Cedar *O. clarki* (62%) and hybridized Cedar *O. clarki* /*O. mykiss* (19%). No coastal cutthroat trout of native lineage were sampled in the Weeks Falls and Grouse Ridge segments, but hybrid Cedar *O. clarki* /*O. mykiss* (21%) and pure Cedar *O. mykiss* (50%) represented the majority of genetic samples in those segments. A few mixed native/hatchery rainbow and coastal cutthroat trout were also sampled in these segments (25%). In the lower South Fork downstream of Twin Falls genetically pure hatchery rainbow trout were sampled (8%) as were pure native rainbow trout (Cedar *O. mykiss*, 16%) along with hybrid rainbow and coastal cutthroat trout (Snoq. *O. clarki* and Cedar *O. clarki* /Cedar *O. mykiss*, 18%). Mixed native-lineage coastal cutthroat trout (Snoq. *O. clarki*/ Cedar *O. clarki*, 5%) were sampled in the lower South Fork as were hatchery/ native mixed coastal cutthroat (5%) and hatchery/ native mixed hybrids (13%). Between the Sallal Prairie segment and the North Bend - Three Forks segments the proportion of genetically pure native coastal cutthroat (Snoq. *O. clarki*) increased (7% v. 50%, Figures 6 and 7).

Mainstem Snoqualmie and the Three Forks segments

In the three forks segment of each fork numbers of pure native coastal cutthroat increased and this pattern continued into the mainstem Snoqualmie River. A majority of samples consisted of pure Snoq *O. clarki* (Figures 6 and 7).

Discussion

The trout collected in the USRW are a complex mix of native coastal cutthroat trout, native rainbow trout, introduced hatchery rainbow trout, introduced hatchery coastal and westslope cutthroat trout, and fish with mixed hatchery and wild ancestry of both species. Although golden trout were planted in the system, we found no evidence suggesting that the collection included golden trout. We identified native trout by comparing USRW trout genetically to local native trout populations and to hatchery rainbow and cutthroat trout that had been stocked in the region. Native Snoqualmie cutthroat trout were genetically more similar to native South Puget Sound cutthroat trout than to hatchery cutthroat trout whose original broodstock was from North Puget Sound. Further, the Snoqualmie cutthroat trout were distinct from other South Puget Sound cutthroat trout, indicating that they were restricted to the Snoqualmie River. Native Snoqualmie rainbow trout were also distinct in comparisons to hatchery and native Puget Sound rainbow trout.

North Fork Snoqualmie River

The majority of trout in the upper and middle North Fork sections were of hatchery origin, which might suggest that native trout production is inherently limited in these sections. We found weak genetic signals of native *O. clarki* and *O.mykiss* in individuals sampled from these sections, but native genetic signals were overwhelmed by hatchery genetic signals. Habitat in the Calligan and Black Canyon river segments seem to be the least diverse as off-channel habitat is more limited compared to other segments in the USRW (Thompson et al. 2011). The combination of low production and a lack of habitat diversity may have rendered native populations more vulnerable to colonization by introduced hatchery lineages. Hatchery fish introduced in multiple sequential plantings may have been relatively unchallenged if there were few native fish and little habitat complexity and thus no specialized niche for native fish. In contrast, the lower North Fork contained a greater density of complex habitat and higher trout production than other North Fork river sections (Thompson et al. 2011) and also contained the only pure native trout encountered in the North Fork during this study.

Middle Fork Snoqualmie River

Native coastal cutthroat trout dominated the species composition and distribution in the Middle Fork (Snoqualmie *O. clarki* 74% of genetic samples). Some unidentified Pacific trout were sampled in the upper and lower Middle Fork, but overall native coastal cutthroat trout were the most abundant game fish in all river sections of the Middle Fork. In contrast to the North Fork, the Middle Fork is productive and contains a highly diverse system of habitats (Thompson et al. 2011). These two factors probably helped native trout outcompete their introduced hatchery counterparts as high numbers of locally-adapted native fish already occupied the wide array of habitats when less well-adapted hatchery-strains were being stocked into the Middle Fork.

South Fork Snoqualmie River

The South Fork contained the most diverse and complex composition of trout in the USRW. Westslope cutthroat dominated most of the steepest portions of the upper South Fork, but essentially were limited to this river section. Given that there are records for stocking this variety of hatchery cutthroat trout somewhere in the South Fork, it is likely that these westslope cutthroat trout are descendants of hatchery fish stocked into the South Fork or recruited from stocked alpine lakes. Since this variety has not been stocked lately, hatchery fish may have found an unoccupied or partially occupied niche and were thus unchallenged or maybe able to exploit the resources more effectively than the sparser native trout population, especially if they were stocked multiple times.

Downstream of the steep bedrock-cascade portion of the upper South Fork the channel levels off at the Asahel Curtis segment, the area where a high proportion of sampled fish were identified as native coastal cutthroat (Cedar *O. clarki*). The external characteristics of these cutthroat trout were distinct from cutthroat trout found in all other river segments (Thompson et al. 2011). They lacked the typical narrow, elongated body, the yellow body color, and did not have the pattern of spots that cover the entire body. Instead their spots were larger in diameter and more clustered on the posterior end of the fish, much like spotting on a westslope cutthroat (see Figure 24a). Native hybrids (Cedar *O. clarki*/ Cedar *O. mykiss*) were also found in the Asahel Curtis segment and native rainbow and hybrids were found in all South Fork river segments downstream of this point except the lowermost Three Forks segment. The Grouse Ridge and Weeks Falls segments in the Mid SF were heavily populated by native Cedar strain rainbow trout (50%) and hybrids (21%).

Interestingly, Snoqualmie-type native cutthroat and rainbow trout were limited to the lower portion of the South Fork below Twin Falls and Cedar-type native cutthroat and rainbow trout were found above Twin Falls. There is a causal mechanism for the high proportion of Cedar strain trout in the South Fork upstream of Twin Falls suggested by the most recent glacial activity in the USRW (c. 14,000 ybp, see Figure 8). Before the Vashon Lobe of the Cordilleran ice sheet protruded into the region now occupied by the USRW, the upper Cedar River was the acting ‘South Fork’ of the Snoqualmie. After the Vashon Lobe retreated from the USRW it left a number of moraines, one of which diverted the Cedar River away from the Snoqualmie basin. However, water from the Cedar River drainage continued to flow through the moraine in the direction of the Snoqualmie basin (Figure 8, MacKin 1941, Booth 1990, Bethel 2004, Fenner 2008). That porous moraine still exists and conveys groundwater from Masonry Pool in the upper Cedar River watershed to its western slopes where the spring-fed headwaters of Boxley Creek originate, eventually flowing into the South Fork Snoqualmie. Cedar River-type trout probably migrated into the South Fork prior to the last Cordilleran encroachment, and Twin Falls, which was exposed after the last Cordilleran retreat, subsequently blocked upstream colonization by Snoqualmie-type trout. Thus, it seems the timeline of glacial activity and exposure of Twin Falls as a barrier to upstream migration were the main influences on the current distribution of native trout varieties in the South Fork, which was also heavily stocked with both rainbow and cutthroat hatchery trout.

Hatchery fish introductions also appear to influence the genetic structure of trout in the lower South Fork. For example, a private hatchery operates downstream of Twin Falls on Boxley Creek and large-bodied hatchery rainbow trout that had escaped from holding ponds in the hatchery have been captured outside of the hatchery recently (Thompson et al. 2011). Confirmed hatchery rainbow trout, identified by genetic analysis, were found in this vicinity of the main stem South Fork and may have originated from this facility if trout commonly escape. It is unknown how many trout escape from this facility or other water bodies that contain hatchery fish (e.g., private ponds) but their genetic signature is found in the trout in the basin. More intensive genetic profiling centered on these water bodies might be warranted to determine the degree of influx and introgression of trout from the hatchery into the fishery.

Conclusion

The Puget Sound region has an interesting glacial and geologic history overlain by anthropogenic activities. Pleistocene glaciers blocked drainages and formed temporary impoundment lakes that spanned present-day watershed borders, creating dynamic interconnections among waterways and providing refuge lakes for native trout. Tectonic activities further altered landscape features, forming barrier falls within basins. Europeans moving into the area added another layer of complexity by creating anthropogenic barriers (e.g., culverts) and by planting hatchery fish. Further examination of location and genetic identities of trout in relation to detailed hatchery stocking history will inform fish managers on the impact of hatchery planting on native fish and the persistence of native fish in the Upper Snoqualmie River Watershed.

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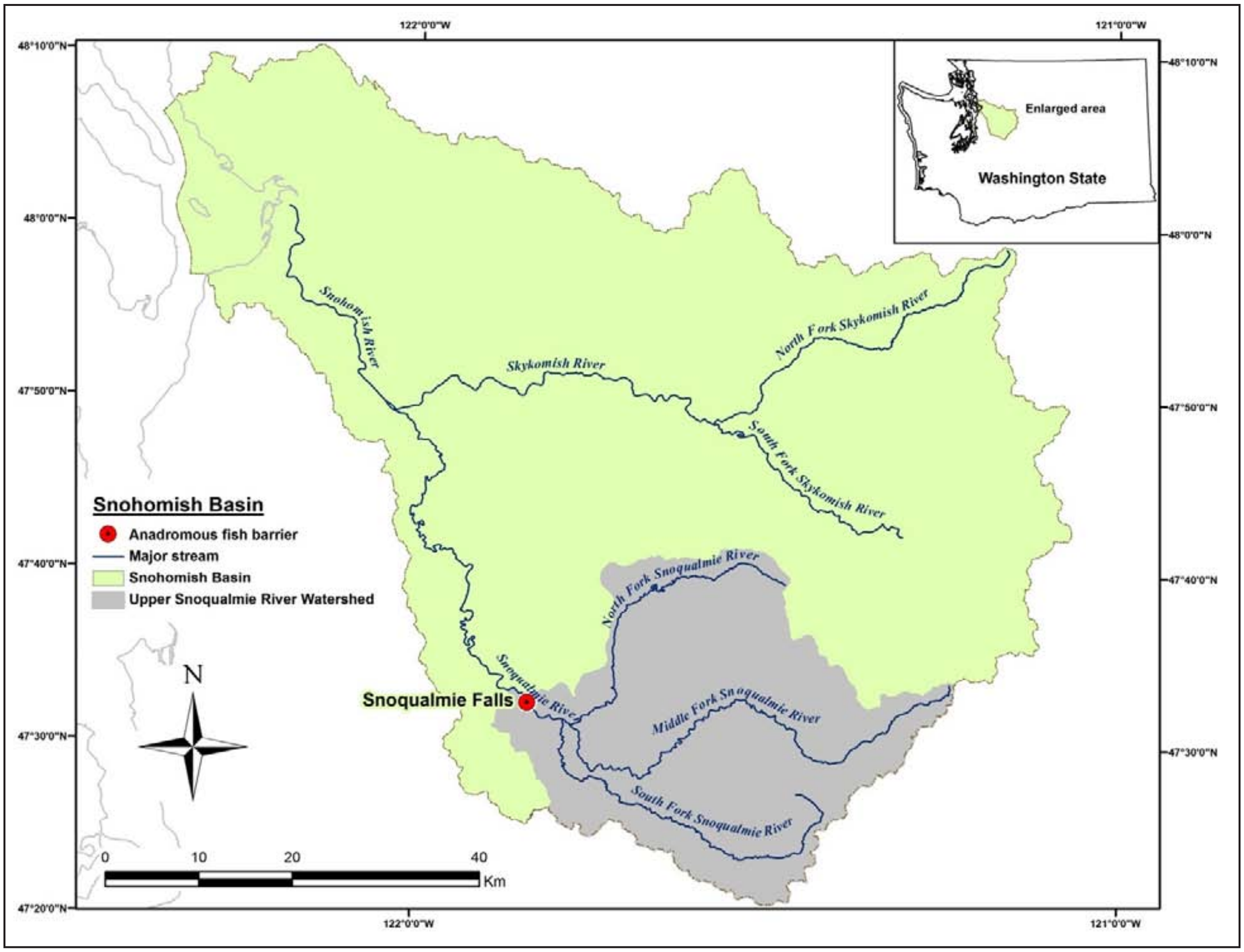

Figure 1. Map of the Snoqualmie, Skykomish and Snohomish watersheds. The upper Snoqualmie River watershed (USRW) is isolated by Snoqualmie Falls and is highlighted in grey.

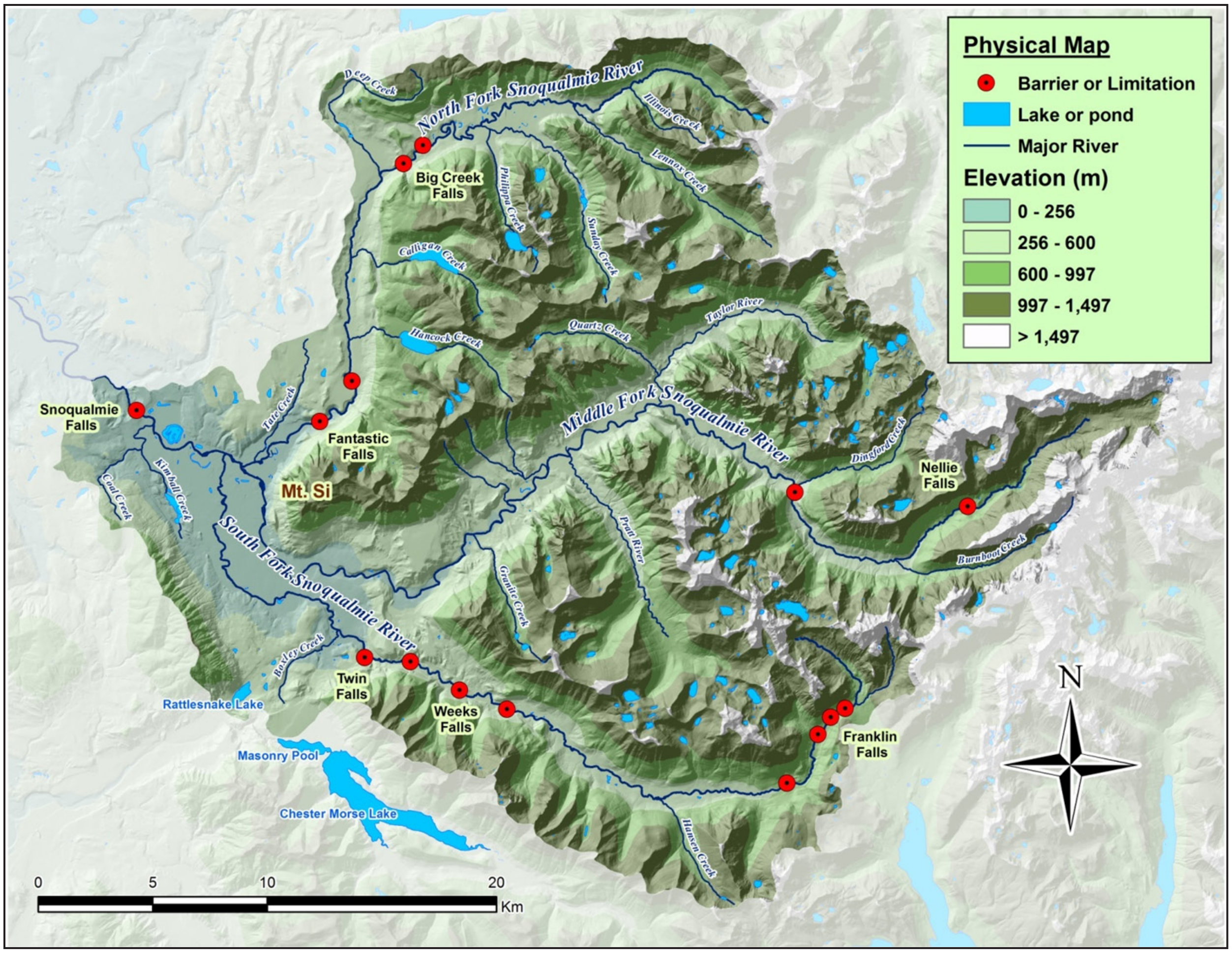

Figure 2. Physical map of the USRW showing the minimum known major barriers and limitations to fish movement. Chester Morse Lake and Masonry Pool (upper Cedar River watershed) are shown because they are linked to the South Fork Snoqualmie River through a glacial moraine near the headwaters of Boxley Creek.

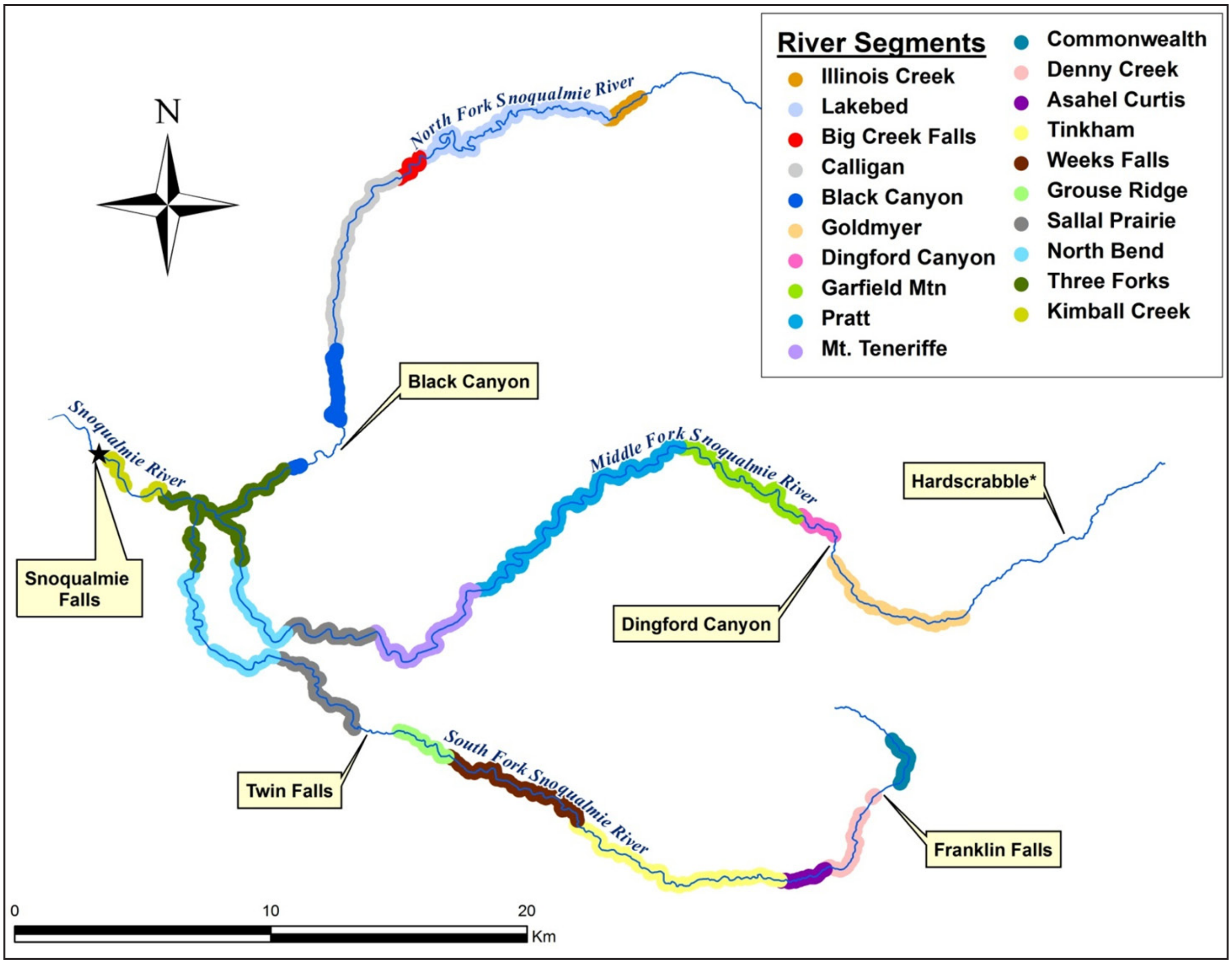

Figure 3. Color-coded river segment divisions show spatial strata for genetic sample collections. Genetic samples were obtained from each river segment and from the Hardscrabble reach in the upper Middle Fork Snoqualmie River, but were not obtained in the Commonwealth (Upper South Fork) or canyon/ falls reaches.

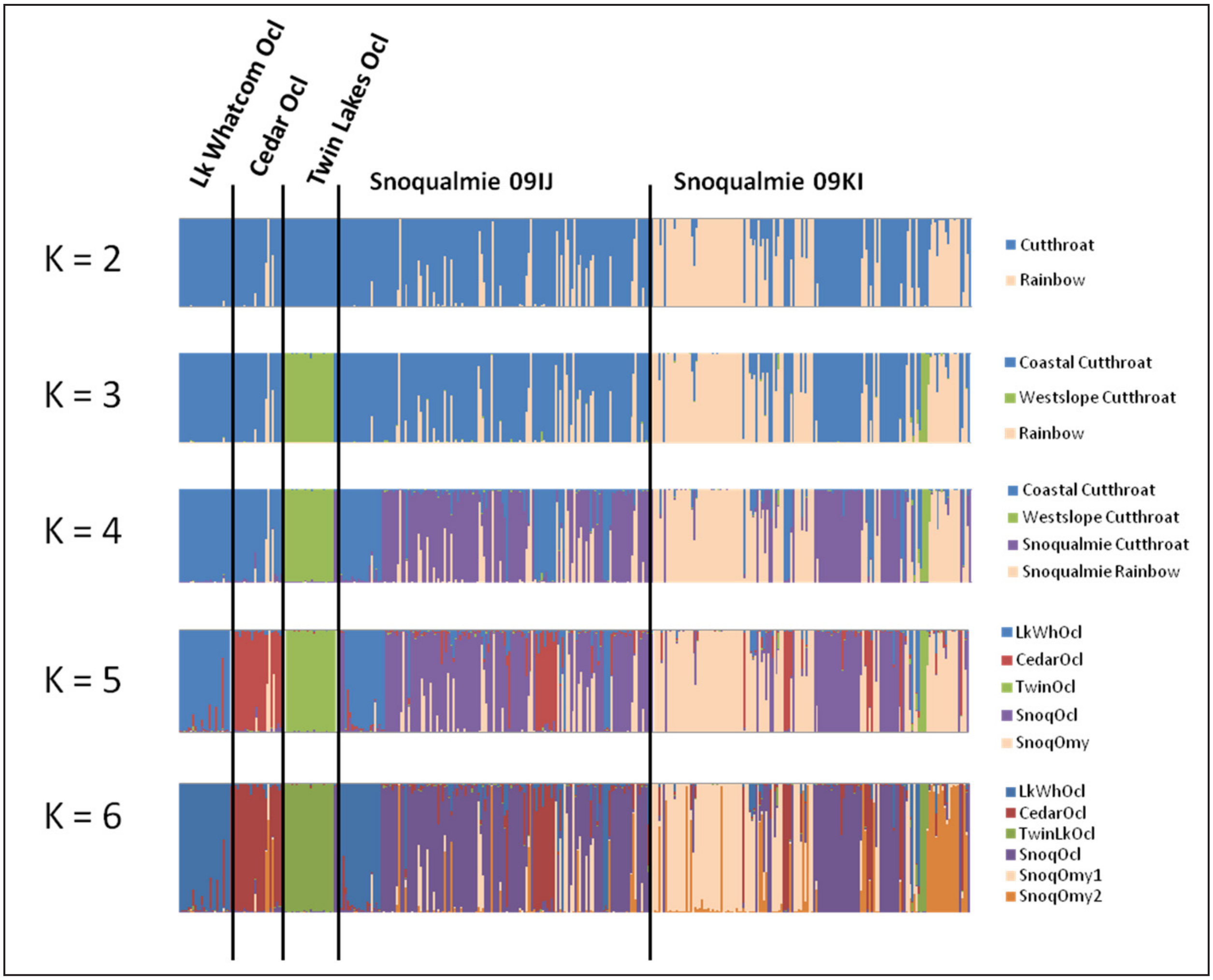

Figure 3a. STRUCTURE plot for K = 2 to K = 6. Each individual fish is represented by a bar of color, with the color corresponding to a genetic cluster or group. The genetic cluster is identified by the most common individuals in the cluster (e.g., at K = 3, one cluster is occupied by westslope cutthroat trout from Twin Lakes and the few unknown trout from the USRW that are also in that cluster are likely westslope cutthroat trout). Figure 3a shows the results of a hierarchical analysis where at increased K values, the data set partitioned according to species and then according to geographic structure and hatchery broodstocks. At K = 2, there are two genetic groups and these are occupied by cutthroat trout and rainbow trout. At K = 3, the westslope cutthroat trout break away from the coastal cutthroat trout and occupy their own cluster. At K = 4, the Snoqualmie cutthroat trout break away from the coastal cutthroat trout and occupy their own cluster. At K = 5, the Cedar cutthroat trout break away from the coastal cutthroat trout and occupy their own cluster and the Lake Whatcom cutthroat trout remain in a single cluster that includes some USRW cutthroat trout that were likely derived from Lake Whatcom broodstock. At K = 6, the Snoqualmie rainbow trout break into two clusters, 1) a putative hatchery rainbow trout cluster and 2) a putative native rainbow trout cluster. At K = 6 clusters are named as follows: Lake Whatcom coastal cutthroat trout = LkWhOcl, Cedar River coastal cutthroat trout = CedarOcl, Twin Lakes westslope cutthroat trout = TwinOcl, Snoqualmie coastal cutthroat trout = SnoqOcl, Snoqualmie rainbow trout = SnoqOmy1 (hatchery rainbow) and SnoqOmy2 (native rainbow).

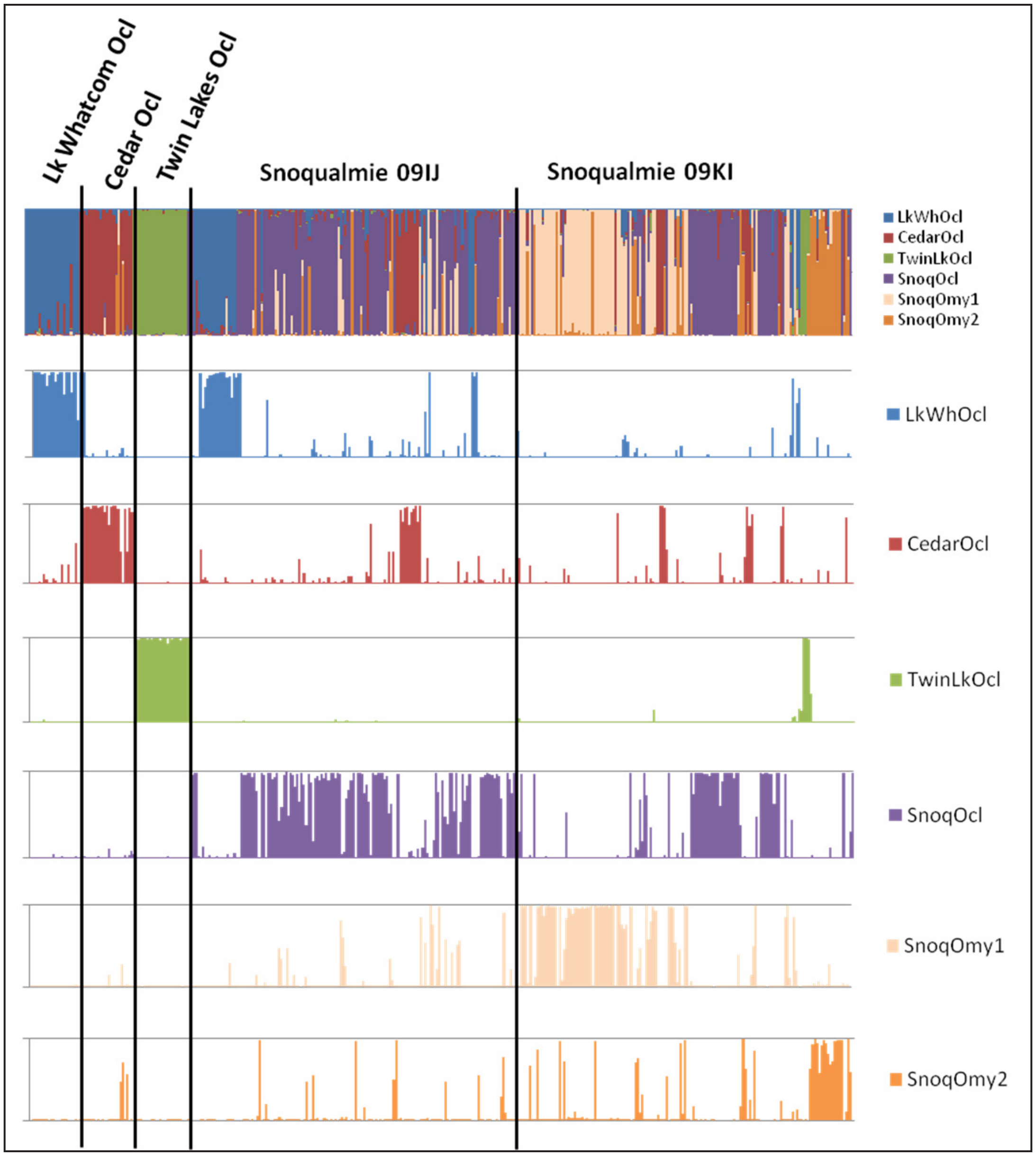

Figure 3b. This shows the breakdown of the STRUCTURE result for K = 6 from Figure 3a. The plot at the top is decomposed into its individual clusters below to enhance viewing of individual fish and membership in clusters (genetic groups). The genetic groups are labeled according to the most common member in the genetic group and nomenclature follows Figure 3a.

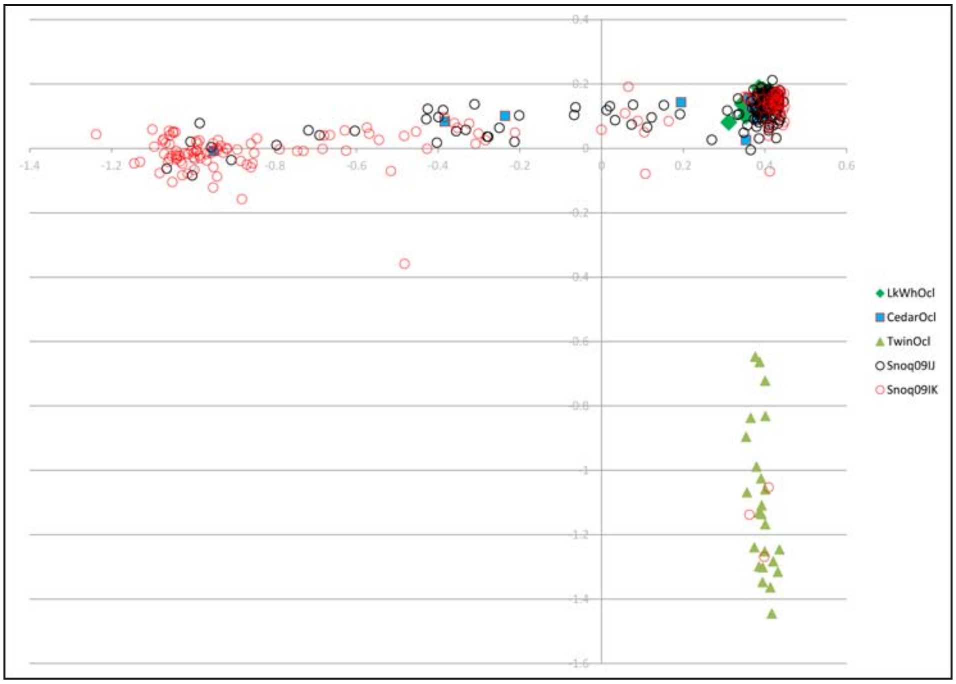

Figure 4. Factorial correspondence analysis (FCA) from GENETIX. Each individual fish is plotted in two dimensional space defined by two axes that explain the maximum amount of genetic variance in the data set. Individuals were genotyped with the full suite of loci (microsatellites and SNPs). Each collection type is indicated by a unique marker (Lake Whatcom coastal cutthroat trout = LkWhOcl, Cedar River coastal cutthroat trout = CedarOcl, Twin Lakes westslope cutthroat trout = TwinOcl, Snoqualmie 09IJ (mostly cutthroat trout) = Snoq09IJ and Snoqualmie 09IK (mostly rainbow trout) = Snoq09IK. Note: the USRW rainbow trout plotted with the Twin Lakes westslope cutthroat trout had been identified in the field as possible westslope cutthroat trout (see Table 6). Also note: many cutthroat trout plotted close to or on top of each other on the right side of the first axis. See Figure 5a for plot of collection centers rather than individuals.

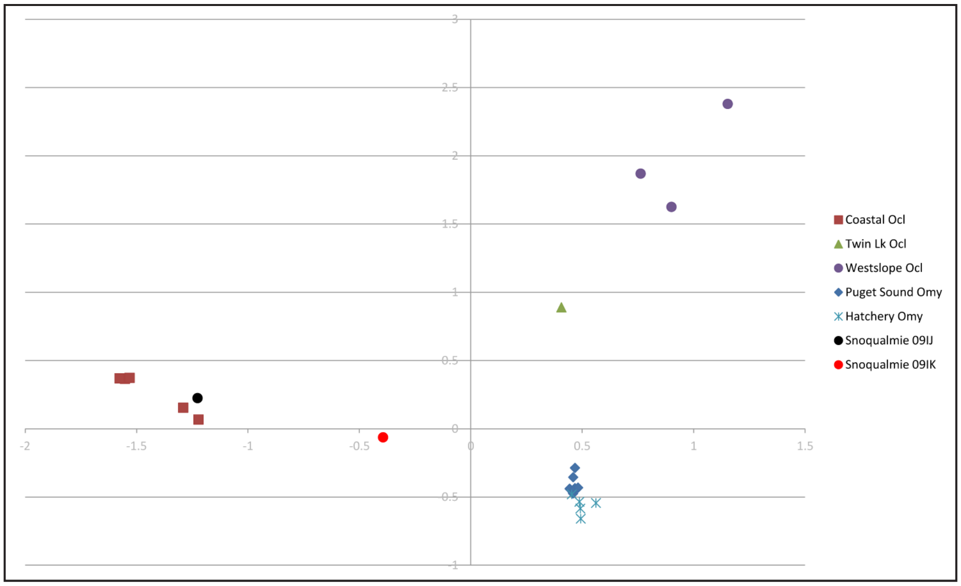

Figure 5a. FCA plot with contemporary and archived WDFW data comparison (five microsatellite loci). Only collection centers are shown in this plot; the collection center is the center of the distribution of all the individuals in the genetic space defined by the axes in the FCA. In addition to Lake Whatcom and Cedar River coastal cutthroat trout, the analysis included two other cutthroat trout collections from Puget Sound from Bear and Minter creeks (all listed as "Coastal Ocl). The Snoqualmie 09IJ (mostly cutthroat trout) cluster with the coastal cutthroat trout collections. The westslope cutthroat trout collections included Twin Lakes Hatchery broodstock (Twin Lk Ocl) and three collections from the Pend Oreille basin (westslope Ocl). The Puget Sound rainbow trout (Puget Sound Omy) included eight collections from Puget Sound tributaries (Cedar, Green and Puyallup rivers and Chester Morse Lake). Also included are four hatchery rainbow trout broodstocks (Hatchery Omy) that had been planted throughout Washington State. The Puget Sound Omy and the Hatchery Omy separated from each other on the third axis (not shown in this plot). Note that the Snoqualmie 09IK (mostly rainbow trout) plotted between the cutthroat trout and the rainbow trout collection centers since cutthroat trout were mixed in with the rainbow trout.

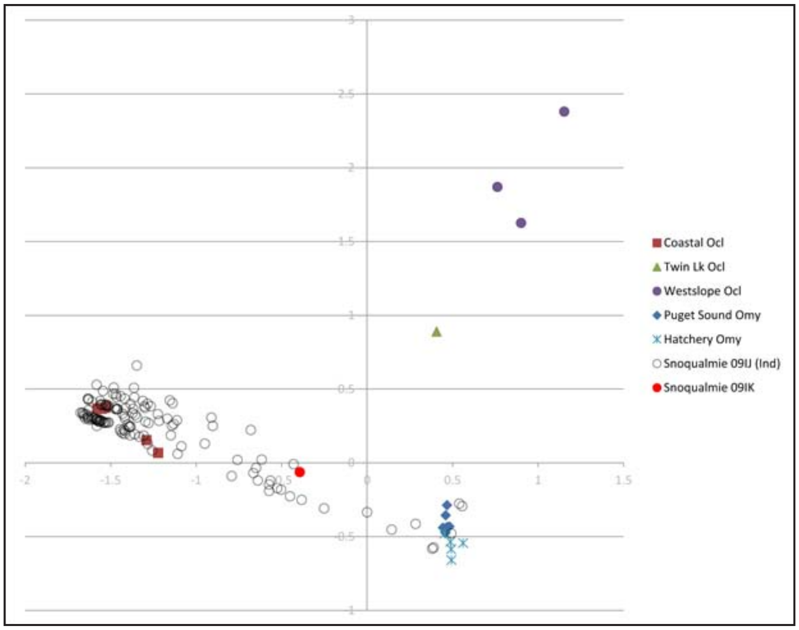

Figure 5b. The Snoqualmie 09IJ individuals (ind, mostly cutthroat trout) are plotted over the collection centers in the FCA plot from Figure 5a.

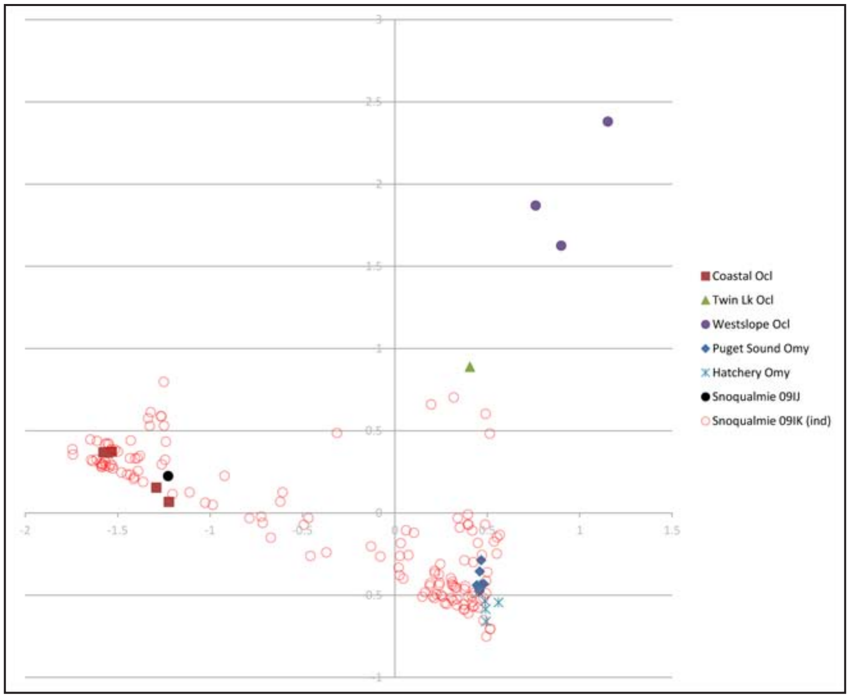

Figure 5c. The Snoqualmie 09IK individuals (ind, mostly rainbow trout) are plotted over the collection centers in the FCA plot from Figure 5a.

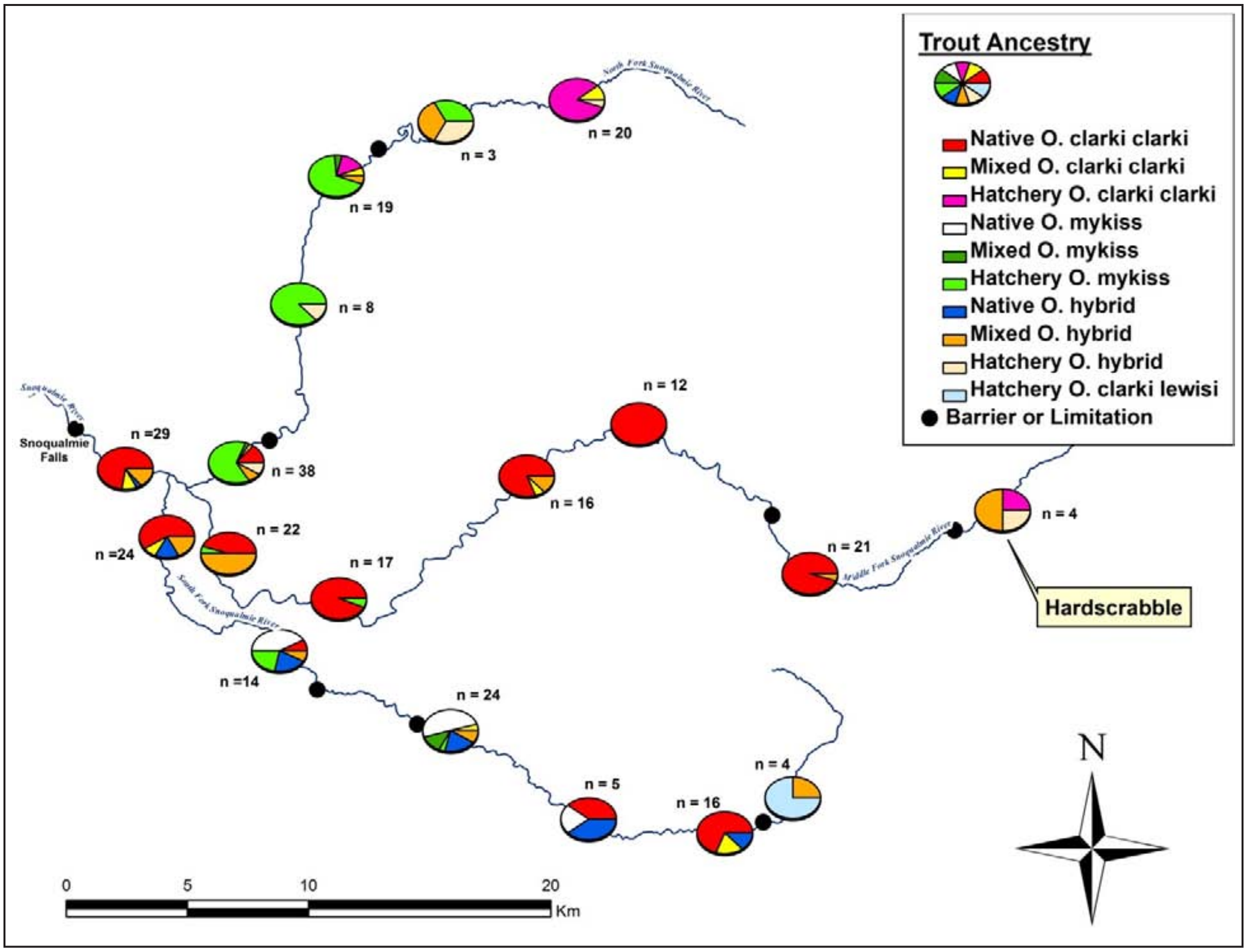

Figure 6. Inter-basin distribution of native and hatchery-origin lineages of Pacific trout in the USRW. Pie charts represent approximate sample locations. Captions next to pie charts indicate the total sample size for each pie chart. Species abbreviations: *O. clarki clarki* = coastal cutthroat, *O. mykiss* = rainbow trout, *O*. hybrid = hybrid between Pacific trout species.

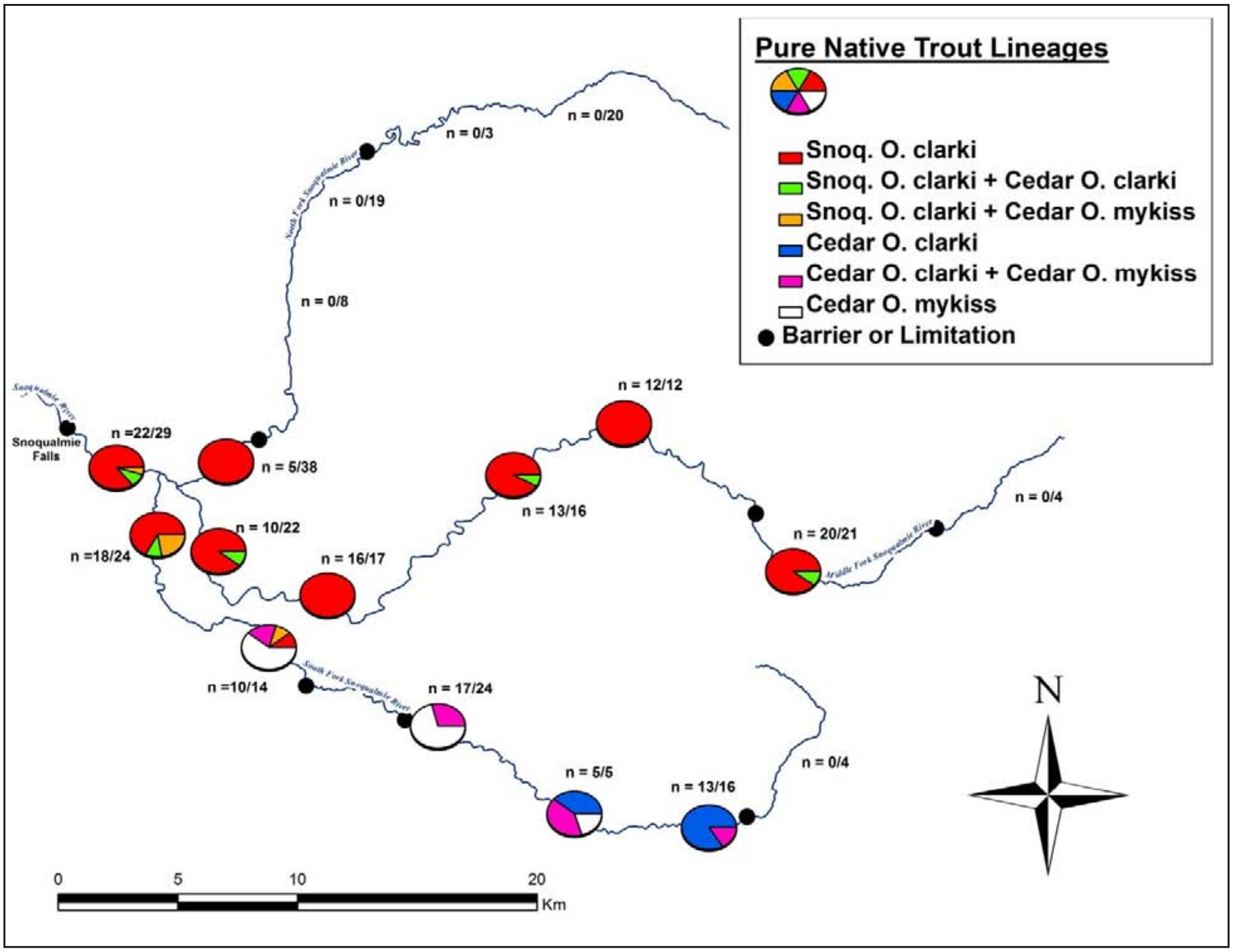

Figure 7. Inter-basin distribution of pure native lineage Pacific trout in the USRW. Pie charts represent approximate sample locations. Captions next to pie charts indicate a ratio of the total number of pure native trout per total sample size for each river segment. Abbreviations: Snoq. = upper Snoqualmie River watershed, Cedar = Cedar River watershed, *O. clarki* = coastal cutthroat, *O. mykiss* = rainbow trout.

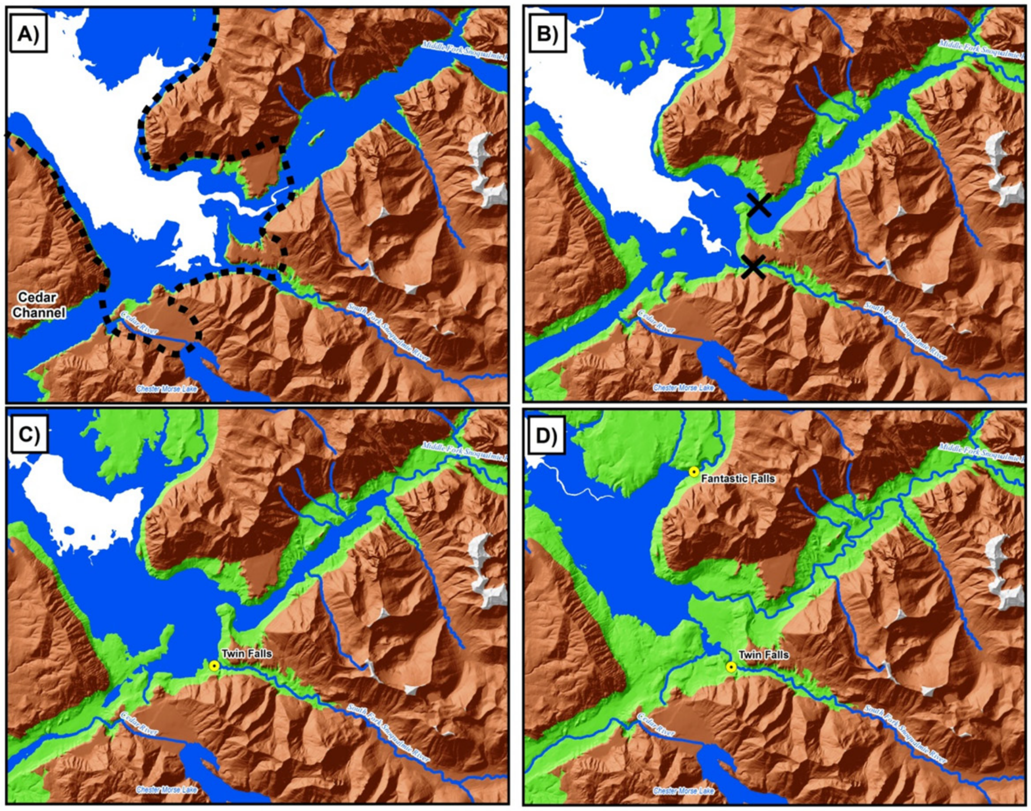

Figure 8. Conceptual illustration of the latter stages of the Vashon-Puget glacial recession (white) from the USRW (A–D: relative oldest to more recent periods). The Cedar Channel served as the original outlet of Lake Snoqualmie (blue – panel A), where native Cedar-strain coastal cutthroat and rainbow trout moved freely between the Cedar and Snoqualmie drainages. The furthest eastern extent of glacial encroachment in the USRW (black hashes – panel A) was located at the Grouse Ridge (upper X) and Cedar (lower X) moraines (panel B), which blocked the South Fork, Middle Fork, and upper Cedar River valleys until both moraines were eroded at differing rates during later periods (panels C and D). See additional conceptualizations in (MacKin 1941).

Table 1a. History of hatchery Pacific trout stockings in the North Fork, USRW (1933–1989). Stocking data were queried from 0–94Relhistoric.mdb, Stocking data were categorized by river section where release location data were available.

				1933–1989					
Fork	River Section*	Hatchery Facility	Stock	Coastal cutthroat	Cutthroat	Rainbow	Westslope cutthroat	Golden	Total
North Fork					**422,426**	**1,345,422**			**1,767,848**
	Up				18,410	17,925			36,335
		Arlington			*2,996*				*2,996*
		Tokul Creek			*15,414*	17,925			*33,339*
	Mid				*52,170*	466,943			519,113
		Arlington				55,980			*55,980*
		Tokul Creek			*52,170*	410,963			*463,133*
	Low				23,000	134,252			157,252
		Arlington				12,537			*12,537*
		Seward Park				4,756			*4,756*
		Tokul Creek			*23,000*	116,959			*139,959*
	Unspecified				328,846	726,302			1,055,148
		Arlington				7,600			*7,600*
		Seward Park			*6,000*	177,160			*183,160*
		Tokul Creek			*322,846*	510,542			*833,388*
		Tokul Creek	*Mt. Whitney*			*31,000*			*31,000*

*All stocked bodies of water that drain into the specified River Section were pooled; includes ponds, lakes, tributaries and main stem channels.

Table 1b. History of hatchery Pacific trout stockings in the Middle Fork, USRW (1933–1989). Stocking data were queried from 0–94Relhistoric.mdb, Stocking data were categorized by river section where release location data were available.

				1933–1989					
Fork	**River Section***	**Hatchery Facility**	**Stock**	**Coastal cutthroat**	**Cutthroat**	**Rainbow**	**Westslope cutthroat**	**Golden**	**Total**
Middle Fork					**419,002**	**1,406,899**		**5,984**	**1,831,885**
	Up				20,406	6,909		5,984	33,299
		Arlington			*750*				750
		Lakewood				3,134			3,134
		Naches			*9,000*				9,000
		Tokul Creek			*10,656*	3,775		5,984	20,415
	Mid				108,344	296,363			404,707
		Arlington				12,720			12,720
		Montlake				600			600
		Montlake	*Mt. Whitney*			900			900
		Tokul Creek			*108,344*	282,143			390,487
	Low					300			300
		Tokul Creek				300			300
	Unspeci-fied				290,252	1,103,327			1,393,579
		Arlington				5,140			5,140
		Chiwaukum			*10,500*				10,500
		Lakewood				7,099			7,099
		Naches				3,060			3,060
		Seward Park			*1,300*	115,975			117,275
		Tokul Creek			*278,452*	921,653			1,200,105
		Tokul Creek	*Mt. Whitney*			*50,400*			*50,400*

*All stocked bodies of water that drain into the specified River Section were pooled; includes ponds, lakes, tributaries and main stem channels.

Table 1c. History of hatchery Pacific trout stockings in the South Fork and Mainstem Snoqualmie, USRW (1933–1989). Stocking data were queried from 0–94Relhistoric.mdb, Stocking data were categorized by river section where release location data were available.

				1933–1989					
Fork	**River Section***	**Hatchery Facility**	**Stock**	**Coastal cutthroat**	**Cutthroat**	**Rainbow**	**Westslope cutthroat**	**Golden**	**Total**
South Fork				2,255	732,610	1,139,936	720		1,875,521
	Up				151,443	129,302			280,745
		Arlington				*900*			*900*
		NMFS				*600*			*600*
		Seward Park				*10,000*			*10,000*
		Tokul Creek			*151,443*	*117,802*			*269,245*
	Mid				66,100				66,100
		Tokul Creek			*66,100*				*66,100*
	Low				16,822	1,156			17,978
		Tokul Creek			*16,822*				*16,822*
		Tokul Creek	*Mt. Whitney*			*1,156*			*1,156*
	Unspecified			2,255	498,245	1,009,478	720		1,510,698
		Kittitas			*50,000*	*25,000*			*75,000*
		N/A			*1,488*				*1,488*
		Naches				*3,060*			*3,060*
		Puyallup Tribal				*4,000*			*4,000*
		Rattlesnake Lk			*67*				*67*
		Seward Park			*7,000*	*291,313*			*298,313*
		Tokul Creek			*439,690*	*645,072*			*1,084,762*
		Tokul Creek	*Twin Lakes*				*720*		*720*
		Tokul Creek	*Mt. Whitney*			*41,033*			*41,033*
		Tokul Creek	*Lk. Whatcom*	*2,255*					*2,255*
Mainstem					12,527	208,333			220,860
	Low				*12,527*	*208,333*			*220,860*
		Seward Park				*23,941*			*23,941*
		Tokul Creek			*12,527*	*184,392*			*196,919*
Total		**Grand Total**		**2,255**	**745,137**	**1,348,269**	**720**	**0**	**2,096,381**

*All stocked bodies of water that drain into the specified River Section were pooled; includes ponds, lakes, tributaries and main stem channels.

Table 1d. History of hatchery Pacific trout stockings in the USRW (1990–2007). Stocking data were queried from 0–94Relhistoric.mdb, Stocking data were categorized by river section where release location data were available.

				1990–2007					
Fork	River Section*	Hatchery Facility	Stock	Coastal cutthroat	Cutthroat	Rainbow	Westslope cutthroat	Golden	Total
Middle Fork						**2745**			**2745**
	Up					*150*			*150*
		Tokul Creek	*Mt. Whitney*			*150*			*150*
	Mid					*2595*			*2595*
		Tokul Creek				*2070*			*2070*
			Mt. Whitney			*525*			*525*
South Fork						**2140**	**3260**		**5400**
	Unspecified					*2140*	*3260*		*5400*
		Tokul Creek	*Goldendale - McCloud*			*1260*			*1260*
		Tokul Creek	*Twin Lakes*				*3260*		*3260*
		Tokul Creek	*Mt. Whitney*			*880*			*880*
Mainstem					**600**	**2038**			**2638**
	Low				*600*	*2038*			*2638*
		Arlington	*Goldendale - McCloud*			*1296*			*1296*
		Arlington	*Spokane*			*342*			*342*
		Puyallup	*Goldendale - McCloud*			*400*			*400*
		Tokul Creek			*600*				*600*
Snoqualmie Police Ponds	n/a	*Tokul Creek*	*Goldendale - McCloud*			*744*			**744**
Unspecified High Lake	n/a	*Reiter Ponds*						*100*	**100**
Total				**0**	**600**	**7667**	**3260**	**100**	**11627**

*All stocked bodies of water that drain into the specified River Section were pooled; includes ponds, lakes, tributaries and main stem channels.

Table 2. Number of trout samples collected among river sections and segments in the upper Snoqualmie River watershed (USRW).

River Section	River Segment	Sample size (n)
Upper North Fork		**20**
	Illinois Creek	20
Middle North Fork		**30**
	Lakebed	3
	Big Creek Falls	16
	Calligan	3
	Black Canyon	8
Lower North Fork		**38**
	Black Canyon	27
	Three Forks	11
Upper Middle Fork		**25**
	Hardscrabble	4
	Goldmyer	18
	Dingford	3
Middle Middle Fork		**28**
	Garfield Mtn.	12
	Pratt	16
Lower Middle Fork		**39**
	Mt. Teneriffe	14
	Sallal Prairie	3
	North Bend	21
	Three Forks	1
Upper South Fork		**20**
	Denny Creek	4
	Asahel Curtis	16
Middle South Fork		**29**
	Tinkham	5
	Weeks Falls	11
	Grouse Ridge	13
Lower South Fork		**38**
	Sallal Prairie	14
	North Bend	22
	Three Forks	2
Upper Mainstem		**21**
	Three Forks	21
Lower Mainstem		**8**
	Three Forks	8
Total		**296**

Table 3. Microsatellite and SNP loci used in Snoqualmie River trout genetic study. To simplify nomenclature, WDFW gives SNP loci a nickname associated in the database with the original name. Both names are given in the table. Species ID SNPs are indicated by "SpI" in the WDFW nickname. Names are followed by the percentage of samples that were genotyped at each SNP locus "% genotyped".

	SNPS					
Microsatellites	**WDFW_name**	**AssayName:**	**% worked**	**WDFW_name**	**AssayName:**	**% worked**
Ogo-3	AOmy001	Omy_180	95.05%	AOmy125	Omy_u09-56.119	89.06%
Omm1138	AOmy004	Omy_ALDOA_1	84.64%	AOmy126	Omy_ADP-r3.159	31.77%
One-108	AOmy005	Omy_aspAT.123	96.09%	AOmy127	Omy_BAMBI2.312	90.10%
Ots-103	AOmy006	Omy_B1.266	95.57%	AOmy128	Omy_BAMBI4.112	95.05%
Omy-77	AOmy007	Omy_B9.164	0.00%	AOmy129	Omy_BAMBI4.238	95.57%
Ots-1	AOmy009	Omy_CRB_F_1	95.05%	AOmy131	Omy_G3PD_2.191	37.24%
Ots-3M	AOmy013	Omy_DM20_2_1	95.05%	AOmy132	Omy_G3PD_2.246	91.67%
	AOmy015	Omy_gdh.271	95.31%	AOmy133	Omy_G3PD_2.371	94.53%
	AOmy016	Omy_GH1P1_2	95.05%	AOmy134	Omy_Il-1b_.028	89.58%
	AOmy017	Omy_HOXD_1_1	95.05%	AOmy135	Omy_Il-8r1.101	95.05%
	AOmy018	Omy_ID_1	95.83%	AOmy136	Omy_MyoCL2.108	94.53%
	AOmy019	Omy_LDH	95.83%	AOmy137	Omy_u09-61.043	95.57%
	AOmy020	Omy_LDH.156	94.01%	AOmy138	Omy_u09-61.107	94.53%
	AOmy021	Omy_LDHB-2_e5	94.53%	AOmy139	Omy_u09-63.173	83.85%
	AOmy024	Omy_myo1a.264	0.00%	AOmy140	Omy_u09-64.062	91.93%
	AOmy027	Omy_nkef.241	95.57%	AOmy141	Omy_u09-64.108	0.00%
	AOmy036	Omy_sSOD	94.79%	AOmy142	Omy_u09-64.147	46.35%
	AOmy038	Omy_BAC-B4.324	0.00%	AOmy143	Omy_u09-66.139	95.57%
	AOmy039	Omy_BAC-B4.388	0.00%	AOmy144	Omy_UT16_2.173	0.00%
	AOmy040	Omy_BAC-F5.238	95.31%	AOmy145	Omy_BAC-B9.125	34.11%
	AOmy042	Omy_BAC-F5.284	94.79%	AOmy146	Omy_U11_2a.114	94.53%
	AOmy047	Omy_u07-79.166	95.57%	AOmy147	Omy_U11_2b.154	95.05%
	AOmy051	Omy_121713-115	95.57%	AOmy148	Omy_dacd1-131	95.05%
	AOmy055	Omy_127236-583	95.31%	AOmy149	Omy_gluR-79	95.05%
	AOmy062	Omy_97077-73	95.31%	AOmy150	0my_Il-1b.198	88.80%
	AOmy065	Omy_97954-618	95.83%	AOmy151	Omy_p53-262	69.27%
	AOmy067	Omy_aromat-280	33.07%	AOmy152	Omy_SECC22b-88	0.00%
	AOmy068	Omy_arp-630	31.77%	AOmy153	Omy_UT11_2.046	94.53%
	AOmy071	Omy_cd59-206	40.63%	ASpI001	Ocl_Okerca	81.25%
	AOmy073	Omy_colla1-525	95.57%	ASpI002	Ocl_Oku202	94.01%
	AOmy079	Omy_g12-82	88.80%	ASpI003	Ocl_Oku211	0.00%
	AOmy081	Omy_gh-475	95.83%	ASpI004	Ocl_Oku216	93.49%
	AOmy089	Omy_hsp-90BA-193	32.55%	ASpI005	Ocl_Oku217	95.31%
	AOmy092	Omy_IL1b-163	95.31%	ASpI006	Ocl_SsaHM5	0.00%
	AOmy100	Omy_nach-200	95.83%	ASpI007	Ocl_u800	66.67%
	AOmy103	Omy_nkef-308	92.71%	ASpI008	Ocl_u801	89.06%
	AOmy108	Omy_oxct-85	94.01%	ASpI009	Ocl_u802	95.31%
	AOmy110	Omy_star-206	95.57%	ASpI010	Ocl_u803	94.79%

Table 3. (Continued)

	SNPS					
Microsatellites	**WDFW_name**	**AssayName:**	**% worked**	**WDFW_name**	**AssayName:**	**% worked**
	AOmy111	Omy_stat3-273	94.53%	ASpI011	Ocl_u804	47.66%
	AOmy112	Omy_tgfb-207	95.31%	ASpI012	Omy_B9_228	95.05%
	AOmy113	Omy_tlr3-377	95.57%	ASpI013	Omy_CTDL1_243	96.88%
	AOmy114	Omy_tlr5-205	95.31%	ASpI014	Omy_F5_136	95.57%
	AOmy117	u09-52.284	95.83%	ASpI015	Omy_HOXD_287	0.00%
	AOmy118	Omy_u09-53.469	95.57%	ASpI016	Omy_myc-larp404-111	0.00%
	AOmy120	Omy_u09-54.311	95.57%	ASpI017	Omy_my-clgh1043-156	94.79%
	AOmy121	Omy_u09-55.112	96.09%	ASpI018	Omy_Omy-clmk436-96	92.71%
	AOmy123	Omy_u09-55.233	94.27%	ASpI019	Omy_RAG11_280	93.23%
	AOmy124	Omy_u09-56.073	94.53%	ASpI020	Omy_URO_302	94.79%

Table 4. Genetic variance per locus (% var) among populations from ARLEQUIN (invariant loci are indicated by "fixed"). Loci identified as under selection in the FST outlier test are highlighted in yellow. Variance for loci under directional selection loci are in pink.

Locus	% var	Locus	% var	Locus	% var
Ogo-3	27.31	AOmy065	21.61	AOmy137	0.27
Omm1138	24.18	AOmy073	21.81	AOmy138	-0.19
One-108	10.92	AOmy079	fixed	AOmy139	34.35
Ots-103	24.04	AOmy081	3.07	AOmy140	26.11
Omy-77	12.80	AOmy092	5.83	AOmy143	fixed
Ots-1	13.15	AOmy100	15.19	AOmy146	11.56
Ots-3M	12.20	AOmy103	10.91	AOmy147	27.61
AOmy001	21.30	AOmy108	13.28	AOmy148	0.15
AOmy004	6.64	AOmy110	10.83	AOmy149	14.77
AOmy005	0.10	AOmy111	9.06	AOmy150	5.91
AOmy006	5.56	AOmy112	18.09	AOmy151	19.36
AOmy009	21.17	AOmy113	1.77	AOmy153	fixed
AOmy013	fixed	AOmy114	6.91	ASpI001	36.95
AOmy015	0.66	AOmy117	14.79	ASpI002	34.77
AOmy016	11.22	AOmy118	10.77	ASpI004	82.47
AOmy017	68.17	AOmy120	4.44	ASpI005	86.12
AOmy018	fixed	AOmy121	1.15	ASpI007	35.98
AOmy019	2.94	AOmy123	29.76	ASpI008	34.02
AOmy020	24.81	AOmy124	4.76	ASpI009	83.27
AOmy021	16.98	AOmy125	22.00	ASpI010	36.00
AOmy027	10.60	AOmy127	32.04	ASpI012	-0.52
AOmy036	5.28	AOmy128	0.16	ASpI013	39.08
AOmy040	37.05	AOmy129	1.36	ASpI014	37.18
AOmy042	23.93	AOmy132	1.80	ASpI017	33.45
AOmy047	8.48	AOmy133	1.47	ASpI018	35.46
AOmy051	2.09	AOmy134	18.14	ASpI019	34.56
AOmy055	-0.43	AOmy135	1.33	ASpI020	32.93
AOmy062	1.31	AOmy136	18.06		

Table 5. Analysis of molecular variance (AMOVA) with microsatellites (msats), SNPs and both locus sets combined (both). Values are the percentage of the molecular variance at each level: among populations, among individuals within populations, within individuals.

	averaged over all loci in respective data sets		
	msats only	**SNPs only**	**both**
Among populations	16.74	25.97	23.69
Among individuals within populations	14.56	33.18	28.59
Within individuals	68.70	40.85	47.72

Table 6. Count of different types of trout identified in the USRW from STRUCTURE analysis (see Table 7 for details). Fish had been field-identified to species, but were inconsistently grouped according to species ID (see Table 7 for field identifications and text for explanation of categories or types). Snoqualmie *O. mykiss* population 1 (SnoqOmy1) are putative hatchery ancestry fish and Snoqualmie *O. mykiss* population 2 (SnoqOmy2) are putative native rainbow trout. Lake Whatcom cutthroat trout (LkWhOcl) and Twin Lakes cutthroat trout (TwinOcl) are hatchery ancestry cutthroat trout. Cedar and Snoqualmie cutthroat trout (CedarOcl and SnoqOcl, respectively) are putative native cutthroat trout.

Types	Snoq 09IJ	Snoq 09IK
CedarOcl	7	6
CedarOcl-SnoqOcl	5	3
CedarOcl-SnoqOmy1	1	1
CedarOcl-SnoqOmy2	3	8
LkWhOcl	20	1
LkWhOcl-CedarOcl	5	1
LkWhOcl-SnoqOcl	7	1
LkWhOcl-SnoqOmy1	2	4
LkWhOcl-SnoqOmy2	1	1
LkWhOcl-TwinOcl		1
Ocl	1	
Ocl-Omy		1
Ocl-SnoqOmy1	1	1
Ocl-SnoqOmy2	1	2
Ocl-SnoqOmy1	1	2
SnoqOcl	69	35
SnoqOcl-SnoqOmy1	14	4
SnoqOcl-SnoqOmy1,2	1	2
SnoqOcl-SnoqOmy2	3	3
SnoqOmy1	3	46
SnoqOmy1,2		4
SnoqOmy2	3	16
TwinOcl		3
TwinOcl-SnoqOmy1		1
TwinOcl-SnoqOmy2		1
Total	148	148

Table 7. Genetic identities from STRUCTURE with field collection data. Field data are in the first seven columns, followed by the genetic type indicated by the STRUCTURE analysis: pure fish had at least 90% ancestry in a single cluster (pink cells) and mixed ancestry fish had more than 10% ancestry in at least one other cluster (green cells were 10% to 50% and yellow cells were 50% to 90%). Cells are colored to aid viewing the proportion of ancestry in each cluster. The ancestry proportion values are plotted in Figure 5. Ancestry type is listed under "Genetic ID".

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
9/17/09	Upper North Fork	Illinois Creek	225	CCT	LkWhOcl	09IJ0004	0.969	0.007	0.002	0.021	0.001	0
9/17/09	Upper North Fork	Illinois Creek	194	CCT	LkWhOcl-CedarOcl	09IJ0005	0.562	0.423	0.002	0.012	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	152	CCT	LkWhOcl-SnoqOcl	09IJ0006	0.81	0.049	0.002	0.137	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	146	CCT	LkWhOcl	09IJ0007	0.906	0.078	0.002	0.012	0.002	0
9/17/09	Upper North Fork	Illinois Creek	178	CCT	LkWhOcl	09IJ0008	0.952	0.032	0.002	0.013	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	131	CCT	LkWhOcl	09IJ0009	0.947	0.015	0.002	0.035	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	107	CCT	LkWhOcl	09IJ0010	0.963	0.017	0.002	0.01	0.005	0.003
9/17/09	Upper North Fork	Illinois Creek	235	CCT	LkWhOcl	09IJ0011	0.975	0.016	0.001	0.004	0.001	0.003
9/17/09	Upper North Fork	Illinois Creek	234	CCT	LkWhOcl	09IJ0012	0.969	0.008	0.002	0.019	0.001	0
9/17/09	Upper North Fork	Illinois Creek	233	CCT	LkWhOcl	09IJ0013	0.989	0.003	0.001	0.006	0.001	0
9/17/09	Upper North Fork	Illinois Creek	205	CCT	LkWhOcl	09IJ0014	0.986	0.005	0.001	0.006	0.001	0
9/17/09	Upper North Fork	Illinois Creek	185	CCT	LkWhOcl	09IJ0015	0.989	0.003	0.001	0.005	0.001	0
9/17/09	Upper North Fork	Illinois Creek	178	CCT	LkWhOcl	09IJ0016	0.918	0.074	0.001	0.005	0.001	0
9/17/09	Upper North Fork	Illinois Creek	165	CCT	LkWhOcl	09IJ0017	0.935	0.018	0.002	0.044	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	180	CCT	LkWhOcl-SnoqOmy1	09IJ0018	0.692	0.006	0.002	0.01	0.288	0.003
9/17/09	Upper North Fork	Illinois Creek	88	CCT	LkWhOcl	09IJ0019	0.968	0.008	0.005	0.018	0.001	0.001
9/17/09	Upper North Fork	Illinois Creek	93	CCT	LkWhOcl	09IJ0020	0.928	0.009	0.002	0.061	0.001	0
6/30/10	Upper North Fork	Illinois Creek	147	CCT	LkWhOcl	09IJ0126	0.985	0.005	0.001	0.008	0.001	0
6/30/10	Upper North Fork	Illinois Creek	127	CCT	LkWhOcl	09IJ0127	0.939	0.043	0.003	0.014	0.001	0
6/30/10	Upper North Fork	Illinois Creek	93	CCT	LkWhOcl	09IJ0128	0.981	0.009	0.002	0.008	0.001	0
6/17/10	Middle North Fork	Lakebed	281	CCT	LkWhOcl-SnoqOmy2	09IJ0034	0.668	0.068	0.002	0.011	0.058	0.194
6/17/10	Middle North Fork	Lakebed	263	Onxx	SnoqOmy1	09IJ0068	0.068	0.018	0.001	0.055	0.818	0.039
6/17/10	Middle North Fork	Lakebed	300	CCT	LkWhOcl-SnoqOmy1	09IJ0069	0.284t	0.035	0.003	0.071	0.599	0.008
9/18/09	Middle North Fork	Big Creek Falls	183	CCT	LkWhOcl	09IJ0021	0.975	0.015	0.001	0.007	0.001	0
9/18/09	Middle North Fork	Big Creek Falls	169	CCT	LkWhOcl	09IJ0022	0.976	0.013	0.001	0.009	0.001	0
6/7/10	Middle North Fork	Big Creek Falls	145	CCT	LkWhOcl-SnoqOcl	09IJ0105	0.525	0.029	0.002	0.442	0.001	0.001
9/18/09	Middle North Fork	Big Creek Falls	193	RBT	SnoqOmy1	09IK0019	0.017	0.099	0.004	0.005	0.835	0.041

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
9/18/09	Middle North Fork	Big Creek Falls	178	RBT	SnoqOmy1	09IK0020	0.001	0.001	0.001	0.001	0.97	0.025
9/18/09	Middle North Fork	Big Creek Falls	182	RBT	SnoqOmy1	09IK0021	0.001	0.001	0.001	0.001	0.964	0.031
9/18/09	Middle North Fork	Big Creek Falls	177	RBT	SnoqOmy1,2	09IK0022	0.001	0.001	0.001	0.001	0.895	0.102
9/18/09	Middle North Fork	Big Creek Falls	220	Onxx	SnoqOmy1	09IK0023	0.001	0.001	0.001	0.001	0.973	0.023
9/18/09	Middle North Fork	Big Creek Falls	184	RBT	SnoqOmy1	09IK0024	0.001	0.001	0.001	0.001	0.972	0.025
9/18/09	Middle North Fork	Big Creek Falls	198	RBT	SnoqOmy1	09IK0025	0.001	0.001	0.001	0.001	0.961	0.036
9/18/09	Middle North Fork	Big Creek Falls	156	RBT	SnoqOmy1	09IK0026	0.002	0.001	0.001	0.001	0.99	0.006
11/2/09	Middle North Fork	Big Creek Falls	80	RBT	SnoqOmy1	09IK0028	0.001	0.001	0.001	0.001	0.988	0.008
11/2/09	Middle North Fork	Big Creek Falls	87	RBT	SnoqOmy1	09IK0029	0.003	0.003	0.003	0.003	0.973	0.014
11/2/09	Middle North Fork	Big Creek Falls	70	Onxx	SnoqOmy1	09IK0030	0.001	0.001	0.001	0.001	0.992	0.003
11/2/09	Middle North Fork	Big Creek Falls	73	Onxx	SnoqOmy1	09IK0033	0.001	0.001	0.001	0.001	0.991	0.004
11/3/09	Middle North Fork	Big Creek Falls	252	RBT	SnoqOmy1	09IK0034	0.001	0.001	0.001	0.001	0.984	0.013
6/8/10	Middle North Fork	Calligan	352	CCT	CedarOcl-SnoqOmy1	09IJ0106	0.048	0.321	0.001	0.06	0.545	0.026
6/8/10	Middle North Fork	Calligan	146	CCT	LkWhOcl	09IJ0107	0.98	0.007	0.001	0.01	0.001	0
6/8/10	Middle North Fork	Calligan	103	RBT	SnoqOmy1	09IK0067	0.001	0.001	0.001	0.001	0.977	0.02
9/14/09	Middle North Fork	Black Canyon	401	RBT	SnoqOmy1	09IK0032	0.001	0.001	0.001	0.001	0.994	0.002
11/4/09	Middle North Fork	Black Canyon	272	RBT	SnoqOmy1	09IK0037	0.001	0.001	0.001	0.001	0.994	0.002
11/4/09	Middle North Fork	Black Canyon	128	RBT	SnoqOmy1	09IK0038	0.001	0.001	0.001	0.001	0.969	0.028
11/4/09	Middle North Fork	Black Canyon	110	RBT	SnoqOmy1	09IK0039	0.001	0.001	0.001	0.001	0.993	0.004
5/14/10	Middle North Fork	Black Canyon	401	Onxx	TwinOcl-SnoqOmy1	09IK0057	0.01	0.019	0.144	0.016	0.803	0.008
5/14/10	Middle North Fork	Black Canyon	260	RBT	SnoqOmy1	09IK0058	0.001	0.001	0.001	0.001	0.985	0.011
5/14/10	Middle North Fork	Black Canyon	269	Onxx	SnoqOmy1	09IK0059	0.001	0.001	0.001	0.001	0.931	0.065
7/1/10	Middle North Fork	Black Canyon	28	Onxx	SnoqOmy1	09IK0073	0.001	0.001	0.001	0.001	0.99	0.008
9/16/09	Lower North Fork	Black Canyon	140	CCT	SnoqOcl	09IJ0001	0.02	0.011	0.001	0.966	0.001	0
9/16/09	Lower North Fork	Black Canyon	208	CCT	SnoqOcl	09IJ0002	0.006	0.011	0.001	0.981	0.001	0
9/16/09	Lower North Fork	Black Canyon	156	CCT	SnoqOcl	09IJ0003	0.01	0.008	0.001	0.98	0.001	0
2/2/10	Lower North Fork	Black Canyon	145	CCT	LkWhOcl-SnoqOcl	09IJ0071	0.124	0.091	0.001	0.783	0.001	0
6/16/10	Lower North Fork	Black Canyon	110	RBT	SnoqOmy1	09IJ0108	0.001	0.001	0.001	0.001	0.994	0.003
6/16/10	Lower North Fork	Black Canyon	105	RBT	SnoqOcl-SnoqOmy1	09IJ0109	0.012	0.004	0.002	0.215	0.765	0.002

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
6/16/10	Lower North Fork	Black Canyon	237	RBT	SnoqOmy1	09IJ0112	0.001	0.001	0.001	0.001	0.99	0.007
9/16/09	Lower North Fork	Black Canyon	214	RBT	SnoqOmy1	09IJ0149	0.001	0.001	0.001	0.001	0.994	0.002
9/16/09	Lower North Fork	Black Canyon	190	RBT	SnoqOmy1	09IJ0150	0.001	0.001	0.001	0.001	0.983	0.014
9/16/09	Lower North Fork	Black Canyon	224	RBT	SnoqOmy1	09IK0001	0.001	0.001	0.001	0.001	0.994	0.003
9/16/09	Lower North Fork	Black Canyon	251	RBT	SnoqOmy1	09IK0006	0.002	0.002	0.002	0.002	0.989	0.003
9/16/09	Lower North Fork	Black Canyon	227	RBT	SnoqOmy1	09IK0007	0.001	0.001	0.001	0.001	0.983	0.014
9/16/09	Lower North Fork	Black Canyon	205	RBT	SnoqOmy1	09IK0008	0.001	0.001	0.001	0.001	0.993	0.003
9/16/09	Lower North Fork	Black Canyon	143	RBT	SnoqOmy1	09IK0009	0.064	0.024	0.012	0.019	0.872	0.008
9/16/09	Lower North Fork	Black Canyon	192	RBT	SnoqOmy1	09IK0010	0.002	0.002	0.001	0.002	0.981	0.012
9/16/09	Lower North Fork	Black Canyon	173	RBT	SnoqOmy1	09IK0011	0.001	0.001	0.001	0.001	0.992	0.004
9/16/09	Lower North Fork	Black Canyon	228	RBT	SnoqOmy1	09IK0012	0.001	0.002	0.001	0.001	0.987	0.007
9/16/09	Lower North Fork	Black Canyon	152	RBT	SnoqOmy1	09IK0013	0.001	0.001	0.001	0.001	0.988	0.008
9/16/09	Lower North Fork	Black Canyon	212	RBT	SnoqOmy1	09IK0014	0.002	0.003	0.001	0.002	0.986	0.006
9/16/09	Lower North Fork	Black Canyon	63	RBT	SnoqOmy1	09IK0016	0.001	0.001	0.002	0.001	0.991	0.003
2/2/10	Lower North Fork	Black Canyon	134	RBT	SnoqOmy1	09IK0042	0.001	0.001	0.001	0.001	0.992	0.004
2/2/10	Lower North Fork	Black Canyon	137	RBT	SnoqOmy1	09IK0043	0.001	0.001	0.001	0.001	0.995	0.002
2/2/10	Lower North Fork	Black Canyon	98	RBT	LkWhOcl-SnoqOmy1	09IK0044	0.207	0.007	0.005	0.006	0.767	0.008
2/2/10	Lower North Fork	Black Canyon	97	RBT	LkWhOcl-SnoqOmy1	09IK0045	0.262	0.014	0.006	0.01	0.705	0.004
2/2/10	Lower North Fork	Black Canyon	91	RBT	LkWhOcl-SnoqOmy1	09IK0046	0.186	0.025	0.002	0.027	0.757	0.003
6/16/10	Lower North Fork	Black Canyon	430	CCT	CedarOcl-SnoqOmy1	09IK0068	0.084	0.303	0.003	0.061	0.535	0.014
7/1/10	Lower North Fork	Black Canyon	27	Onxx	SnoqOmy1	09IK0081	0.001	0.001	0.001	0.001	0.994	0.002
6/18/09	Lower North Fork	Three Forks	444	Onxx	SnoqOmy1	09IK0003	0.001	0.001	0.001	0.001	0.995	0.002
6/15/10	Lower North Fork	Three Forks	351	RBT	SnoqOmy1	09IK0035	0.001	0.001	0.001	0.001	0.994	0.003
6/15/10	Lower North Fork	Three Forks	278	RBT	SnoqOmy1	09IK0036	0.001	0.001	0.001	0.001	0.986	0.01
3/8/10	Lower North Fork	Three Forks	EGG	Onxx	SnoqOcl	09IK0047	0.012	0.005	0.001	0.981	0.001	0
3/8/10	Lower North Fork	Three Forks	EGG	Onxx	SnoqOmy1	09IK0048	0.004	0.004	0.001	0.003	0.986	0.002
9/8/10	Lower North Fork	Three Forks	326	Onxx	SnoqOcl-SnoqOmy1	09IK0103	0.004	0.005	0.004	0.483	0.5	0.004
9/8/10	Lower North Fork	Three Forks	259	Onxx	SnoqOmy1	09IK0104	0.001	0.001	0.001	0.001	0.994	0.003
10/7/10	Lower North Fork	Three Forks	149	CCT	SnoqOcl	09IK0116	0.01	0.004	0.007	0.977	0.001	0.001
10/7/10	Lower North Fork	Three Forks	68	Onxx	SnoqOmy1	09IK0117	0.055	0.055	0.003	0.024	0.858	0.005

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
10/7/10	Lower North Fork	Three Forks	310	RBT	SnoqOmy1	09IK0118	0.001	0.001	0.001	0.001	0.995	0.001
6/15/10	Lower North Fork	Three Forks	279	RBT	SnoqOmy1,2	09IK0121	0.001	0.001	0.001	0.001	0.858	0.139
10/13/10	Upper Middle Fork	Hardscrabble	180	CCT	Ocl-Omy	09IK0119	0.257	0.024	0.06	0.442	0.108	0.11
10/13/10	Upper Middle Fork	Hardscrabble	192	CCT	LkWhOcl	09IK0120	0.915	0.008	0.07	0.006	0.001	0
10/13/10	Upper Middle Fork	Hardscrabble	191	CCT	Ocl-SnoqOmy1	09IK0122	0.623	0.007	0.164	0.004	0.199	0.003
10/13/10	Upper Middle Fork	Hardscrabble	190	CCT	LkWhOcl-TwinOcl	09IK0123	0.796	0.063	0.136	0.004	0.001	0.001
8/1/10	Upper Middle Fork	Goldmyer	135	Onxx	SnoqOcl	09IJ0085	0.005	0.006	0.002	0.986	0.001	0.001
8/1/10	Upper Middle Fork	Goldmyer	151	Onxx	SnoqOcl	09IJ0086	0.007	0.006	0.001	0.985	0.001	0
8/1/10	Upper Middle Fork	Goldmyer	250	CCT	SnoqOcl	09IK0079	0.005	0.005	0.002	0.987	0.001	0
8/1/10	Upper Middle Fork	Goldmyer	215	CCT	SnoqOcl	09IK0080	0.01	0.01	0.002	0.977	0.001	0.001
8/1/10	Upper Middle Fork	Goldmyer	208	CCT	SnoqOcl	09IK0081	0.012	0.009	0.001	0.976	0.001	0
8/1/10	Upper Middle Fork	Goldmyer	203	CCT	SnoqOcl	09IK0082	0.035	0.014	0.002	0.948	0.001	0
8/1/10	Upper Middle Fork	Goldmyer	198	CCT	SnoqOcl	09IK0083	0.005	0.012	0.002	0.981	0.001	0.001
8/1/10	Upper Middle Fork	Goldmyer	195	CCT	SnoqOcl	09IK0084	0.013	0.005	0.001	0.98	0.001	0.001
8/1/10	Upper Middle Fork	Goldmyer	185	CCT	SnoqOcl	09IK0085	0.003	0.005	0.008	0.983	0	0
8/2/10	Upper Middle Fork	Goldmyer	241	CCT	SnoqOcl	09IK0086	0.007	0.005	0.002	0.985	0.001	0
8/2/10	Upper Middle Fork	Goldmyer	133	CCT	CedarOcl-SnoqOcl	09IK0087	0.005	0.393	0.001	0.599	0.001	0
8/2/10	Upper Middle Fork	Goldmyer	136	CCT	CedarOcl-SnoqOcl	09IK0088	0.003	0.108	0.003	0.885	0.001	0
8/2/10	Upper Middle Fork	Goldmyer	134	CCT	SnoqOcl	09IK0089	0.005	0.005	0.002	0.988	0.001	0
8/2/10	Upper Middle Fork	Goldmyer	138	CCT	SnoqOcl	09IK0090	0.007	0.005	0.001	0.986	0.001	0
8/3/10	Upper Middle Fork	Goldmyer	81	Onxx	SnoqOcl	09IK0091	0.005	0.009	0.002	0.983	0.001	0
8/3/10	Upper Middle Fork	Goldmyer	30	Onxx	SnoqOcl	09IK0092	0.006	0.006	0.001	0.986	0.001	0
8/3/10	Upper Middle Fork	Goldmyer	248	CCT	SnoqOcl	09IK0093	0.003	0.072	0.004	0.919	0.001	0.001
8/6/10	Upper Middle Fork	Goldmyer	283	CCT	SnoqOcl	09IK0142	0.005	0.009	0.001	0.984	0.001	0
8/4/10	Upper Middle Fork	Dingford	245	CCT	SnoqOcl	09IK0094	0.007	0.01	0.001	0.981	0.001	0
8/4/10	Upper Middle Fork	Dingford	259	CCT	SnoqOcl	09IK0095	0.006	0.009	0.002	0.982	0.001	0
8/4/10	Upper Middle Fork	Dingford	243	Onxx	SnoqOcl-SnoqOmy1,2	09IK0096	0.013	0.04	0.002	0.387	0.39	0.168
10/21/09	Middle Middle Fork	Pratt	71	Onxx	SnoqOcl-SnoqOmy1	09IJ0070	0.005	0.005	0.021	0.686	0.248	0.035
7/9/10	Middle Middle Fork	Pratt	272	CCT	SnoqOcl	09IJ0075	0.003	0.004	0.002	0.989	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	348	CCT	SnoqOcl	09IJ0083	0.004	0.01	0.025	0.96	0.001	0.001

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
6/21/10	Middle Middle Fork	Pratt	298	CCT	SnoqOcl	09IJ0117	0.009	0.005	0.002	0.983	0.001	0.001
6/28/10	Middle Middle Fork	Pratt	194	CCT	SnoqOcl	09IJ0125	0.012	0.005	0.003	0.979	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	222	CCT	SnoqOcl	09IJ0142	0.006	0.006	0.002	0.985	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	234	CCT	SnoqOcl	09IJ0143	0.005	0.081	0.004	0.908	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	193	CCT	SnoqOcl-SnoqOmy1	09IJ0144	0.004	0.011	0.013	0.747	0.216	0.008
7/9/10	Middle Middle Fork	Pratt	195	CCT	SnoqOcl	09IJ0145	0.005	0.004	0.002	0.989	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	237	CCT	SnoqOcl	09IJ0146	0.009	0.009	0.012	0.969	0.001	0.001
7/9/10	Middle Middle Fork	Pratt	306	CCT	Ocl	09IJ0147	0.313	0.328	0.047	0.31	0.001	0.001
5/11/10	Middle Middle Fork	Pratt	ALEVIN	Onxx	SnoqOcl	09IK0060	0.003	0.003	0.002	0.99	0.001	0.001
5/11/10	Middle Middle Fork	Pratt	EGG	Onxx	CedarOcl-SnoqOcl	09IK0061	0.049	0.224	0.002	0.723	0.001	0.001
7/26/10	Middle Middle Fork	Pratt	139	CCT	SnoqOcl	09IK0076	0.004	0.007	0.002	0.986	0.001	0.001
7/26/10	Middle Middle Fork	Pratt	140	CCT	SnoqOcl	09IK0077	0.006	0.004	0.002	0.987	0.001	0
7/26/10	Middle Middle Fork	Pratt	134	CCT	SnoqOcl	09IK0078	0.005	0.003	0.002	0.99	0.001	0.001
10/20/09	Middle Middle Fork	Garfield Mtn.	173	CCT	SnoqOcl	09IJ0056	0.067	0.009	0.002	0.922	0.001	0.001
10/20/09	Middle Middle Fork	Garfield Mtn.	210	CCT	SnoqOcl	09IJ0057	0.004	0.003	0.001	0.954	0.01	0.028
10/20/09	Middle Middle Fork	Garfield Mtn.	126	CCT	SnoqOcl	09IJ0058	0.038	0.061	0.001	0.898	0.001	0
10/20/09	Middle Middle Fork	Garfield Mtn.	93	CCT	SnoqOcl	09IJ0059	0.007	0.013	0.001	0.978	0.001	0
10/20/09	Middle Middle Fork	Garfield Mtn.	118	CCT	SnoqOcl	09IJ0060	0.014	0.029	0.001	0.918	0.009	0.028
10/20/09	Middle Middle Fork	Garfield Mtn.	65	CCT	SnoqOcl	09IJ0061	0.003	0.004	0.003	0.989	0.001	0.001
10/20/09	Middle Middle Fork	Garfield Mtn.	167	CCT	SnoqOcl	09IJ0062	0.019	0.081	0.001	0.898	0.001	0
10/20/09	Middle Middle Fork	Garfield Mtn.	182	CCT	SnoqOcl	09IJ0063	0.007	0.006	0.002	0.983	0.001	0.001
10/20/09	Middle Middle Fork	Garfield Mtn.	123	CCT	SnoqOcl	09IJ0064	0.006	0.005	0.004	0.984	0.001	0
10/20/09	Middle Middle Fork	Garfield Mtn.	119	CCT	SnoqOcl	09IJ0065	0.013	0.022	0.034	0.928	0.001	0.001
10/20/09	Middle Middle Fork	Garfield Mtn.	119	CCT	SnoqOcl	09IJ0066	0.005	0.003	0.001	0.989	0.001	0
10/20/09	Middle Middle Fork	Garfield Mtn.	67	CCT	SnoqOcl	09IJ0067	0.003	0.017	0.002	0.969	0.005	0.004
7/24/09	Lower Middle Fork	Three Forks	232	CCT	SnoqOcl-SnoqOmy1	09IJ0030	0.007	0.014	0.002	0.778	0.145	0.054
9/25/09	Lower Middle Fork	Sallal Prairie	294	CCT	SnoqOcl	09IJ0032	0.007	0.005	0.002	0.984	0.001	0
2/4/10	Lower Middle Fork	Sallal Prairie	143	CCT	SnoqOcl	09IJ0076	0.004	0.003	0.004	0.988	0.001	0.001
6/22/10	Lower Middle Fork	Sallal Prairie	103	CCT	SnoqOcl	09IJ0119	0.004	0.003	0.002	0.989	0.001	0.001
10/9/09	Lower Middle Fork	North Bend	298	CCT	SnoqOcl	09IJ0033	0.025	0.01	0.002	0.962	0.001	0.001

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
9/30/09	Lower Middle Fork	North Bend	419	CCT	SnoqOcl-SnoqOmy1	09IJ0040	0.038	0.011	0.004	0.427	0.473	0.048
9/30/09	Lower Middle Fork	North Bend	293	CCT	SnoqOcl-SnoqOmy1	09IJ0041	0.01	0.048	0.002	0.587	0.349	0.004
9/30/09	Lower Middle Fork	North Bend	305	CCT	SnoqOcl	09IJ0042	0.018	0.016	0.001	0.963	0.001	0
10/1/09	Lower Middle Fork	North Bend	276	CCT	SnoqOcl	09IJ0043	0.003	0.002	0.002	0.992	0.001	0.001
10/1/09	Lower Middle Fork	North Bend	266	CCT	SnoqOcl-SnoqOmy1	09IJ0044	0.006	0.006	0.005	0.498	0.472	0.013
10/1/09	Lower Middle Fork	North Bend	142	CCT	SnoqOcl	09IJ0045	0.004	0.004	0.003	0.989	0.001	0.001
10/1/09	Lower Middle Fork	North Bend	166	CCT	SnoqOcl	09IJ0046	0.005	0.025	0.003	0.966	0.001	0.001
10/1/09	Lower Middle Fork	North Bend	174	CCT	SnoqOcl-SnoqOmy1	09IJ0047	0.007	0.009	0.002	0.821	0.149	0.012
10/1/09	Lower Middle Fork	North Bend	154	CCT	SnoqOcl	09IJ0048	0.01	0.005	0.008	0.976	0.001	0.001
10/1/09	Lower Middle Fork	North Bend	142	CCT	CedarOcl-SnoqOcl	09IJ0049	0.004	0.311	0.005	0.658	0.011	0.01
10/1/09	Lower Middle Fork	North Bend	93	CCT	SnoqOcl	09IJ0050	0.004	0.004	0.001	0.99	0	0
10/9/09	Lower Middle Fork	North Bend	302	CCT	Ocl-Omy2	09IJ0055	0.213	0.034	0.001	0.202	0.003	0.547
9/11/10	Lower Middle Fork	North Bend	301	Onxx	SnoqOcl-SnoqOmy1	09IJ0104	0.004	0.005	0.003	0.129	0.854	0.004
9/14/10	Lower Middle Fork	North Bend	314	CCT	SnoqOcl	09IJ0110	0.006	0.01	0.002	0.982	0.001	0.001
10/18/10	Lower Middle Fork	North Bend	370	CCT	SnoqOcl-SnoqOmy1	09IJ0111	0.004	0.025	0.002	0.759	0.208	0.002
6/22/10	Lower Middle Fork	North Bend	321	CCT	SnoqOcl-SnoqOmy1	09IJ0118	0.015	0.005	0.002	0.54	0.423	0.016
6/24/10	Lower Middle Fork	North Bend	111	CCT	SnoqOcl	09IJ0122	0.013	0.011	0.002	0.973	0.001	0.001
5/13/10	Lower Middle Fork	North Bend	202	Onxx	SnoqOcl-SnoqOmy1	09IK0018	0.006	0.008	0.002	0.524	0.458	0.002
5/13/10	Lower Middle Fork	North Bend	319	RBT	SnoqOmy1	09IK0063	0.001	0.001	0.001	0.001	0.994	0.003
5/13/10	Lower Middle Fork	North Bend	229	Onxx	SnoqOcl-SnoqOmy1	09IK0056	0.005	0.059	0.002	0.356	0.573	0.005
9/21/09	Lower Middle Fork	Mt. Teneriffe	188	CCT	SnoqOcl	09IJ0023	0.005	0.004	0.001	0.989	0.001	0
9/21/09	Lower Middle Fork	Mt. Teneriffe	219	CCT	SnoqOcl	09IJ0024	0.006	0.009	0.026	0.955	0.003	0.001
9/21/09	Lower Middle Fork	Mt. Teneriffe	207	CCT	SnoqOcl	09IJ0025	0.005	0.015	0.012	0.966	0.001	0.001
9/21/09	Lower Middle Fork	Mt. Teneriffe	183	CCT	SnoqOcl	09IJ0026	0.005	0.005	0.002	0.986	0.001	0.001
9/21/09	Lower Middle Fork	Mt. Teneriffe	184	CCT	SnoqOcl	09IJ0027	0.009	0.006	0.002	0.982	0.001	0
9/21/09	Lower Middle Fork	Mt. Teneriffe	239	CCT	SnoqOcl	09IJ0028	0.005	0.052	0.001	0.937	0.003	0.001
9/21/09	Lower Middle Fork	Mt. Teneriffe	241	CCT	SnoqOcl	09IJ0029	0.008	0.004	0.001	0.985	0.001	0
9/23/09	Lower Middle Fork	Mt. Teneriffe	175	CCT	SnoqOcl	09IJ0035	0.003	0.003	0.002	0.991	0.001	0.001
9/23/09	Lower Middle Fork	Mt. Teneriffe	94	CCT	SnoqOcl	09IJ0036	0.007	0.008	0.002	0.982	0.001	0
9/23/09	Lower Middle Fork	Mt. Teneriffe	201	CCT	SnoqOcl	09IJ0037	0.005	0.076	0.002	0.913	0.004	0

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
9/23/09	Lower Middle Fork	Mt. Teneriffe	145	CCT	SnoqOcl	09IJ0038	0.006	0.045	0.007	0.94	0.001	0.001
9/23/09	Lower Middle Fork	Mt. Teneriffe	122	CCT	SnoqOcl	09IJ0039	0.003	0.003	0.002	0.991	0.001	0.001
9/24/09	Lower Middle Fork	Mt. Teneriffe	249	CCT	SnoqOcl	09IK0004	0.012	0.008	0.002	0.977	0.001	0.001
9/23/09	Lower Middle Fork	Mt. Teneriffe	212	RBT	SnoqOmy1	09IK0027	0.003	0.004	0.003	0.003	0.961	0.025
10/19/10	Upper South Fork	Denny Creek	239	WCT	TwinOcl	09IK0124	0.001	0.001	0.995	0.001	0	0
10/19/10	Upper South Fork	Denny Creek	208	WCT	TwinOcl	09IK0125	0.001	0.001	0.995	0.001	0.001	0.001
10/19/10	Upper South Fork	Denny Creek	229	WCT	TwinOcl	09IK0126	0.001	0.001	0.991	0.005	0.001	0
10/19/10	Upper South Fork	Denny Creek	155	Onxx	TwinOcl-SnoqOmy2	09IK0127	0.003	0.003	0.343	0.002	0.021	0.629
5/24/10	Upper South Fork	Asahel Curtis	239	CCT	CedarOcl	09IJ0094	0.04	0.925	0.002	0.008	0.003	0.022
5/24/10	Upper South Fork	Asahel Curtis	200	CCT	LkWhOcl-CedarOcl	09IJ0095	0.215	0.777	0.001	0.006	0.001	0
5/24/10	Upper South Fork	Asahel Curtis	205	CCT	CedarOcl	09IJ0096	0.028	0.954	0.001	0.016	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	154	CCT	CedarOcl	09IJ0097	0.004	0.973	0.013	0.005	0.001	0.003
5/24/10	Upper South Fork	Asahel Curtis	136	CCT	LkWhOcl-CedarOcl	09IJ0098	0.18	0.737	0.002	0.069	0.008	0.004
5/24/10	Upper South Fork	Asahel Curtis	139	CCT	CedarOcl	09IJ0099	0.005	0.901	0.001	0.091	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	121	CCT	CedarOcl	09IJ0100	0.024	0.947	0.001	0.027	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	77	CCT	CedarOcl	09IJ0101	0.012	0.981	0.001	0.005	0.001	0
5/24/10	Upper South Fork	Asahel Curtis	79	CCT	LkWhOcl-CedarOcl	09IJ0102	0.117	0.776	0.001	0.105	0.001	0
5/24/10	Upper South Fork	Asahel Curtis	73	CCT	CedarOcl	09IJ0103	0.008	0.987	0.001	0.003	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	244	WCT	CedarOcl	09IK0060	0.005	0.98	0.002	0.012	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	135	Onxx	CedarOcl	09IK0069	0.004	0.986	0.001	0.008	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	141	Onxx	CedarOcl	09IK0062	0.009	0.957	0.001	0.032	0.001	0.001
5/24/10	Upper South Fork	Asahel Curtis	89	Onxx	CedarOcl-SnoqOmy2	09IK0063	0.006	0.427	0.007	0.014	0.011	0.534
9/28/10	Upper South Fork	Asahel Curtis	155	CCT	CedarOcl-SnoqOmy2	09IK0114	0.008	0.731	0.002	0.007	0.019	0.234
9/28/10	Upper South Fork	Asahel Curtis	191	CCT	CedarOcl	09IK0115	0.018	0.97	0.001	0.01	0.001	0.001
9/2/10	Middle South Fork	Tinkham	217	CCT	CedarOcl	09IK0041	0.029	0.894	0.002	0.041	0.001	0.034
9/2/10	Middle South Fork	Tinkham	189	Onxx	SnoqOmy2	09IK0097	0.001	0.001	0.001	0.001	0.004	0.992
9/2/10	Middle South Fork	Tinkham	226	Onxx	CedarOcl-SnoqOmy2	09IK0098	0.006	0.332	0.002	0.022	0.007	0.632
9/2/10	Middle South Fork	Tinkham	242	CCT	CedarOcl	09IK0099	0.003	0.975	0.002	0.018	0.001	0.001
9/2/10	Middle South Fork	Tinkham	248	CCT	CedarOcl-SnoqOmy2	09IK0100	0.009	0.727	0.002	0.014	0.002	0.246
9/2/10	Middle South Fork	Weeks Falls	248	CCT	LkWhOcl-CedarOcl	09IK0101	0.121	0.874	0.001	0.003	0.001	0.001

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
9/2/10	Middle South Fork	Weeks Falls	247	RBT	SnoqOmy1,2	09IK0102	0.001	0.001	0.001	0.001	0.143	0.854
10/19/10	Middle South Fork	Weeks Falls	177	Onxx	SnoqOmy2	09IK0128	0.012	0.01	0.003	0.032	0.005	0.938
10/19/10	Middle South Fork	Weeks Falls	154	RBT	SnoqOmy2	09IK0129	0.001	0.001	0.001	0.001	0.005	0.993
10/19/10	Middle South Fork	Weeks Falls	185	RBT	SnoqOmy2	09IK0130	0.004	0.009	0.004	0.003	0.039	0.941
10/19/10	Middle South Fork	Weeks Falls	168	CCT	Ocl-Omy2	09IK0131	0.233	0.17	0.002	0.009	0.003	0.583
10/19/10	Middle South Fork	Weeks Falls	148	Onxx	SnoqOmy2	09IK0132	0.001	0.005	0.001	0.002	0.07	0.922
10/19/10	Middle South Fork	Weeks Falls	138	Onxx	SnoqOmy2	09IK0133	0.001	0.001	0.011	0.001	0.002	0.984
10/19/10	Middle South Fork	Weeks Falls	144	Onxx	SnoqOmy2	09IK0134	0.005	0.008	0.003	0.006	0.033	0.944
10/19/10	Middle South Fork	Weeks Falls	142	Onxx	CedarOcl-SnoqOmy2	09IK0135	0.003	0.161	0.001	0.01	0.014	0.811
10/19/10	Middle South Fork	Weeks Falls	99	Onxx	Ocl-Omy2	09IK0136	0.144	0.014	0.002	0.125	0.034	0.681
8/7/09	Middle South Fork	Grouse Ridge	100	CCT	SnoqOmy2	09IJ0031	0.001	0.001	0.001	0.001	0.01	0.986
10/19/10	Middle South Fork	Grouse Ridge	81	CCT	CedarOcl-SnoqOmy2	09IJ0129	0.057	0.354	0.002	0.025	0.003	0.558
10/19/10	Middle South Fork	Grouse Ridge	111	Onxx	CedarOcl-SnoqOmy2	09IJ0140	0.007	0.192	0.002	0.025	0.005	0.77
10/19/10	Middle South Fork	Grouse Ridge	112	RBT	SnoqOmy1	09IJ0141	0.001	0.001	0.001	0.001	0.9	0.096
8/7/09	Middle South Fork	Grouse Ridge	41	Onxx	CedarOcl-SnoqOmy2	09IK0002	0.028	0.223	0.002	0.036	0.045	0.666
8/7/09	Middle South Fork	Grouse Ridge	97	Onxx	SnoqOmy1,2	09IK0005	0.001	0.001	0.001	0.002	0.122	0.873
8/7/09	Middle South Fork	Grouse Ridge	98	RBT	SnoqOmy2	09IK0015	0.001	0.001	0.001	0.001	0.019	0.978
5/6/10	Middle South Fork	Grouse Ridge	255	Onxx	CedarOcl-SnoqOmy2	09IK0017	0.009	0.186	0.004	0.007	0.076	0.717
10/19/10	Middle South Fork	Grouse Ridge	222	RBT	SnoqOmy1,2	09IK0137	0.001	0.001	0.001	0.001	0.274	0.723
10/19/10	Middle South Fork	Grouse Ridge	222	RBT	SnoqOmy2	09IK0138	0.001	0.001	0.001	0.001	0.021	0.974
10/19/10	Middle South Fork	Grouse Ridge	206	RBT	SnoqOmy2	09IK0139	0.001	0.002	0.001	0.001	0.005	0.99
10/19/10	Middle South Fork	Grouse Ridge	187	Onxx	SnoqOmy2	09IK0140	0.003	0.002	0.001	0.002	0.014	0.979
10/19/10	Middle South Fork	Grouse Ridge	170	Onxx	SnoqOmy2	09IK0141	0.001	0.001	0.001	0.001	0.008	0.99
9/8/10	Lower South Fork	Three Forks	312	CCT	SnoqOcl	09IJ0087	0.016	0.047	0.002	0.906	0.015	0.014
9/8/10	Lower South Fork	Three Forks	332	CCT	SnoqOcl	09IK0105	0.004	0.005	0.003	0.987	0.001	0
6/29/10	Lower South Fork	Sallal Prairie	259	Onxx	SnoqOmy2	09IJ0074	0.002	0.002	0.003	0.002	0.014	0.976
4/30/10	Lower South Fork	Sallal Prairie	170	CCT	CedarOcl-SnoqOmy2	09IJ0091	0.004	0.402	0.001	0.006	0.085	0.503
4/30/10	Lower South Fork	Sallal Prairie	206	RBT	SnoqOmy2	09IJ0092	0.001	0.001	0.001	0.001	0.008	0.99
9/9/09	Lower South Fork	Sallal Prairie	311	RBT	SnoqOmy2	09IK0031	0.001	0.001	0.001	0.001	0.019	0.978
1/13/10	Lower South Fork	Sallal Prairie	274	RBT	SnoqOmy1	09IK0040	0.001	0.001	0.001	0.001	0.994	0.003

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
6/3/10	Lower South Fork	Sallal Prairie	552	Onxx	SnoqOmy1	09IK0065	0.001	0.001	0.002	0.001	0.991	0.005
6/3/10	Lower South Fork	Sallal Prairie	416	RBT	SnoqOmy1	09IK0066	0.001	0.001	0.001	0.001	0.991	0.005
6/29/10	Lower South Fork	Sallal Prairie	241	Onxx	SnoqOmy2	09IK0069	0.001	0.001	0.001	0.001	0.049	0.946
6/29/10	Lower South Fork	Sallal Prairie	237	Onxx	Ocl-Omy1	09IK0070	0.137	0.018	0.005	0.299	0.457	0.085
6/29/10	Lower South Fork	Sallal Prairie	233	RBT	SnoqOmy2	09IK0071	0.001	0.001	0.001	0.001	0.012	0.985
6/29/10	Lower South Fork	Sallal Prairie	272	CCT	CedarOcl-SnoqOmy2	09IK0143	0.005	0.829	0.004	0.006	0.045	0.111
4/30/10	Lower South Fork	Sallal Prairie	179	RBT	SnoqOmy2	09IK0144	0.001	0.001	0.001	0.001	0.005	0.992
4/30/10	Lower South Fork	Sallal Prairie	159	RBT	SnoqOcl-SnoqOmy2	09IK0145	0.048	0.014	0.006	0.309	0.027	0.597
4/30/10	Lower South Fork	Sallal Prairie	172	CCT	SnoqOcl	09IK0146	0.009	0.009	0.002	0.98	0.001	0
3/31/10	Lower South Fork	North Bend	ALEVIN	Onxx	SnoqOcl	09IJ0077	0.018	0.007	0.001	0.973	0.001	0
4/29/10	Lower South Fork	North Bend	189	CCT	SnoqOcl-SnoqOmy2	09IJ0078	0.005	0.005	0.009	0.749	0.069	0.163
4/29/10	Lower South Fork	North Bend	199	CCT	CedarOcl-SnoqOcl	09IJ0079	0.007	0.144	0.002	0.846	0.001	0
4/29/10	Lower South Fork	North Bend	155	CCT	LkWhOcl-SnoqOcl	09IJ0080	0.251	0.095	0.001	0.651	0.001	0.001
4/29/10	Lower South Fork	North Bend	135	CCT	LkWhOcl-CedarOcl	09IJ0081	0.203	0.756	0.001	0.037	0.001	0.002
4/29/10	Lower South Fork	North Bend	125	CCT	SnoqOcl	09IJ0082	0.007	0.003	0.001	0.987	0.001	0
7/13/10	Lower South Fork	North Bend	334	CCT	SnoqOcl	09IJ0084	0.01	0.007	0.001	0.98	0.001	0
4/29/10	Lower South Fork	North Bend	95	CCT	SnoqOcl	09IJ0088	0.029	0.014	0.001	0.944	0.011	0.001
4/29/10	Lower South Fork	North Bend	96	CCT	CedarOcl-SnoqOcl	09IJ0089	0.068	0.408	0.007	0.514	0.001	0.001
4/29/10	Lower South Fork	North Bend	280	CCT	SnoqOcl-SnoqOmy1	09IJ0090	0.006	0.007	0.002	0.633	0.347	0.005
5/5/10	Lower South Fork	North Bend	363	CCT	SnoqOcl	09IJ0093	0.005	0.005	0.001	0.979	0.005	0.005
7/8/10	Lower South Fork	North Bend	279	CCT	SnoqOcl	09IJ0136	0.024	0.053	0.002	0.92	0.001	0
7/8/10	Lower South Fork	North Bend	263	CCT	SnoqOcl	09IJ0137	0.005	0.005	0.002	0.978	0.005	0.005
7/8/10	Lower South Fork	North Bend	214	CCT	SnoqOcl	09IJ0138	0.024	0.024	0.002	0.949	0.001	0
7/8/10	Lower South Fork	North Bend	211	CCT	SnoqOcl-SnoqOmy2	09IJ0139	0.005	0.004	0.001	0.692	0.004	0.295
7/13/10	Lower South Fork	North Bend	343	CCT	SnoqOcl	09IJ0148	0.016	0.008	0.002	0.973	0.001	0.001
4/29/10	Lower South Fork	North Bend	128	Onxx	SnoqOcl-SnoqOmy2	09IK0049	0.066	0.098	0.009	0.119	0.004	0.704
4/29/10	Lower South Fork	North Bend	120	RBT	LkWhOcl-SnoqOmy2	09IK0057	0.11	0.008	0.001	0.098	0.021	0.762
4/29/10	Lower South Fork	North Bend	109	Onxx	SnoqOcl-SnoqOmy1	09IK0051	0.005	0.005	0.006	0.676	0.22	0.088
4/29/10	Lower South Fork	North Bend	223	RBT	SnoqOcl-SnoqOmy1,2	09IK0059	0.006	0.016	0.002	0.194	0.471	0.311
6/3/10	Lower South Fork	North Bend	ALEVIN	Onxx	SnoqOcl	09IK0064	0.003	0.005	0.001	0.989	0.001	0

Table 7. (Continued)

Date	River Section	River Segment	TL (mm)	Field ID	Type	Fish ID	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy1	SnoqOmy2
7/13/10	Lower South Fork	North Bend	28	Onxx	SnoqOcl-SnoqOmy2	09IK0075	0.005	0.003	0.001	0.743	0.07	0.177
10/6/09	Upper Mainstem	Three Forks	294	CCT	CedarOcl-SnoqOcl	09IJ0051	0.005	0.13	0.002	0.854	0.004	0.005
10/6/09	Upper Mainstem	Three Forks	317	CCT	SnoqOcl-SnoqOmy1,2	09IJ0052	0.007	0.017	0.002	0.379	0.124	0.472
10/6/09	Upper Mainstem	Three Forks	322	CCT	SnoqOcl	09IJ0053	0.01	0.004	0.009	0.976	0.001	0
10/8/09	Upper Mainstem	Three Forks	336	CCT	LkWhOcl-SnoqOcl	09IJ0054	0.1	0.008	0.005	0.879	0.004	0.004
6/18/10	Upper Mainstem	Three Forks	320	CCT	SnoqOcl	09IJ0113	0.09	0.011	0.001	0.897	0.001	0
6/18/10	Upper Mainstem	Three Forks	300	CCT	SnoqOcl-SnoqOmy2	09IJ0114	0.014	0.013	0.006	0.481	0.007	0.48
6/18/10	Upper Mainstem	Three Forks	259	CCT	SnoqOcl-SnoqOmy1	09IJ0115	0.013	0.004	0.001	0.393	0.585	0.004
6/18/10	Upper Mainstem	Three Forks	210	CCT	SnoqOcl	09IJ0116	0.005	0.008	0.001	0.984	0.001	0
6/25/10	Upper Mainstem	Three Forks	95	CCT	LkWhOcl-SnoqOcl	09IJ0123	0.288	0.04	0.003	0.669	0.001	0.001
6/25/10	Upper Mainstem	Three Forks	95	CCT	CedarOcl-SnoqOcl	09IJ0124	0.003	0.151	0.006	0.839	0.001	0.001
7/7/10	Upper Mainstem	Three Forks	113	CCT	SnoqOcl	09IJ0130	0.014	0.049	0.001	0.935	0.001	0.001
7/7/10	Upper Mainstem	Three Forks	132	CCT	SnoqOcl	09IJ0131	0.016	0.04	0.001	0.939	0.004	0.001
7/7/10	Upper Mainstem	Three Forks	133	CCT	SnoqOcl	09IJ0132	0.024	0.008	0.002	0.966	0.001	0
7/7/10	Upper Mainstem	Three Forks	169	CCT	SnoqOcl	09IJ0133	0.004	0.006	0.001	0.988	0.001	0.001
7/7/10	Upper Mainstem	Three Forks	182	CCT	SnoqOcl	09IJ0134	0.017	0.011	0.001	0.969	0.001	0.001
7/7/10	Upper Mainstem	Three Forks	227	CCT	SnoqOcl	09IJ0135	0.026	0.007	0.001	0.966	0.001	0
7/7/10	Upper Mainstem	Three Forks	161	Onxx	SnoqOcl	09IK0074	0.009	0.004	0.001	0.985	0.001	0
9/13/10	Upper Mainstem	Three Forks	300	CCT	SnoqOcl	09IK0106	0.013	0.005	0.002	0.979	0.001	0
9/13/10	Upper Mainstem	Three Forks	254	CCT	SnoqOcl	09IK0107	0.005	0.006	0.001	0.987	0.001	0
9/13/10	Upper Mainstem	Three Forks	225	CCT	SnoqOcl	09IK0108	0.007	0.006	0.001	0.985	0.001	0
9/13/10	Upper Mainstem	Three Forks	290	CCT	SnoqOcl	09IK0109	0.016	0.005	0.002	0.976	0	0
2/2/10	Lower Mainstem	Three Forks	198	CCT	SnoqOcl	09IJ0072	0.009	0.088	0.002	0.9	0.001	0.001
2/2/10	Lower Mainstem	Three Forks	145	CCT	SnoqOcl	09IJ0073	0.004	0.003	0.002	0.99	0.001	0
6/23/10	Lower Mainstem	Three Forks	421	CCT	Ocl-Omy1	09IJ0120	0.132	0.284	0.004	0.054	0.51	0.017
6/23/10	Lower Mainstem	Three Forks	246	Onxx	SnoqOcl-SnoqOmy1	09IJ0121	0.006	0.005	0.001	0.413	0.565	0.009
9/13/10	Lower Mainstem	Three Forks	282	CCT	SnoqOcl	09IK0110	0.009	0.011	0.001	0.979	0.001	0
9/13/10	Lower Mainstem	Three Forks	292	CCT	LkWhOcl-SnoqOcl	09IK0111	0.345	0.024	0.001	0.628	0.001	0.001
9/13/10	Lower Mainstem	Three Forks	226	CCT	SnoqOcl	09IK0112	0.004	0.005	0.002	0.987	0.001	0
9/13/10	Lower Mainstem	Three Forks	195	CCT	SnoqOcl	09IK0113	0.006	0.005	0.001	0.987	0.001	0

Appendix I. Allele frequencies: values over 0.5 are in pink cells and values between 0.1 and 0.5 are in green cells. The column "Private?" lists alleles found in a single collection in this study (private alleles).

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Ogo-3	1	182	1	0.8947	0	0.874	0.4563	0.6603	
Ogo-3	2	186	0	0	0	0.0076	0.0278	0.0144	
Ogo-3	3	191	0	0.0263	0	0.0229	0.0317	0.024	
Ogo-3	4	194	0	0	0	0	0.004	0.0016	SnoqOmy
Ogo-3	5	195	0	0.0789	0	0.0458	0.1944	0.1026	
Ogo-3	6	197	0	0	0	0.0115	0.0516	0.0256	
Ogo-3	7	199	0	0	0	0.0115	0.1349	0.0593	
Ogo-3	8	200	0	0	0	0.0038	0.004	0.0032	
Ogo-3	9	201	0	0	0	0.0038	0.0198	0.0096	
Ogo-3	10	203	0	0	0	0.0038	0.0278	0.0128	
Ogo-3	11	218	0	0	0.0263	0	0	0.0016	TwinOcl
Ogo-3	12	226	0	0	0	0.0153	0.0159	0.0128	
Ogo-3	13	228	0	0	0	0	0.0079	0.0032	SnoqOmy
Ogo-3	14	230	0	0	0.6579	0	0.0198	0.0481	
Ogo-3	15	242	0	0	0.0263	0	0	0.0016	TwinOcl
Ogo-3	16	251	0	0	0.2105	0	0	0.0128	TwinOcl
Ogo-3	17	253	0	0	0.0263	0	0.004	0.0032	
Ogo-3	18	261	0	0	0.0526	0	0	0.0032	TwinOcl
Ogo-3		# samples	17	19	19	131	126	312	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
Omm1138+a	1	150	0	0	0	0.0038	0.018	0.0091	
Omm1138+a	2	152	0	0	0	0.0114	0.0468	0.0244	
Omm1138+a	3	154	0	0	0	0.0152	0.0755	0.0381	
Omm1138+a	4	156	0	0.0667	0.125	0.0568	0.3273	0.1723	
Omm1138+a	5	158	0	0	0	0.0379	0.0935	0.0549	
Omm1138+a	6	160	0	0	0.825	0.0985	0.054	0.1128	
Omm1138+a	7	162	0.6136	0.0333	0	0.0758	0.0216	0.0823	
Omm1138+a	8	166	0.3864	0.9	0.025	0.7008	0.3633	0.5046	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Omm1138+a	9	170	0	0	0.025	0	0	0.0015	TwinOcl
Omm1138+a		# samples	22	15	20	132	139	328	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
One-108	1	134	0	0	0	0.0036	0.0071	0.0045	
One-108	2	148	0	0.25	0	0.0362	0.0143	0.0344	
One-108	3	152	0.0263	0.4167	0	0.3659	0.1536	0.2395	
One-108	4	156	0.2105	0.0833	0	0.3116	0.1857	0.2231	
One-108	5	161	0.1053	0.0278	0	0.0326	0.0071	0.024	
One-108	6	164	0	0.0556	0	0.0217	0.0929	0.0509	
One-108	7	169	0	0	0	0.0254	0.0429	0.0284	
One-108	8	173	0.0263	0	0	0.0145	0.0214	0.0165	
One-108	9	177	0	0	0	0.0036	0.025	0.012	
One-108	10	181	0	0	0	0.0109	0.0143	0.0105	
One-108	11	185	0	0	0	0.0109	0.0321	0.018	
One-108	12	189	0	0	0	0.0036	0.0179	0.009	
One-108	13	193	0	0	0	0.0145	0.0607	0.0314	
One-108	14	197	0	0	0	0.0181	0.0214	0.0165	
One-108	15	201	0.4211	0.0833	0	0.0072	0.0393	0.0479	
One-108	16	205	0.1579	0.0278	0	0.0435	0.0929	0.0674	
One-108	17	209	0	0.0556	0	0.0072	0.0321	0.0195	
One-108	18	213	0	0	0	0	0.0107	0.0045	SnoqOmy
One-108	19	217	0	0	0	0	0.0036	0.0015	SnoqOmy
One-108	20	225	0	0	0	0.0036	0.0107	0.006	
One-108	21	233	0	0	0.6842	0	0	0.0389	TwinOcl
One-108	22	237	0	0	0.1842	0.0072	0.0393	0.0299	
One-108	23	241	0	0	0	0.0072	0.0179	0.0105	
One-108	24	244	0	0	0	0	0.0107	0.0045	SnoqOmy
One-108	25	249	0	0	0.0526	0.0109	0.0143	0.0135	
One-108	26	253	0	0	0	0.0036	0.0071	0.0045	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
One-108	27	257	0	0	0.0263	0.0036	0	0.003	
One-108	28	261	0	0	0.0526	0.029	0.0036	0.0165	
One-108	29	267	0	0	0	0.0036	0	0.0015	SnoqOcl
One-108	30	317	0.0526	0	0	0	0.0214	0.012	
One-108		# samples	19	18	19	138	140	334	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
Ots-103	1	50	0	0	0	0.2555	0.1187	0.1537	
Ots-103	2	56	0	0	0	0.0073	0.0971	0.0433	
Ots-103	3	60	0.95	0.9211	0	0.6168	0.2914	0.4821	
Ots-103	4	64	0	0	0.075	0	0	0.0045	TwinOcl
Ots-103	5	72	0	0	0.45	0.0073	0.0072	0.0328	
Ots-103	6	74	0	0	0.1	0	0.0036	0.0075	
Ots-103	7	76	0	0	0.25	0	0.0072	0.0179	
Ots-103	8	78	0	0.0526	0	0.0036	0.0036	0.006	
Ots-103	9	82	0.05	0.0263	0.075	0.1095	0.4568	0.2433	
Ots-103	10	86	0	0	0.05	0	0.0144	0.009	
Ots-103		# samples	20	19	20	137	139	335	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
Omy-77	1	83	0	0	0	0	0.0219	0.0091	SnoqOmy
Omy-77	2	97	0	0	0	0.0074	0.0401	0.0197	
Omy-77	3	99	0	0	0.0938	0.0185	0.1241	0.0636	
Omy-77	4	103	0	0	0.8438	0.0111	0.0365	0.0606	
Omy-77	5	105	0	0	0	0.0037	0.0401	0.0182	
Omy-77	6	107	0	0	0.0312	0	0.0365	0.0167	
Omy-77	7	108	0	0.2955	0.0312	0.1852	0.0876	0.1333	
Omy-77	8	110	0	0	0	0.0148	0.0219	0.0152	
Omy-77	9	112	0	0	0	0.0111	0	0.0045	SnoqOcl
Omy-77	10	114	0	0	0	0.0444	0.1095	0.0636	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Omy-77	11	116	0.025	0.1136	0	0.0074	0.0146	0.0182	
Omy-77	12	118	0.025	0	0	0.0074	0.0365	0.0197	
Omy-77	13	120	0	0.0455	0	0	0.0036	0.0045	
Omy-77	14	122	0	0.0227	0	0.0111	0.0036	0.0076	
Omy-77	15	124	0	0.0227	0	0.0037	0.0182	0.0106	
Omy-77	16	126	0.025	0.1364	0	0.037	0.0657	0.053	
Omy-77	17	128	0	0.0227	0	0.0481	0.0766	0.053	
Omy-77	18	130	0.625	0.0909	0	0.0444	0.0255	0.0727	
Omy-77	19	132	0.225	0.2045	0	0.4111	0.1861	0.2727	
Omy-77	20	134	0.025	0	0	0.0148	0.0219	0.0167	
Omy-77	21	136	0	0.0455	0	0.0889	0.0219	0.0485	
Omy-77	22	140	0.05	0	0	0.0296	0.0073	0.0182	
Omy-77		# samples	20	22	16	135	137	330	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
Ots-1	1	158	0	0	0	0	0.0407	0.0171	SnoqOmy
Ots-1	2	160	0	0	0	0	0.0185	0.0078	SnoqOmy
Ots-1	3	164	0	0	0	0.0038	0.0185	0.0093	
Ots-1	4	166	0	0.0227	0	0.0573	0.1593	0.0916	
Ots-1	5	168	0	0.0227	0	0.0267	0.063	0.0388	
Ots-1	6	170	0	0	0	0.0038	0.1	0.0435	
Ots-1	7	172	0	0	0	0	0.0037	0.0016	SnoqOmy
Ots-1	8	177	0	0	0	0	0.0037	0.0016	SnoqOmy
Ots-1	9	179	0	0	0	0.0115	0.0407	0.0217	
Ots-1	10	181	0	0	0	0	0.0037	0.0016	SnoqOmy
Ots-1	11	237	0	0.0227	0	0.0038	0.0037	0.0047	
Ots-1	12	241	0	0	0	0.0229	0.0519	0.0311	
Ots-1	13	243	0	0	0.0357	0	0.0074	0.0047	
Ots-1	14	245	0	0	0	0	0.0259	0.0109	SnoqOmy
Ots-1	15	247	0	0	0	0	0.0037	0.0016	SnoqOmy

Appendix I. (Continued)

Locus	**Allele**	**Size**	**LkWh Ocl**	**Cedar Ocl**	**Twin Ocl**	**Snoq Ocl**	**Snoq Omy**	**Overall**	**Private?**
Ots-1	16	258	0	0	0.7857	0.0802	0.0259	0.0776	
Ots-1	17	260	0.05	0.4091	0	0.0763	0.063	0.0885	
Ots-1	18	262	0.875	0.1364	0	0.2557	0.1111	0.2143	
Ots-1	19	264	0	0	0	0	0.0037	0.0016	SnoqOmy
Ots-1	20	266	0	0.0227	0	0.0038	0.0037	0.0047	
Ots-1	21	268	0	0.0227	0	0	0	0.0016	CedarOcl
Ots-1	22	270	0.075	0	0	0.1718	0.0593	0.0994	
Ots-1	23	272	0	0.0227	0	0.0458	0.0148	0.0264	
Ots-1	24	276	0	0.3182	0	0.0267	0.0481	0.0528	
Ots-1	25	280	0	0	0	0.0802	0.037	0.0481	
Ots-1	26	282	0	0	0	0.0802	0.0741	0.0637	
Ots-1	27	288	0	0	0	0.0267	0	0.0109	SnoqOcl
Ots-1	28	292	0	0	0	0.0191	0.0111	0.0124	
Ots-1	29	297	0	0	0	0.0038	0	0.0016	SnoqOcl
Ots-1	30	315	0	0	0.0357	0	0	0.0016	TwinOcl
Ots-1	31	319	0	0	0.0357	0	0.0037	0.0031	
Ots-1	32	323	0	0	0.1071	0	0	0.0047	TwinOcl
Ots-1		# samples	20	22	14	131	135	322	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
Ots-3M	1	128	0.1	0.0909	0	0.015	0.0109	0.0228	
Ots-3M	2	132	0	0	0.125	0	0.029	0.0182	
Ots-3M	3	134	0	0	0	0.0038	0.0399	0.0182	
Ots-3M	4	136	0.025	0.0455	0	0.0752	0.2464	0.1383	
Ots-3M	5	138	0	0.0455	0	0.0639	0.2065	0.1155	
Ots-3M	6	140	0	0	0.125	0.0075	0.0616	0.035	
Ots-3M	7	145	0	0	0.75	0	0.0181	0.0441	
Ots-3M	8	152	0	0	0	0.0075	0	0.003	SnoqOcl
Ots-3M	9	158	0	0	0	0.0038	0.0036	0.003	
Ots-3M	10	160	0	0.1591	0	0.0038	0	0.0122	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Ots-3M	11	162	0.025	0	0	0.0075	0.0072	0.0076	
Ots-3M	12	164	0	0.0682	0	0.0338	0.0072	0.0213	
Ots-3M	13	166	0.1	0	0	0.0038	0.0036	0.0091	
Ots-3M	14	168	0	0.0227	0	0	0.0036	0.003	
Ots-3M	15	170	0	0	0	0.0451	0.0217	0.0274	
Ots-3M	16	172	0	0.1818	0	0.203	0.1486	0.1565	
Ots-3M	17	174	0	0.0455	0	0.2632	0.0725	0.1398	
Ots-3M	18	176	0	0.1818	0	0.0451	0.0217	0.0395	
Ots-3M	19	178	0	0.0227	0	0.0038	0.0072	0.0061	
Ots-3M	20	180	0	0.0227	0	0.0865	0.0181	0.0441	
Ots-3M	21	182	0	0.0227	0	0.0827	0.0399	0.0517	
Ots-3M	22	184	0	0	0	0	0.0036	0.0015	SnoqOmy
Ots-3M	23	186	0	0	0	0	0.0036	0.0015	SnoqOmy
Ots-3M	24	188	0	0	0	0	0.0036	0.0015	SnoqOmy
Ots-3M	25	190	0	0.0682	0	0.0113	0.0036	0.0106	
Ots-3M	26	192	0.425	0	0	0.0226	0.0036	0.0365	
Ots-3M	27	194	0	0.0227	0	0	0	0.0015	CedarOcl
Ots-3M	28	196	0	0	0	0.0038	0	0.0015	SnoqOcl
Ots-3M	29	198	0.325	0	0	0.0075	0.0145	0.0289	
Ots-3M		# samples	20	22	16	133	138	329	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy001	1	3	0	0.0833	0	0.0845	0.3793	0.1904	
AOmy001	2	4	1	0.9167	1	0.9155	0.6207	0.8096	
AOmy001		# samples	24	24	24	148	145	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy004	1	2	0.1458	0.1739	0	0.36	0.3192	0.2892	
AOmy004	2	3	0.8542	0.8261	1	0.64	0.6808	0.7108	
AOmy004		# samples	24	23	23	125	130	325	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy005	1	3	0	0	0	0.0068	0.0203	0.0109	
AOmy005	2	5	1	1	1	0.9932	0.9797	0.9891	
AOmy005		# samples	24	24	24	148	148	368	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy006	1	4	1	0.9792	1	0.9493	0.8537	0.9196	
AOmy006	2	5	0	0.0208	0	0.0507	0.1463	0.0804	
AOmy006		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy009	1	3	1	0.9583	1	0.9592	0.6849	0.8548	
AOmy009	2	5	0	0.0417	0	0.0408	0.3151	0.1452	
AOmy009		# samples	24	24	24	147	146	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy013	1	3	1	1	1	1	1	1	
AOmy013		# samples	24	24	24	146	146	364	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy015	1	3	1	0.9792	1	0.9932	0.969	0.9836	
AOmy015	2	5	0	0.0208	0	0.0068	0.031	0.0164	
AOmy015		# samples	24	24	24	148	145	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy016	1	3	1	0.9783	1	0.9558	0.7925	0.8973	
AOmy016	2	5	0	0.0217	0	0.0442	0.2075	0.1027	
AOmy016		# samples	24	23	24	147	147	365	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy017	1	2	0	0	1	0.0101	0.0972	0.1061	
AOmy017	2	4	1	1	0	0.9899	0.9028	0.8939	
AOmy017		# samples	24	24	23	148	144	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy018	1	3	1	1	1	1	1	1	
AOmy018		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy019	1	2	0	0	0	0	0.0411	0.0164	SnoqOmy
AOmy019	2	4	1	1	1	1	0.9589	0.9836	
AOmy019		# samples	24	24	24	148	146	366	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy020	1	3	0	0.3043	1	0.2483	0.3147	0.3116	
AOmy020	2	5	1	0.6957	0	0.7517	0.6853	0.6884	
AOmy020		# samples	24	23	24	147	143	361	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy021	1	3	1	0.9583	1	0.9097	0.6701	0.8278	
AOmy021	2	5	0	0.0417	0	0.0903	0.3299	0.1722	
AOmy021		# samples	24	24	24	144	147	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy027	1	2	0	0.0625	0	0.0236	0.1803	0.0858	
AOmy027	2	3	1	0.9375	1	0.9764	0.8197	0.9142	
AOmy027		# samples	24	24	24	148	147	367	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy036	1	4	0	0.0208	0.2292	0.1724	0.2568	0.1887	
AOmy036	2	5	1	0.9792	0.7708	0.8276	0.7432	0.8113	
AOmy036		# samples	24	24	24	145	146	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy040	1	3	0	0.0833	0	0.1027	0.5578	0.2712	
AOmy040	2	4	1	0.9167	1	0.8973	0.4422	0.7288	
AOmy040		# samples	24	24	24	146	147	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy042	1	1	1	1	1	0.9626	0.6724	0.8544	
AOmy042	2	5	0	0	0	0.0374	0.3276	0.1456	
AOmy042		# samples	24	24	24	147	145	364	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy047	1	4	1	0.9583	1	0.9865	0.863	0.9372	
AOmy047	2	5	0	0.0417	0	0.0135	0.137	0.0628	
AOmy047		# samples	24	24	24	148	146	366	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy051	1	2	0	0.0208	0	0.0236	0.0714	0.0395	
AOmy051	2	5	1	0.9792	1	0.9764	0.9286	0.9605	
AOmy051		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy055	1	3	1	1	1	0.9899	0.9863	0.9904	
AOmy055	2	4	0	0	0	0.0101	0.0137	0.0096	
AOmy055		# samples	24	24	24	148	146	366	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy062	1	2	1	0.9583	1	0.983	0.9456	0.9686	
AOmy062	2	5	0	0.0417	0	0.017	0.0544	0.0314	
AOmy062		# samples	24	24	24	147	147	366	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy065	1	3	0	0.0208	0	0.0608	0.3412	0.163	
AOmy065	2	5	1	0.9792	1	0.9392	0.6588	0.837	
AOmy065		# samples	24	24	24	148	148	368	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy073	1	3	0	0.1042	0	0.102	0.4075	0.211	
AOmy073	2	5	1	0.8958	1	0.898	0.5925	0.789	
AOmy073		# samples	24	24	24	147	146	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy079	1	3	0.0208	0.0833	------	0.0608	0.2222	0.1279	
AOmy079	2	5	0.9792	0.9167	------	0.9392	0.7778	0.8721	
AOmy079		# samples	24	24	------	148	144	340	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy081	1	3	1	0.9792	1	0.9864	0.9286	0.9645	
AOmy081	2	5	0	0.0208	0	0.0136	0.0714	0.0355	
AOmy081		# samples	24	24	24	147	147	366	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy092	1	4	0	0	0	0.0169	0.1027	0.0478	
AOmy092	2	5	1	1	1	0.9831	0.8973	0.9522	
AOmy092		# samples	24	24	24	148	146	366	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy100	1	2	0	0.0208	0	0.0608	0.2721	0.1349	
AOmy100	2	5	1	0.9792	1	0.9392	0.7279	0.8651	
AOmy100		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy103	1	4	1	0.9167	1	0.9724	0.808	0.9085	
AOmy103	2	5	0	0.0833	0	0.0276	0.192	0.0915	
AOmy103		# samples	24	24	24	145	138	355	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy108	1	2	1	1	1	0.9493	0.7676	0.8878	
AOmy108	2	5	0	0	0	0.0507	0.2324	0.1122	
AOmy108		# samples	24	24	23	148	142	361	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy110	1	2	1	0.9583	1	0.9358	0.7687	0.8787	
AOmy110	2	4	0	0.0417	0	0.0642	0.2313	0.1213	
AOmy110		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy111	1	1	1	0.9375	1	0.9479	0.7993	0.8939	
AOmy111	2	4	0	0.0625	0	0.0521	0.2007	0.1061	
AOmy111		# samples	24	24	24	144	147	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy112	1	3	1	0.875	1	0.9048	0.637	0.8082	
AOmy112	2	5	0	0.125	0	0.0952	0.363	0.1918	
AOmy112		# samples	24	24	24	147	146	365	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy113	1	3	1	1	1	0.9797	0.9422	0.9687	
AOmy113	2	5	0	0	0	0.0203	0.0578	0.0313	
AOmy113		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy114	1	2	1	0.913	1	0.973	0.8562	0.926	
AOmy114	2	5	0	0.087	0	0.027	0.1438	0.074	
AOmy114		# samples	24	23	24	148	146	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy117	1	4	0	0	0	0.0709	0.2736	0.1386	
AOmy117	2	5	1	1	1	0.9291	0.7264	0.8614	
AOmy117		# samples	24	24	24	148	148	368	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy118	1	3	1	0.9792	1	0.9831	0.8367	0.9264	
AOmy118	2	5	0	0.0208	0	0.0169	0.1633	0.0736	
AOmy118		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy120	1	3	0.9583	0.9583	1	0.9595	0.8639	0.9237	
AOmy120	2	5	0.0417	0.0417	0	0.0405	0.1361	0.0763	
AOmy120		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy121	1	2	1	0.9792	1	0.9831	0.9493	0.9715	
AOmy121	2	4	0	0.0208	0	0.0169	0.0507	0.0285	
AOmy121		# samples	24	24	24	148	148	368	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy123	1	2	1	0.9375	1	0.869	0.4896	0.7396	
AOmy123	2	4	0	0.0625	0	0.131	0.5104	0.2604	
AOmy123		# samples	24	24	24	145	144	361	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy124	1	2	1	0.9583	1	0.9824	0.8986	0.9489	
AOmy124	2	3	0	0.0417	0	0.0176	0.1014	0.0511	
AOmy124		# samples	24	24	24	142	148	362	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy125	1	3	0	0.0625	0	0.0882	0.3893	0.1988	
AOmy125	2	5	1	0.9375	1	0.9118	0.6107	0.8012	
AOmy125		# samples	24	24	18	136	140	342	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy127	1	4	0.0208	0.1042	0.1875	0.1223	0.5746	0.2942	
AOmy127	2	5	0.9792	0.8958	0.8125	0.8777	0.4254	0.7058	
AOmy127		# samples	24	24	24	139	134	345	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy128	1	2	0	0	0	0.0034	0.017	0.0082	
AOmy128	2	4	1	1	1	0.9966	0.983	0.9918	
AOmy128		# samples	24	24	24	146	147	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy129	1	3	1	1	1	0.9966	0.9694	0.9864	
AOmy129	2	5	0	0	0	0.0034	0.0306	0.0136	
AOmy129		# samples	24	24	24	148	147	367	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy132	1	3	1	1	1	0.9577	0.9239	0.9531	
AOmy132	2	5	0	0	0	0.0423	0.0761	0.0469	
AOmy132		# samples	24	24	24	142	138	352	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy133	1	2	1	1	1	0.9931	0.9623	0.9821	
AOmy133	2	3	0	0	0	0.0069	0.0377	0.0179	
AOmy133		# samples	24	24	24	145	146	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy134	1	3	1	0.8846	1	0.8921	0.6301	0.7951	
AOmy134	2	5	0	0.1154	0	0.1079	0.3699	0.2049	
AOmy134		# samples	22	13	24	139	146	344	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy135	1	3	1	1	1	0.9662	0.9375	0.9615	
AOmy135	2	5	0	0	0	0.0338	0.0625	0.0385	
AOmy135		# samples	24	24	24	148	144	364	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy136	1	3	1	0.9583	1	0.9218	0.6713	0.8356	
AOmy136	2	5	0	0.0417	0	0.0782	0.3287	0.1644	
AOmy136		# samples	24	24	24	147	143	362	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy137	1	2	1	1	1	0.9797	0.966	0.9782	
AOmy137	2	5	0	0	0	0.0203	0.034	0.0218	
AOmy137		# samples	24	24	24	148	147	367	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy138	1	4	1	1	1	1	0.993	0.9972	
AOmy138	2	5	0	0	0	0	0.007	0.0028	SnoqOmy
AOmy138		# samples	24	24	24	148	143	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy139	1	2	0.9286	0.1087	0	0.725	0.3546	0.4736	
AOmy139	2	5	0.0714	0.8913	1	0.275	0.6454	0.5264	
AOmy139		# samples	14	23	24	120	141	322	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy140	1	3	1	0.8636	1	0.8322	0.4792	0.711	
AOmy140	2	5	0	0.1364	0	0.1678	0.5208	0.289	
AOmy140		# samples	24	22	20	143	144	353	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy143	1	5	1	1	1	1	1	1	
AOmy143		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy146	1	3	0.6042	0.5	0.9375	0.465	0.3537	0.4627	
AOmy146	2	5	0.3958	0.5	0.0625	0.535	0.6463	0.5373	
AOmy146		# samples	24	24	24	143	147	362	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy147	1	3	0	0.0208	0	0.0845	0.431	0.2068	
AOmy147	2	5	1	0.9792	1	0.9155	0.569	0.7932	
AOmy147		# samples	24	24	24	148	145	365	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy148	1	2	1	0.9792	1	0.9932	0.9762	0.9863	
AOmy148	2	5	0	0.0208	0	0.0068	0.0238	0.0137	
AOmy148		# samples	24	24	24	146	147	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy149	1	3	0	0.0208	0	0.0479	0.2517	0.1219	
AOmy149	2	5	1	0.9792	1	0.9521	0.7483	0.8781	
AOmy149		# samples	24	24	24	146	147	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy150	1	2	1	0.9792	1	0.975	0.8759	0.9355	
AOmy150	2	5	0	0.0208	0	0.025	0.1241	0.0645	
AOmy150		# samples	24	24	8	140	145	341	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy151	1	2	0	0.0526	0	0.2209	0.4391	0.266	
AOmy151	2	5	1	0.9474	1	0.7791	0.5609	0.734	
AOmy151		# samples	21	19	24	86	115	265	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
AOmy153	1	2	1	1	1	1	1	1	
AOmy153		# samples	24	21	24	147	147	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI001	1	3	1	0.8077	1	0.7958	0.3511	0.641	
ASpI001	2	5	0	0.1923	0	0.2042	0.6489	0.359	
ASpI001		# samples	24	13	24	120	131	312	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI002	1	2	0	0.0625	0	0.1259	0.5548	0.2784	
ASpI002	2	3	1	0.9375	1	0.8741	0.4452	0.7216	
ASpI002		# samples	24	24	24	143	146	361	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI004	1	2	0	0	1	0.0142	0.0342	0.0864	
ASpI004	2	3	1	1	0	0.9858	0.9658	0.9136	
ASpI004		# samples	24	24	24	141	146	359	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI005	1	2	0	0	0.9583	0	0.0274	0.0738	
ASpI005	2	3	1	1	0.0417	1	0.9726	0.9262	
ASpI005		# samples	24	24	24	148	146	366	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI007	1	3	1	0.625	1	0.7473	0.3092	0.5449	
ASpI007	2	5	0	0.375	0	0.2527	0.6908	0.4551	
ASpI007		# samples	2	8	24	91	131	256	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI008	1	2	0	0.087	0	0.1602	0.5804	0.3085	
ASpI008	2	5	1	0.913	1	0.8398	0.4196	0.6915	
ASpI008		# samples	24	23	24	128	143	342	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI009	1	3	1	1	0.0625	1	0.9692	0.9262	
ASpI009	2	5	0	0	0.9375	0	0.0308	0.0738	
ASpI009		# samples	24	24	24	148	146	366	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI010	1	3	0	0.1042	0	0.113	0.5621	0.2769	
ASpI010	2	5	1	0.8958	1	0.887	0.4379	0.7231	
ASpI010		# samples	24	24	24	146	145	363	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI012	1	2	1	1	1	1	0.9966	0.9986	
ASpI012	2	3	0	0	0	0	0.0034	0.0014	SnoqOmy
ASpI012		# samples	24	24	24	146	146	364	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI013	1	2	1	0.9583	0	0.726	0.3367	0.5548	
ASpI013	2	3	0	0.0417	1	0.274	0.6633	0.4452	
ASpI013		# samples	24	24	24	146	147	365	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI014	1	3	0	0.0833	0	0.1081	0.5646	0.2752	
ASpI014	2	4	1	0.9167	1	0.8919	0.4354	0.7248	
ASpI014		# samples	24	24	24	148	147	367	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI017	1	3	0	0.1087	0	0.1336	0.5578	0.2857	
ASpI017	2	5	1	0.8913	1	0.8664	0.4422	0.7143	
ASpI017		# samples	24	23	24	146	147	364	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI018	1	2	0	0.0833	0	0.1187	0.5586	0.2795	
ASpI018	2	3	1	0.9167	1	0.8813	0.4414	0.7205	
ASpI018		# samples	24	24	24	139	145	356	

Appendix I. (Continued)

Locus	Allele	Size	LkWh Ocl	Cedar Ocl	Twin Ocl	Snoq Ocl	Snoq Omy	Overall	Private?
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI019	1	2	1	0.9167	1	0.8759	0.4448	0.7207	
ASpI019	2	5	0	0.0833	0	0.1241	0.5552	0.2793	
ASpI019		# samples	24	24	24	141	145	358	
Locus	Allele	Size	LkWhOcl	CedarOcl	TwinOcl	SnoqOcl	SnoqOmy	Overall	Private?
ASpI020	1	3	0.9583	0.9167	1	0.8664	0.4414	0.7149	
ASpI020	2	5	0.0417	0.0833	0	0.1336	0.5586	0.2851	
ASpI020		# samples	24	24	24	146	145	363	

A SYNTHESIS OF EXISTING DATA FOR RESIDENT FISHES IN THE SNOQUALMIE RIVER ABOVE SNOQUALMIE FALLS

PREPARED FOR PUGET SOUND ENERGY AS PARTIAL FULFILLMENT OF THE SNOQUALMIE RIVER GAME FISH ENHANCEMENT PLAN LICENSE ARTICLE 413

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June 2008

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EXECUTIVE SUMMARY

This synthesis is a summary of the fisheries research conducted on trout and mountain whitefish *Prosopium williamsoni* in the Snoqualmie River, with emphasis on resident cutthroat trout *Oncorhynchus clarki*, rainbow trout *Oncorhynchus mykiss*, and eastern brook trout *Salvelinus fontinalis* above Snoqualmie Falls and sea-run cutthroat trout below the Falls. Specifically, it is intended to provide a comprehensive summary of the studies and data that will be useful in implementing the Snoqualmie River Game Fish Enhancement Plan (SRGFEP), and to identify data gaps for ten primary research topics identified in the Plan: relative trout abundance, trout distribution, trout movement, trout reproductive life history, age and growth studies, creel census, background environmental data monitoring, habitat surveys and mapping, habitat enhancement, and public education.

Fisheries and environmental data relevant to these topics have been collected periodically by various entities; however, rigorous field studies of the fish resources in the Snoqualmie River are limited. In 1985, a comprehensive management plan for wild trout was assembled for the Snoqualmie River above Snoqualmie Falls that summarized most of the relevant fisheries data from 1969-1984 (Pfeifer 1985). Since then, data have been collected both opportunistically and as part of larger studies, and this synthesis is intended to be as inclusive as possible.

Results of this review indicate that data gaps are present for almost all the research tasks identified in the Plan, although the extent to which research has already been conducted for each task varies from non-existent to comprehensive. Tasks with the fewest data gaps are the habitat surveys and mapping and background environmental data portions of the Plan. Most of this information has been collected or is currently being monitored, and allocating significant resources to these tasks is not warranted. Tasks with the most glaring data gaps include behavioral data such as instream movement and spawning behavior, and a rigorous age and growth analysis for each salmonid species including mountain whitefish. Trout densities have been estimated periodically for various reaches in all three forks, however species-specific abundance estimates for each fork are still needed. Existing creel survey data is outdated; updated creel information is needed to evaluate the state of the fishery, its potential, and regulations affecting angler

harvest and effort. Finally, studies focused specifically on sea-run cutthroat trout in the Snoqualmie River below the falls are largely absent.

Relative Trout Abundance – Density and abundance estimates are outdated and surveys did not always differentiate among trout species. New species-specific density estimates should be obtained using more rigorous mark-recapture techniques.

Trout Distribution – Trout distribution and species composition needs to be reassessed in each fork and in the major tributaries to the forks using data collected with a variety of fisheries techniques.

Trout Movement – Radiotagging efforts are needed to assess whether trout exhibit extensive instream or among-fork movements including seasonal transitions to summer feeding stations, overwintering areas, and spawning sites.

Trout Reproductive Life History – Spawning surveys, radiotagging, and redd capping are needed to assess current spawning distribution, habitat preference, spawning duration, and egg/alevin incubation periods.

Age and Growth Studies – Rigorous age and growth analyses are needed for each salmonid species including mountain whitefish.

Creel Census – New creel surveys are needed to assess the current status of the fishery and to evaluate regulations affecting angler harvest and effort.

Background Environmental Data Monitoring – Measurements of stream temperature, turbidity, discharge, and other water quality parameters are currently recorded at monitoring stations operated by various agencies.

Habitat Surveys and Mapping – Extensive habitat surveys and mapping have already been conducted. The detail and extent of these surveys is beyond the scope of this project and allocating effort to this aspect of the Plan is largely unwarranted.

Habitat Enhancement – Very little habitat enhancement has been conducted on the Snoqualmie River. Enhancement recommendations should be provided to Puget Sound Energy and other government entities upon completion of the Plan.

Public Education – As the project nears completion, a pamphlet should be developed and posted on the WDFW website promoting the fishery resource in the Snoqualmie River. The potential for constructing kiosks or placing signs at strategic locations in the watershed should also be evaluated. The final report should be made available to the public and results presented at local angling clubs.

Trophic Interactions – Although the SRGFEP does not specifically outline plans to study trophic interactions, some of this data can be collected opportunistically while addressing other research questions. Diet data in particular is very sparse and should be collected during this study.

Sea-run Cutthroat Trout – Quantitative information for coastal cutthroat trout in the Snoqualmie River below the falls is minimal. Although the majority of the time and effort in this project will be directed above Snoqualmie Falls, some effort should be allocated to collection and analysis of sea-run cutthroat trout in the river below the falls. At a minimum, snorkeling should be conducted to characterize relative abundance and general distribution of sea-run cutthroat trout.

INTRODUCTION

In June 2004 the Federal Energy Regulatory Commission renewed the operating license for the Snoqualmie Falls Hydroelectric Project (FERC No. 2493) that is owned and operated by Puget Sound Energy. Terms of the renewal required Puget Sound Energy (PSE) to file a final Snoqualmie River Game Fish Enhancement Plan for the purpose of enhancing fish resources in the vicinity of the project. This Plan was developed through collaborative efforts with the Washington Department of Fish and Wildlife (WDFW), and a final report was submitted December 2005 (Puget Sound Energy 2005). The Plan provides for an intensive three-year study beginning with a literature review of the relevant studies already conducted in the basin. Puget Sound Energy contracted WDFW to implement the Plan, and the three-year study was initiated in January 2008.

The goal of the Plan is to enhance the game fish resources in the project vicinity, with emphasis on resident trout (cutthroat trout, rainbow trout, and eastern brook trout) above Snoqualmie Falls and sea-run cutthroat trout below the Falls. The Plan is consistent with WDFW's mission to provide maximum recreational fishing opportunities compatible with healthy and diverse fish populations, and is a necessary step for continued management of the Snoqualmie River as a wild trout resource. Investigations of trout abundance, distribution, life history, angling effort, and harvest data will be conducted using a variety of fisheries techniques. These will include electrofishing, snorkeling, radiotagging or other methods for investigating movement, creel surveys, spawner surveys, water quality monitoring, habitat assessment, and other methods described in the Plan. When appropriate, data from previous studies will be used to supplement data collected for this study and to help fulfill Plan objectives.

This synthesis of the relevant studies and data collected to date is provided to identify data gaps and to refine the scope of field work necessary to implement the SRGFEP. The intent, as outlined in the Plan, is to include all relevant fish inventories, limiting factors analyses, existing condition reports, physical habitat surveys and assessments, databases, and other reports published by the agencies, King and Snohomish Counties, tribes, consulting firms, and academia. This literature review focuses on the studies and data that will be most useful in implementing ten primary tasks that are outlined in the Plan as follows:

1. Relative Trout Abundance – Relative trout abundance will be estimated for various stream reaches in the basin.
2. Trout Distribution – This study will determine the presence or absence of native and non-native trout (juvenile and adult) in the basin as practical including some assessment of alpine lake trout stock influence on the distribution of native or non-native species.
3. Trout Movement – Trout movement will be studied to assess whether trout exhibit extensive instream movements including seasonal transitions to summer feeding stations, overwintering areas, and spawning sites.
4. Trout Reproductive Life History – Trout reproductive life history will be examined to determine spawning distribution, habitat preference, quality and type of spawning habitat, spawning duration, and egg/alevin incubation periods.
5. Age and Growth Studies – Age and growth studies will be conducted to refine knowledge of population age structure, growth, mortality, and age at maturity. This information is critical for establishment of size restrictions on harvestable trout.
6. Creel Census – Recreational and harvest effort for native and non-native trout will be quantified in the Snoqualmie River Basin as practical.
7. Background Environmental Data Monitoring – Water quality measurements including stream temperature, turbidity, and discharge are monitored by various agencies and will be used to assess potential impacts on trout ecology and life history.
8. Habitat Surveys and Mapping – Habitat surveys will be conducted in the three forks of the Snoqualmie River to describe the quality and quantity of game fish habitat.
9. Habitat Enhancement – Habitat enhancement needs may be identified during the literature review process and while completing the study.
10. Public Education – PSE will assist WDFW by providing resources to fund public education of the fishery resource in the Snoqualmie River.

Fisheries and environmental data relevant to these tasks have been collected periodically by various entities. Techniques used in these investigations include snorkel and electrofishing surveys, angling efforts, creel surveys, stream habitat surveys, and monitoring stream gauges. Rigorous field studies of the fish resources in the Snoqualmie River are limited, and tend to be focused on reaches where hydroelectric projects exist or have been proposed, such as the reach above the Black Canyon on the North Fork Snoqualmie River, and the Twin Falls region on the South Fork Snoqualmie River. In 1985, a comprehensive management plan for wild trout was assembled for the Snoqualmie River above Snoqualmie Falls (Pfeifer 1985). The intent of the report, which relied heavily on data from creel surveys and volunteer anglers, was to compile all the available biological data and relevant fisheries data for management purposes. Most of the relevant fisheries data from 1969-1984 were summarized in this report including intensive creel surveys on the North and Middle Fork Snoqualmie River in 1969 and on the North Fork in 1979, and a less intensive creel survey on all three forks in 1984.

U.S. Forest Service (USFS) stream habitat surveys have been conducted in all three forks of the Snoqualmie River (USFS, North Bend Ranger District Mount Baker-Snoqualmie National Forest). Stream surveys were conducted in the North Fork in 1993 and 2007, in the Middle Fork in 1990 and 1996 (Cascades Environmental Services 1997), and in the South Fork in 1990-1991 and in 1998. Several tributaries were also surveyed including Lennox Creek (North Fork tributary) in 1990, the Taylor River (Middle Fork tributary) in 1992, and the Pratt River (Middle Fork Tributary) in 1992 (Raleigh Consultants 1992), Carter Creek (South Fork tributary) in 1991, and Quartz Creek (Taylor River tributary) in 1991. With the exception of the 2007 survey in the North Fork, surveys included a species-specific count of juvenile and adult fish in the reaches surveyed.

Electrofishing and snorkel data have been collected on all three forks beginning in 1979 with mitigation studies on the North Fork (Kurko et al. 1980), and then periodically through the fall of 2000 when all three forks were snorkeled for presence of native char (Berge and Mavros 2001). Almost all of the USFS stream surveys included snorkel surveys and followed the USFS Stream Inventory Handbook Level I and II protocols (USFS 2006). The only long-term fisheries dataset is the mitigation work in the Twin Falls area of the South Fork where from 1984 to 2005 several study reaches were monitored for trout abundance with electrofishing and snorkel surveys (Twin Falls Hydro

Company 2006). In August 1992, snorkel survey index reaches were established in all three forks to determine baseline trout densities for future monitoring of fishing regulations and to evaluate the Basic Stream Management Strategy in effect for these streams (Jackson and Jackson 1993). Additional data from various reaches above Snoqualmie Falls have been collected both opportunistically and as part of larger studies, and are summarized in this review.

STUDY AREA

Snoqualmie River Basin

The Snoqualmie River drainage encompasses the southern 703 mi^2 of the Snohomish River Basin (**Fig. 1**)(Pentec Environmental and NW GIS, 1999). Tributaries extend high into the Cascade Mountains where flows are heavily influenced by snowmelt but are not glacially fed. The river runs through a relatively unconfined, alluvial floodplain that divides into two segments by bedrock protruding at Snoqualmie Falls (Pentec Environmental and NW GIS, 1999). Below the 268-ft falls, the river meanders through low gradient, moderately confined habitat until its confluence with the Skykomish River, at which point the two rivers form the Snohomish River. Above the falls (RM 40.4), the mainstem Snoqualmie River branches into three forks: the South Fork at RM 43.8, and both the Middle Fork and North Fork at RM 44.5. The mainstem Snoqualmie River continues as the Middle Fork at RM 44.5, whereas rivermiles reset to RM 0 at the mouths of the North and South Forks (Williams et al. 1975). Extensive analysis of the ecological structure and function, human dimension, and management of the basin is included in the Federal Watershed Analyses completed for the Middle Fork (USFS 1998a) and South Fork (USFS 1995) watersheds. Detailed descriptions of the three forks are provided in Williams et al. (1975) and again in Pfeifer (1985), and a brief summary from these documents is given below.

North Fork Snoqualmie River

The upper six miles of the North Fork Snoqualmie River (**Fig. 2**) runs through high-gradient, mountain habitat with a series of cascades, rapids, and small falls. For the next seven miles, habitat is relatively flat with moderately low gradient. Substrate switches from boulder, rubble and bedrock to primarily gravel, rubble, and silt in the slower areas. The channel width ranges from 6 to 12 yards in early Fall and exhibits considerable braiding. Pool habitat is abundant and there are many long, slow glides, with a few shallow riffles. The gradient becomes steeper from below this section down to the Black Canyon where a series of cascades fall through narrowly confined habitat. The remaining few miles until the confluence with the Middle Fork exhibit moderate gradient with quality pool-riffle habitat and boulder or rubble substrate (Williams et al. 1975; Pfeifer 1985).

Middle Fork Snoqualmie River

The upper ten miles of the Middle Fork Snoqualmie River (**Fig. 3**) flow through high-gradient habitat within a narrow valley and with mountain side-slopes rising to over 6000 feet in elevation. Below Burntboot Creek (RM 74.6), the gradient is moderate until just below Granite Creek (RM 56.3). Downstream of Granite Creek the gradient is relatively steep until the river flows east of North Bend where, for the final four miles, gradient is moderate to gentle. As in the upper reaches of the North Fork, substrate in the upper Middle Fork consists primarily of boulder, rubble, and bedrock. When the gradient levels out, substrate switches to gravel and rubble between stable earth or rock banks. Fall channel widths range from 6 to 30 yards in the stretch between Burntboot Creek and Granite Creek and the river exhibits relatively little braiding. Widths expand to between 15 and 40 yards in the eight miles below Granite Creek where fast riffles, a few rapids, and short cascades are separated by a number of large deep pools. Over the lower four miles of the Middle Fork, substrate is gravel or rubble and channel widths range from 10 to 25 yards with good pool-riffle balance (Williams et al. 1975; Pfeifer 1985).

South Fork Snoqualmie River

The upper six miles of the South Fork Snoqualmie River (**Fig. 4**) run through Fall channel widths of 3 to 7 yards in narrow ravine-like habitat with side-slopes rising to over 4000 feet. Below Rockdale Creek (RM 25.1), gradient is moderate and the channel is relatively confined with widths from 6 to 14 yards, and with occasional braided channel areas. Pool-riffle balance is good and long broad stretches of riffles are common. Substrate consists of gravel and rubble with only a few boulder areas, and the banks are primarily stable earth or rock. Below Change Creek (RM 12.9) gradient increases and widths range from 7 to 12 yards. This stretch is characterized by cascades and rapids and includes two relatively large falls, the largest being Twin Falls. Below Twin Falls (near RM 11), gradient is moderate, the channel is relatively confined with few braids, channel widths range from 8 to 20 yards, and substrate switches to gravel and rubble with a few scattered boulders. Most streambanks are naturally stable although considerable bank armoring exists near North Bend (Williams et al. 1975; Pfeifer 1985).

Mainstem Snoqualmie River above Snoqualmie Falls

The four-mile reach between the confluence of the North and Middle Forks and Snoqualmie Falls is broad and flat with moderate to low gradient. Quality pool-riffle habitat through gravel and rubble substrate turns to long riffle-free glides with a few sandy point bars, and finally to long deep glides and pools over sandy to muddy substrate as the river nears Snoqualmie Falls (Pfeifer 1985).

Mainstem Snoqualmie River below Snoqualmie Falls

The Snoqualmie River from below Snoqualmie Falls to its confluence with the Skykomish River (RM 20.5) drops about three feet per mile while meandering through a floodplain zoned primarily for low-density agriculture use (King County 2001). Channel widths vary from 67 to 133 yards with depths varying from 18 to 48 feet (U.S. Army Corps of Engineers 1968). Two large rivers drain into the Snoqualmie River below Snoqualmie Falls, the Raging River at RM 36.2 and the Tolt River at RM 24.9.

FISH RESOURCES

Above Snoqualmie Falls

Fish species known to inhabit the Snoqualmie River above Snoqualmie Falls include cutthroat trout, rainbow trout, eastern brook trout, mountain whitefish, largescale sucker *Catostomus macrocheilus*, longnose dace *Rhinichthys cataractae*, shorthead sculpin *Cottus confusus*, and mottled sculpin *Cottus bairdi* (Pfeifer 1985, Sweeney et al.

1981, Kurko et al. 1980). In addition to these species, substantial numbers of western brook lamprey *Lampetra richardsoni* were found in the mainstem below the South Fork confluence (Dames & Moore 1985), and threespine stickleback *Gasterosteus aculeatus* were found in Kimball Creek, a mainstem tributary approximately one-half mile above Snoqualmie Falls (U.S. Fish and Wildlife Service 1980, unpublished data). Hatchery propagated Chinook salmon *Oncorhynchus tshawytscha* and coho salmon juveniles *Oncorhynchus kisutch* were planted occasionally in the past to make use of rearing potential in the South Fork (Williams et al. 1975), but this no longer occurs (USFS 1995). In addition, the Washington Department of Fisheries made four plants of coho salmon fry in the North Fork between 1977 and 1979 (Kurko et al. 1980), and arctic grayling *Thymallus arcticus* eggs were planted in the Middle Fork in June 1947 (WDFW hatchery release database, Olympia Washington). There is no record of arctic grayling having survived. Dolly Varden *Salvelinus malma* or bull trout *Salvelinus confluentus* were listed in a popular fishing guide as present in the North Fork (Jones 1973, and newer editions of the Washington State Fishing Guide). However, no studies have reported observations of native char above Snoqualmie Falls, including during snorkel surveys designed to detect their presence (Berge and Mavros 2001). It is possible that these were misidentified brook trout introduced in prior years (Pfeifer 1985), or an undetermined species of char that once inhabited nearby Lake Calligan that drains into the North Fork (Rief 1906). The Smithsonian National Museum of Natural History has three other sculpin species in collection. Torrent sculpin *Cottus rhotheus* and Paiute sculpin *Cottus beldingii* were collected in the South Fork near North Bend in 1929, and in 2003, reticulate sculpin *Cottus perplexus* (and also torrent sculpin) were collected in the Pratt River (near RM 7), a tributary to the Middle Fork. Finally, a number of fishes have been planted in the alpine lakes within the Snoqualmie River drainage including: cutthroat trout, rainbow trout, golden trout *Oncorhynchus aguabonita*, eastern brook trout, arctic grayling, and lake trout *Salvelinus namaycush* (WDFW stocking records).

Cutthroat trout have always been known to be abundant and, along with mountain whitefish, are likely native to these reaches. Rainbow trout may be native above Snoqualmie Falls, but, as with eastern brook trout, have also been established through planting of hatchery fish (Pfeifer 1985). Hybrid characteristics between cutthroat trout and rainbow trout have been observed although genetic methods are required to determine the extent to which hybridization has occurred (Pfeifer 1985). There is a long history of stocking all three trout species, and detailed records beginning in 1933 are available in Pfeifer (1985) and in the WDFW hatchery release database. These records indicate that cutthroat trout were last planted in the North Fork in 1980, the Middle Fork (Quartz creek) in 1983, and the South Fork in 1990, that rainbow trout were last planted in the North Fork in 1982, the Middle Fork (Quartz creek) in 1983, and the South Fork in 1992, and that eastern brook trout were last planted in the North Fork in 1959, the Middle Fork in 1964, and the South Fork in 1965. Limited numbers of legal-sized trout were also stocked from 1956 through 2002 in either Coal Creek or Kimball Creek just above Snoqualmie Falls to supply fish for a juvenile fishing derby.

Quantitative fisheries data collected on the mainstem reach of the Snoqualmie River above the Falls are limited (Puget Sound Power & Light Company 1991, Dames & Moore 1985, City of Bellevue 1985). However, there is a long history of large, presumably wild cutthroat trout caught in this stretch of the river (Pfeifer 1985). Although some large rainbow trout from annual plants in Coal Creek and Kimball Creek have also been caught in the mainstem, survival of hatchery fish has probably been low (Pfeifer 1985).

Below Snoqualmie Falls

Snoqualmie Falls forms a natural barrier to fish passage. Below the falls, resident and anadromous salmonids use the river and many of the river's tributaries for spawning and rearing, however the high prevalence of sand and silt substrate renders portions of this stretch unsuitable for salmonid spawning (Lucchetti 2005). Anadromous salmonids known to use the Snoqualmie River include Chinook salmon, coho salmon, chum salmon *Oncorhynchus keta*, pink salmon *Oncorhynchus gorbuscha*, steelhead *Oncorhynchus mykiss*, and coastal cutthroat trout. Isolated observations of native char (bull trout or Dolly Varden) have been reported (Berge and Mavros 2001) but spawning has not been observed in the Snoqualmie Watershed (Snohomish Basin Salmon Recovery Forum 2005). A few sockeye salmon *Oncorhynchus nerka* have also been observed, but it is not known if these are strays or if a small spawning population exists (Lucchetti 2005).

Rainbow trout, cutthroat trout, and mountain whitefish are the common resident salmonids below the Falls, and a variety of warm-water fishes (primarily Centrarchid spp.) are also present (Pentec Environmental and NW GIS, 1999). Including those found in the tributaries and agricultural areas of the Snoqualmie River, at least thirty fish species have been observed in the Snoqualmie River drainage below the falls (H. Berge, personal communication). Cutthroat trout are ubiquitous throughout the Snohomish River Basin and exhibit anadromous, fluvial, adfluvial, and resident life history forms (Harring 2002). Limited information is available for sea-run coastal cutthroat trout in the Snoqualmie River, and their stock status in the Snohomish Basin is largely unknown (Haring 2002). Almost all tributaries in the Snoqualmie River below the falls contain sea-run cutthroat trout, with major producers including Cherry Creek, Stossel Creek, and the Raging River (Haring 2002).

Current Management

Currently, all three Snoqualmie River Forks are managed for wild trout. The Middle Fork is a year-round catch-and-release fishery, whereas from June through October, a two fish daily limit with a 10-inch minimum size is allowed in the other two forks and in the mainstem above the falls. From November through May all three forks are catch-and-release only. For mountain whitefish, the daily limit is fifteen. Selective gear rules apply for which only unscented artificial flies or lures with one single-point, barbless hook are allowed and fish must be landed with a knotless net. In the river below the falls, a two fish daily limit with a 14-inch minimum size is allowed for trout from June through February. Selective gear rules apply except that motors are allowed.

FISHERIES DATA AND STUDIES

Relative Trout Abundance

Electrofishing and snorkel surveys have been conducted in various reaches of all three forks by several different agencies and consulting firms. In 1979, seven river reaches were block netted and electrofished to estimate densities of fish in the North Fork (Kurko et al. 1980). The following year, the lower stretches of four tributaries and the upper North Fork (RM 21.2 - 22.0) were also electrofished (Sweeney et al. 1981). In nine miles of the river below RM 21.2, mainstem trout densities (all sizes combined) averaged 2,105 ± 358 trout/mile or 18,945 ± 3,222 trout **(Table 1)**. These densities were compared to density estimates from snorkel surveys (**Table 2**) conducted from late July to early October 1979 in twelve mainstem reaches (Kurko et al. 1980). The average snorkel survey covered a 1-mile stretch of river, and two or three observers with underwater wrist slates were used to record fish in 3-inch size categories. Species were recorded when possible, but cutthroat and rainbow trout were usually not differentiated. Three years later, electrofishing (RM 1.1 and 5.3) and snorkel (RM 0.0-6.7 and RM 6.0-11.5) surveys were resumed in the North Fork to supplement these studies (Dames & Moore 1985). Electrofishing produced only two trout at RM 1.1, whereas 1,497 rainbow trout/mile were estimated at RM 5.3 (**Table 3**). Snorkel surveys estimated an average of 109 trout/mile in two reaches above the Black Canyon and no trout were observed in the 0.8 mile reach near the confluence (**Table 4**). Cold autumn temperatures were suggested to have affected the comparability of trout densities with the 1979-80 surveys that had been conducted earlier in the year. Survey results from 1979-1984 for RM 5.3-13.3 are summarized in **Table 5**. It was concluded that several of the density estimates for trout were extreme (4,774, 139, 129, 30, 10 fish/mile) and not likely representative of actual long-term trout densities. Rather, the authors believed that 1,442 fish/mile (the average of six estimates presumed to be more reliable; standard deviation = 844, 95% confidence limit = +/- 1,688) provided a better estimate of trout density in the mainstem North Fork between RM 5.3 and 13.3. Nighttime snorkeling was conducted on October 28, 1983 in one reach below the South Fork confluence. Many more trout were seen attracted to the lights at night compared to surveys conducted in similar habitats after daybreak (Dames & Moore 1985). Trout often confine themselves in the substrate or in woody debris during the day when river temperatures drop below 9˚C (Thurow 1994), as would have been the case at the end of October.

Sections of Calligan Creek and Deep Creek, two North Fork tributaries, were also electrofished, and a mainstem Snoqualmie River site (RM 42.9) below the confluence of the South Fork was electrofished and snorkled (Dames & Moore 1985). Calligan Creek contained 1,388 rainbow trout/mile (only one cutthroat trout was captured) and Deep Creek contained 774 trout/mile (primarily rainbow trout and brook trout) in the lower reach and 1,044 trout/mile (primarily brook trout) in the upper reach (**Table 6**). Only three trout were observed while snorkeling the mainstem reach. However, electrofishing efforts estimated 1,599 cutthroat trout/mile in this area. No rainbow trout were caught, however a few mountain whitefish and a substantial number of sculpin and brook lamprey were encountered. Mountain whitefish in this reach were estimated at 270 fish/mile and largescale sucker were estimated at 245 fish/mile although these numbers were based on snorkel observations limited to about five percent of the stream cross section.

Two other electrofishing and snorkel surveys were conducted in the Black Canyon vicinity of the North Fork (RM 2.5 to 4.7), one by Ott Water Engineers in the Fall of 1984 and a similar survey in August 1985 by R.W. Beck and Associates (**Table 7**). Most fish were concentrated in small areas at the head of plunge pools immediately below cascades or riffles rather than distributed uniformly within study sites. Densities of fish were low in the large deep pools (Beck and Associates 1985).

The only consistent, long-term dataset monitoring trout abundance on the Snoqualmie River is for the South Fork (Twin Falls Hydro Company 2006). Snorkel and electrofishing surveys were conducted from 1984 through 1988 prior to construction of the hydroelectric facility, and again after construction from 1990 through 2005 (with the exception of 1992-1993) to monitor trout populations in the vicinity of the project (RM 10.4 to 16.5). Study sites included a bypass site approximately 1,000 ft upstream of the project's tailrace, two sites selected for habitat enhancement, and a control site. A fifth site at RM 11.3 was dropped from the study in 1996 because too little of the site included habitat affected by the project. Three snorkel surveys were conducted between mid-June and early September and these were followed by electrofishing surveys conducted in late September or early October. Trout densities varied substantially by site and across years, but were markedly higher below Twin Falls in the bypass reach in most years (**Table 8**). Prior to the long-term monitoring initiated in 1984, preliminary electrofishing and snorkel surveys were also conducted in the Twin Falls area by the Washington Department of Game, Hosey and Associates, and the University of Washington Fisheries Research Institute (Scott and Nakatani 1982a, 1982b).

In August 1992, the WDFW established snorkel survey index reaches in each fork of the Snoqualmie River and in the North Fork Tolt River to obtain baseline data for monitoring regulations (Jackson and Jackson 1993, Burley and Jackson 1993). Each reach was about 3 to 5 km long and was snorkeled by a three or four person crew. Trout densities were estimated by expanding snorkel lane counts for total stream width (**Table 9**). In the Snoqualmie River, trout density was highest in the middle reach of the South Fork (the lower South Fork was not surveyed), but was similar to that for the middle reach of the Middle Fork and the lower reach of the North Fork. Densities were relatively low in the upper reaches of the North and South forks, but comparatively high in the upper Middle Fork. Total trout densities in the North Fork had changed very little since surveys in 1979-80 (Sweeney et al. 1981), however densities of trout > 9 in had almost doubled in the middle and lower sections. Similarly, although the proportion of trout ≥ 12 inches had decreased in the Middle Fork, in all three forks, the proportion of trout ≥ 9 inches had increased substantially compared to angler-caught trout in the early 1980s (WDFW 1993).

The most recent data to include all three forks of the Snoqualmie River was collected in 2000 when each fork was snorkeled (October-December) for presence of native char (Berge and Mavros 2001) and electrofished (spring and summer of 1999 and 2000) in the upper reaches to determine the terminal limits of cutthroat trout distributed in the upper watersheds (Latterell 2001). Salmonid densities were 0.046 fish/m^2 in the upper mainstem of the North Fork, 0.026 fish/m^2 in the mainstem of the Middle Fork near RM 65, and 0.040 fish/m^2 in the mainstem of the South Fork upstream of Tinkham campground (Berge and Mavros 2001). No native char were observed.

Trout Distribution

Snorkel observations during USFS stream habitat surveys in the 1990s were used to estimate trout distribution in selected reaches of all three Snoqualmie River Forks including several tributaries to the forks (**Table 10 and 11**)(USFS 1998b, 1993, 1992a, 1992b, 1991a, 1991b, 1991c, 1990a, 1990b, 1990c, Cascades Environmental Services 1997). Cutthroat trout, rainbow trout, brook trout, and *Cottus* spp. were observed in all three forks. Mountain whitefish were observed in the Middle Fork, but not above the

Black Canyon in the North Fork (surveyed from RM 8.0 to 13.1) or above Twin Falls in the South Fork (surveyed from RM 17.3 to 30.6). Various cutthroat trout X rainbow trout hybrids were noted in the upper reaches of the Middle Fork (USFS 1990). Several unidentified salmonid fry were observed (August 22, 1996) in eddies, along channel margins, and in pools along the Middle Fork from RM 60.5 to 64.5, whereas all adult fish in this reach were found in pools (Cascades Environmental Services 1997). In the South Fork, adult and juvenile trout were observed in each reach, but fish diversity and numbers generally declined across reaches from RM 17.9 to 30.6 (USFS 1998b). In the lower two reaches (RM 17.9-23.3) fish were only present in lateral and mid-channel pools if there was wood, undercut banks, or overhanging cover. For all other reaches, fish were primarily found in pools with shade from overhanging cover or undercut bedrock banks (USFS 1998b). Surveys in Lennox Creek (tributary to the upper North Fork) indicated that cutthroat trout and juvenile brook trout were prevalent with a few rainbow trout in the lowermost reach (USFS 1990c). Brook trout were not observed in the Taylor and Pratt Rivers (tributaries to the Middle Fork); rainbow trout and cutthroat trout were the predominate species and a few whitefish were observed in the lowermost reach of the Taylor River (USFS 1992a, 1992b).

In the North Fork, species composition estimated from electrofishing and snorkel surveys heavily favored rainbow trout near the mouth, but gradually shifted to cutthroat trout towards the headwaters (**Table 1**)(Kurko et al. 1980). Cutthroat trout were not found in electrofished sections of the river below RM 11.5 or snorkeled sections below RM 13.3, and rainbow trout were not present in electrofished sections above RM 19 or snorkeled sections above RM 18.2. Brook trout were most abundant between RM 14.6 and 18.2 and never exceeded 15% of the catch in any section. Surveys in 1983 confirmed that salmonids were almost exclusively rainbow trout above the Black Canyon from RM 5 to 12, however cutthroat trout were the predominant trout below the canyon (Dames & Moore 1985). Species diversity was higher below the canyon and included mountain whitefish, largescale sucker, cottids, and brook lamprey.

Non-salmonid fishes were observed in significant numbers during these North Fork surveys. While spot electrofishing between RM 9.2 and 19.2 an average of 4.2 shorthead sculpin were caught for every trout (Kurko et al. 1980). A similar ratio of 3.6

sculpin for every trout was encountered at RM 5.3, and over 10,000 cottids/mile were estimated at Ernie's Grove near RM 1.1 (Dames & Moore 1985). In addition, two schools (N=3 and 80) of largescale sucker averaging 450 to 600 mm were observed in the reach between RM 0.3 and 1.8 (Sweeney et al. 1981) and 129 largescale sucker/mile were estimated in this area from snorkel surveys in 1983 (Dames & Moore 1985).

Creel surveys on the North Fork (1979) also indicated that rainbow trout were more heavily distributed across lower river reaches (Kurko et al. 1980). Of the 4,032 fish caught below RM 12, catch composition consisted almost exclusively of rainbow trout, and only one mountain whitefish was observed. Above RM 12, over 3,500 fish were caught. Species composition was not delineated but was suggested to reflect that for electrofishing results.

In the Middle and South Forks, small sample sizes of angler-caught trout prohibited estimating relative proportions of trout by species (Pfeifer 1985). However, catch data (1981-1984) from volunteer anglers who fished the Middle Fork in all river areas below Burntboot Creek (RM 74.6) indicated cutthroat trout catch rates were much higher than those for rainbow trout that constituted between 0 and 20% of the catch. Angler efforts in the South Fork indicated about 34.6% of Age II and Age III trout were rainbow trout, 17.3% were cutthroat trout, and 48.1% were hybrids. In the fall of 1990, catch results (N=332 trout) from 15 anglers who were used to fish the Middle Fork indicated that cutthroat trout comprised 95% of the catch (Pfeifer 1990). Rainbow trout comprised 22% of the catch in the lowermost section (RM 44.5-64.8) and 12% in the uppermost section (RM 77.5-84.0), but only between 1% and 7% in the middle three sections. One mountain whitefish was caught in the section between RM 70.2 and 77.5. Brook trout were also observed in the Middle Fork during snorkel surveys between approximately RM 60.5 and 81 (Cascades Environmental Services 1997), and were present in the South Fork during electrofishing and snorkel surveys in the vicinity of the Twin Falls Hydroelectric Project (Twin Falls Hydro Company data, 1984-2005).

The upstream limit of trout distribution was compared across 58 drainages in the Cascade Mountains including the three forks of the Snoqualmie River (Latterell 2003). Although upstream distribution was not reported separately for the mainstem headwaters of each fork, trout were consistently absent from streams when slopes were greater than

22% and where the mean width of the wetted channel was less than 0.3 m. Steep channel gradient, declines in pool abundance, and narrow or intermittent wetted channels (in logged drainages), were important predictors of the upstream limits of trout.

Snorkel and electrofishing surveys in the headwaters of the South Fork adjacent to the Alpental ski area (RM 29-30) found only cutthroat trout (Jones and Stokes 2001). Natural barriers, lack of spawning habitat, and naturally low productivity in the headwaters limit fish habitat, and all trout above Franklin Falls are likely descendants of fish plants rather than of wild origin. Coastal cutthroat trout have also been stocked in Source Lake, the upstream end to the South Fork.

In the mainstem Snoqualmie River from above Snoqualmie Falls to the lower reaches of all three forks, Puget Power biologists snorkeled twenty sites in July 1990 and recorded fish species, number, estimated size, and general locations (**Table 12**)(Puget Sound Power & Light Company 1991). The survey was repeated one and eight weeks later after temporary wooden flashboards were installed to study backwater effects resulting from raising the water level above the Project. In the upstream reaches of the mainstem, fish observations primarily consisted of cutthroat trout located in riffle areas and largescale sucker located in deep, slow channelized areas. In the downstream reaches, few cutthroat trout were observed, although numbers increased after water levels were raised. Mountain whitefish, found in faster-moving water or around structure such as logjams, and largescale sucker, again in deeper slower water, were the primary fish observed. In the North and Middle Forks, some cutthroat trout and mountain whitefish were found in the riffle areas, but most fish (which included cutthroat trout, rainbow trout, mountain whitefish, and suckers) were concentrated in the few deeper (2-3.5 ft) side pools. Fish observed in the South Fork tended to be distributed evenly across a variety of habitats such as riffle areas, turbulent and still pools, and around large organic debris. Cutthroat trout and mountain whitefish were the predominant species and were observed in much greater numbers than in the two other forks and in the mainstem. Some juvenile coho salmon, presumably escapees from a fish farm upstream of the Project, were also observed during licensing studies that included forebay and tailrace sampling (Puget Sound Power & Light Company 1991).

Trout Movement

In the summer of 1979, 150 North Fork rainbow and cutthroat trout larger than 130 mm were tagged behind the dorsal fin with a numbered, colored, Floy tag (Kurko et al. 1980). Several tagged fish were observed during snorkel surveys that summer, but observers were not able to get close enough to read the tags. After 10 months, anglers recovered two rainbow trout. One was recovered 1 mile downstream and had grown 64 mm, and the other was recovered 13 miles downstream and had grown 89 mm (Sweeney et al. 1981). It was noted that the number of larger trout observed during snorkel surveys generally increased downstream. It was further speculated that some downstream movement to better adult habitat might occur as trout grow. No other movement studies have been conducted in the Snoqualmie River above Snoqualmie Falls.

Trout Reproductive Life History

Reproductive life history data for fishes in the Snoqualmie River Forks is largely absent and has primarily been limited to a few ancillary observations during studies focused on other research questions. An early May to late July spawning period for wild trout was suggested by Pfeifer (1985) based on observed timing of fry emergence in Washington river systems (Scott and Nakatani 1982b) and Washington Department of Game surveys in the Yakima River in which a larger percent of rainbow trout were ripe or near-ripe in April compared to November (Johnston 1979, 1980). This differed from the late December to early February spawning period characteristic of Tokul Creek cutthroat trout and Mount Whitney rainbow trout that were often used for hatchery plants in the South Fork, and from anadromous coastal cutthroat trout in Washington, for which spawning usually peaks in February (Trotter 1989). Scale analysis for one Age IV (375 mm) rainbow trout from the North Fork indicated it had spawned at Age II. It was captured in October with eggs and was thought likely to have spawned again in the spring. Spawning every other year would be a pattern consistent with other higher elevation trout populations (Sweeney et al. 1981). In early November 1979, newly constructed brook trout redds were observed in the upper North Fork (Sweeney et al. 1981), which is consistent with a fall spawning period for char. Similarly, brook trout that were ripe with gametes and appeared to be spawning in nearby riffle habitat were observed in North Fork snorkel surveys conducted late October through November 2000 (Berge and Mavros 2001). Mountain whitefish are also late fall and winter spawners.

Instream flow studies for limited reaches of the North Fork (Beck and Associates 1985, Dames & Moore 1985, Sweeney et al. 1981), the South Fork (Steward and Stober 1983), and the mainstem above Snoqualmie Falls (Dames & Moore 1985) used the physical characteristics of the river (depth, velocity, and substrate) to quantify life-stage-specific habitat requirements and availability for trout and mountain whitefish. Below Snoqualmie Falls, habitat was modeled for selected life-stages of pink salmon, Chinook salmon, coho salmon, steelhead trout, sea-run cutthroat trout, and mountain whitefish (Dames & Moore 1985). For the North Fork, it was assumed that trout spawned in April and May, fry were present from July through December, and juveniles and adults were present year round (Beck and Associates 1985). For the South Fork, it was assumed that trout spawned from May through late July, and mountain whitefish spawned from October through December. Trout fry were assumed present from July through October, and mountain whitefish fry from April through mid-August, and juveniles and adults of all species were assumed present year round (Steward and Stober 1983). While useful for determining appropriate minimum flows for hydroelectric facilities, no actual observations of spawning behavior or reproductive life-history data were obtained.

Age and Growth Studies

Scale samples have been collected on several occasions from electrofishing and angling efforts but published age and growth data are minimal. Scales were analyzed for North Fork trout collected by electrofishing four high gradient tributaries and one mainstem reach near Lennox Creek (Sweeney et al. 1981). At this elevation, the mainstem is very similar in character to the tributaries. Growth rates were not compared to trout from lower mainstem reaches; however it was noted that numbers of larger trout observed while snorkeling generally increased on downstream surveys and the largest trout observed (estimated to be 20 inches) was in a large pool between RM 9.2 and 10.1 (Sweeney et al. 1981). Growth was also slower than for cutthroat trout collected in nearby beaver ponds. Although limited sample size necessitated combining both species for growth estimates, rainbow trout were not present in the electrofished mainstem sites above RM 19 and only 26.2% of trout sampled in the tributaries were rainbow trout. This suggests that trout used for aging were primarily cutthroat trout. Cutthroat trout and rainbow trout were not differentiated for growth estimates in the Middle and South Forks (Pfeifer 1985). Length frequencies of trout from all three forks are provided in **Figures 5, 6 and 7**.

Age and growth data from the North Fork study and from angler-caught trout collected on the Middle and South Forks from 1981 to 1984 were summarized in Pfeifer (1985)(**Fig. 8, Appendix**). In the tributaries and upper mainstem of the North Fork, length-at-age overlapped considerably for Age II and Age III trout but was discrete by Age IV. Fork lengths ranged from 80 to 174 mm (average 129 mm; N=53) for Age II trout, from 133 to 175 mm (average 158 mm; N=10) for Age III trout, and from 176 to 284 mm (average 224 mm; N=3) for Age IV trout. All trout from the mainstem site were Age II (range 89-164 mm; average 128 mm; N=24). These trout were similar in length to Age II trout from the tributaries (range 80-174 mm; average 130 mm; N=29). However, growth rates were much slower than for cutthroat trout captured in nearby beaver ponds that averaged 177 mm at Age I and 269 mm at Age II. In the Middle Fork, total lengths of angler-caught trout ranged from 108 to 222 mm (average 169 mm; N=52) for Age II trout, 171 to 246 mm (average 209 mm; N=44) for Age III trout, 155 to 318 mm (average 216 mm; N=9) for Age IV trout, 255 to 257 mm (average 256 mm; N=2) for Age V trout, and 259 to 346 mm (average 309 mm; N=3) for Age VI trout. In the South Fork, total lengths of angler-caught trout ranged from 100 to 185 mm (average 143 mm; N=23) for Age II trout, and from 145 to 253 mm (average 207 mm; N=25) for Age III trout. One mountain whitefish scale sample was aged from a fish caught below Ernie's Grove on the lower North Fork. It was 347 mm and six years old. Few mountain whitefish were observed that were larger than this individual (Sweeney et al. 1981).

Mean age at maturity for angler-caught female cutthroat trout in the Middle Fork was 3.9 years (Pfeifer 1990; N=50 trout caught from the Middle Fork mouth to Dingford Creek in 1981-1984 and September 1990). Whereas 100% (5 of 5) of Age V females were mature, 71% (5 of 7) of Age IV females were mature, 20% (3 of 15) of Age III females were mature, and 8.7% (2 of 23) Age II females were mature. Of first-time spawners collected in the Middle Fork in July of 1983 and 1984, nine females age 2-4 were mature (mean age 3.11) and five males age 2-3 were mature (mean age 3.20). On average, trout were first mature at about 211 mm (Pfeifer 1985). Raw data including river section, species, length, sex, maturity, and age for angler-caught trout in both the Middle Fork (N=142) and the South fork (N=52) are included in Pfeifer (1985), Tables 4.10 and 4.11.

Age composition of angler-caught trout in the Middle Fork caught on a single day in 1981 (N=60) and a single day in 1984 (N=61) included 61 Age II, 43 Age III, 11 Age IV, 3 Age V, and 3 Age VI trout. Total annual mortality was estimated to be 68.8% in 1981 and 50.0% in 1984 (Pfeifer 1985). Annual mortality in the South Fork was estimated to be 82.3% in 1986, 72.2% in 1987, and 69.1% in 1988 based on catch curves constructed from trout caught in electrofishing surveys in the Twin Falls region (Pfeifer 1990). Only Age II cutthroat trout were sampled on the upper mainstem of the North Fork (N=24), however 29 Age II, 10 Age III, and 3 Age IV trout were sampled in the upper North Fork tributaries (summarized in Pfeifer 1985).

Creel Census

Two comprehensive scientific creel surveys and several less-intensive surveys have been conducted on the forks of the Snoqualmie River (**Table 13**). Although limited, some creel data from the 1940s is also available for the South Fork and the mainstem Snoqualmie River (**Table 14**). Comprehensive surveys were conducted in 1969 (North Fork and Middle Fork) and 1979 (North Fork) as part of mitigation processes for proposed dam development (Engman 1970, Kurko et al. 1980). All three forks received a less-intensive creel survey in July, August, and September 1984 (Pfeifer 1985). These surveys were not conducted as rigorously as the 1969 or 1979 surveys, but it was felt that the data represented a reasonable estimate of the actual season-long averages. Miscellaneous creel checks were also made on the North and Middle Forks from 1977-1984 and are summarized with the primary results from the 1969 and 1979 surveys in Pfeifer (1985). In 1990, 44 anglers were interviewed along the South Fork (Pfeifer 1990). None had retained catch but 41 fish between 13 and 20 cm were released. Finally, limited creel data from spot checks in the 1940s suggests that fish caught at the end of May in the South Fork were generally 15-25 cm (6-10 inches)(**Table 14**). It should be noted that opportunistic creel checks can be biased when checks involve anglers who have not finished fishing or when surveys only interview anglers at common access points that may not represent more skilled or knowledgeable anglers willing to walk to more remote areas (Pfeifer 1985).

Below Snoqualmie Falls, creel checks from 1959-1979 were the only available data (as of 1980) for sea-run cutthroat trout in the Snoqualmie River. These included 593 creel checks surveying 12,202 anglers with 105 cutthroat trout caught (Pfeifer 1980). However, these checks were primarily of steelhead anglers who incidentally caught cutthroat trout, and catch per angler was low (0.01 trout/angler). Fishing pressure in the Snoqualmie River was thought to be light, but with a significant and consistent fishery in August and September.

Background Environmental Data Monitoring

Environmental data for the Snoqualmie River Basin have been collected during studies or monitored over longer periods by a number of entities including the United States Geological Survey (USGS), the Washington State Department of Ecology (Ecology), the Washington State Department of Natural Resources, the U.S. Army Corps of Engineers, and the King County Department of Natural Resources and Parks (KCDNRP), among others. Discharge and gauge levels for the Snoqualmie River have been recorded by the USGS since as early as 1898 and relevant statistics from streamflow stations are available for all three forks and the mainstem near both Carnation and Snoqualmie, Washington (http://water.usgs.gov/waterwatch/?m=real&r=wa). Ecology has long-term water quality monitoring stations at RM 2.7 near Monroe (station 07D050 installed 1992) and at RM 42.3 above the Falls at Snoqualmie (station 07D130 installed 1959) recording temperature, flow, turbidity, and other water quality parameters (http://www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html#4), and has manual stage height flow stations operating at RM 2.7 near Monroe (station 07D050 installed 1997) and at RM 45.3 on the Middle Fork (station 07D150 installed 2000).

Ecology is currently conducting a TMDL (Total Maximum Daily Load) study for temperature in the Snoqualmie River watershed that includes the three forks up to the USFS boundary. Stream temperatures are being evaluated during critical dry weather months. Stream thermographs from 2006 indicate that temperatures in the Middle Fork are much higher on average than in the North and South Forks. Further research is needed to assess the effect of higher temperatures on trout in the Middle Fork (R. Svrjeck, Ecology, personal communication). King County also monitors temperature and flow in several tributaries below Snoqualmie Falls (http://dnrp.metrokc.gov/WLR/Waterres/hydrology/About.aspx).

Water quality was measured monthly (July 1979 to June 1980) during mitigation studies on the North Fork (U.S. Army Corps of Engineers 1980; summarized in Sweeney et al. 1981 and Kurko et al. 1980). Data included temperature, conductivity, pH, alkalinity, dissolved oxygen, turbidity, and phenolphthalein alkalinity measurements at two stations in the mainstem North Fork (approximately RM 12.1 and 20.4) and at single stations in both Sunday Creek and Lennox Creek (**Table 15**). Water quality was considered good in the North Fork Snoqualmie Basin to the extent that low alkalinity and nutrient values were possibly limiting aquatic production in the upper river (Sweeney et al. 1981). Stream temperatures and conductivity were highest at the downstream mainstem station. Low conductivity at the upper three stations made electrofishing more difficult during seasons other than late summer when conductivity was much higher.

Similar water quality measurements and analyses were summarized for various reaches of the South Fork in Appendix E of the South Fork Watershed Analysis (USFS 1995). The South Fork from its confluence to Twin Falls State Park is listed as a Class A ("excellent") waterway meeting or exceeding the requirements for all or substantially all uses, and a Class AA ("extraordinary") waterway markedly and uniformly exceeding the requirements of all or substantially all uses from Twin Falls State Park to the headwaters (USFS 1995). All streams and rivers in the Middle Fork watershed have been listed as Class AA by the State of Washington (USFS 1998a).

Habitat Surveys and Mapping

Habitat maps for the entire Snoqualmie River Basin in King County have been developed for Geographic Information System (GIS) analyses (King County Department of Natural Resources and Parks). However, finer-scale habitat mapping is limited. Habitat maps were developed for the North Fork using aerial photographs taken for all three forks in May 1979 (Kurko et al. 1980). These maps were refined with field surveys to demarcate pools, glides, riffles, boulders, and falls and to include the amount of streambank vegetation. Some beaver ponds, bogs, and oxbow sloughs were also plotted. To quantify suitable habitat for spawning and rearing, four North Fork tributaries (GF, Philippa, Sunday, and Lennox Creeks) and the mainstem above Forest Service Rd. 2527 were surveyed the following year (Sweeney et al. 1981). Using the same methodology, habitat was mapped again from RM 12.2 downstream to the confluence and then extended downstream on the mainstem to RM 42 at the State Highway 202 bridge in Snoqualmie (Dames & Moore 1985). In addition, habitat was surveyed for Calligan Creek (RM 8.5), Deep Creek (RM 11.2), and for two small ponds in the North Fork drainage. More recently, GIS data were used to locate suitable sites for snorkel surveys on all three forks (Berge and Mavros 2001). An initial query in ArcView™ was used to identify sites with acceptable stream gradient and channel width. Final site selection was made after evaluating access points and visually assessing potential sites. Habitat maps for the Snoqualmie River Basin include GIS layers for gradient, channel width, and land cover, among others (KCDNRP), and should provide a starting point for site selection when implementing the SRGFEP.

U.S. Forest Service stream habitat surveys were conducted in the upper North Fork in 2007 and throughout the 1990s in all three Snoqualmie River Forks including several tributaries to the forks (North Bend Ranger District Mount Baker-Snoqualmie National Forest). These surveys provided an extensive inventory of existing stream channel, riparian vegetation, and aquatic ecosystem conditions on a watershed scale. Surveys were conducted during low flow conditions and specific protocols were followed as outlined in the USFS Stream Inventory Handbook for Level I and II surveys (USFS 2006). Data were entered into the Aquatic Inventory and Aquatic Biota modules of the Natural Resource Inventory System database. A series of standard summary tables were produced from this database to provide the basic information necessary to describe stream condition, habitat, and function. Written documentation of survey results varied from unpublished general summaries to more detailed overviews and analyses describing pool quantity and quality, large woody debris quantity and complexity, spawning gravel quantity and quality, and relative fish abundance and distribution (e.g., Cascades Environmental Services 1997).

Instream flow studies have also taken detailed measurements of depth, velocity, and substrate along selected reaches of the North Fork (Dames & Moore 1985, Beck and Associates 1985, Sweeney et al. 1981) and the South Fork (Steward and Stober 1983). These habitat measurements were combined with published probability-of-use (habitat preference) curves for species-specific life stages (e.g., adult, spawning, juvenile, fry, and incubation) and used to estimate available habitat across a range of simulated flow levels. Fish habitat was reported in terms of Weighted Usable Area (WUA), an index used to quantify the square feet of useable fish habitat per linear length of stream. Spawning habitat WUA was relatively low for trout in the North Fork. However spawning habitat is rarely limiting for trout in western Washington streams and an abundance of juvenile trout observed in electrofishing surveys suggested that trout spawning habitat was adequate in the North Fork (Sweeney et al. 1981). In addition, substrate from RM 5 to 12, was described as generally course but with enough gravel in pockets to support in-reach spawning (Dames & Moore 1985). In the South Fork, available spawning habitat was determined to be minimal even at optimal flows, however the analysis was limited to one study area in the vicinity of the Twin Falls Hydroelectric Project, and the results were not extrapolated to other river sections (Steward and Stober 1983).

Habitat characteristics were measured in August 1992 at sites selected for snorkel surveys in all three forks (Jackson and Jackson 1993). With the exception of the lower reach of the South Fork, length and width of pools, riffles, runs, pocket water, and chutes and cascades were made for 3 to 5 km reaches of the upper, middle, and lower sections of each fork (**Table 16**). Average stream widths (upper, middle, lower) were 18.3 m, 22.8 m, and 22.5 m in the North Fork, 33.8 m, 38.9 m, and 33.2 m in the Middle Fork, and 16.3 m (upper) and 19.4 m (middle) in the South Fork.

General descriptions of the instream habitat from the mainstem above Snoqualmie Falls to the lower reaches of all three forks were provided in licensing studies for the Snoqualmie Falls Project (Puget Sound Power & Light Company 1991). In July 1990, twenty sites were snorkeled by Puget Power biologists and substrate, depth, riffle, and pool habitat were described. In the upstream reaches of the mainstem, depths were typically 10 to 12 feet with large cobble substrate and large amounts of impacted sand. Downstream reaches tended to be deeply channelized with depths about 15 feet. Substrate was primarily large cobble, fallen riprap material, and sunken logs buried in the sand.

Below Snoqualmie Falls to the confluence with the Skykomish River, riparian vegetation was quantitatively assessed to estimate vegetative cover and the potential to supply woody debris from near-channel processes (Pentec Environmental and NW GIS, 1999). Aerial photographs were used to describe the contents of the riparian corridor adjacent to the river and to quantify the channel conditions based on the proportion of diked or riprapped riverbank for each riparian category. It was concluded that flooding was the major force responsible for the formation and maintenance of riparian conditions and that in the absence of natural hydrologic disturbance regimes, any long-term benefit from off-channel or riparian enhancement efforts would require perpetual maintenance.

A Salmonid Habitat Limiting Factors Analysis is available for the Snohomish River Watershed that provides basic descriptions of substrate and riparian conditions and water quantity and quality for the Snoqualmie River (Haring 2002). In addition, Federal Watershed Analyses have been conducted for the Middle Fork (USFS 1998a) and South Fork (USFS 1995) Snoqualmie River. These analyses contain detailed reviews of habitat conditions and resource management in these watersheds.

Habitat Enhancement

Few habitat enhancement projects or investigations have occurred in the three forks of the Snoqualmie River and the mainstem in the Project vicinity. Known habitat enhancement has been limited to work conducted in the South Fork as part of the Twin Falls Aquatic Mitigation Plan (Twin Falls Hydro Company 2006). In 1984 through 1988, baseline snorkel and electrofishing surveys were conducted for the purpose of comparing trout densities before and after habitat enhancement measures were implemented and the hydroelectric facility was completed. Habitat enhancement measures began in 1988, with the placement of 97 boulders at two enhancement sites. These sites were highly impacted by channelization from adjacent highway construction. After two years, data indicated that trout numbers had not increased, and that the boulder placement was not successful.

Many boulders were heavily buried from a landside upstream of the enhancement sites and were not able to trap woody debris. These boulders have since resurfaced because the sediment that buried the boulders has moved through this reach (G. Gilmour, personal communication). Beginning in 1994, large woody debris (LWD) was placed in the enhancement sites each spring to maintain at least 40 logs and root wads during summer low flow conditions. Trout abundance monitoring in 1994-2005 indicated that these enhancement measures were successful in increasing trout numbers. However, increased abundance was only demonstrated from electrofishing data, presumably because trout using the LWD as cover were difficult to see during snorkel surveys.

Cascades Environmental Services conducted habitat surveys in the Middle Fork to identify stream channel, riparian vegetation, and aquatic habitat conditions (Cascades Environmental Services 1997). Enhancement recommendations were made following surveys of three reaches located between RM 60.5 below the Pratt River and RM 81 in the headwaters. For the two reaches between the Pratt River and Burntboot Creek, revegetation efforts were recommended to stabilize slide areas. These reaches were aggrading systems and successful bank stabilization was considered essential before any efforts to enhance fish habitat would be warranted. The removal of a logjam to divert flow away from the road and replacing riprap were also suggested to decrease erosion in the reach between Tributary #0731 and Burntboot Creek. Reach three in the headwaters was the most stable and enhancement was not deemed necessary.

The Western Federal Lands Highway Division of the U.S. Department of Transportation is currently designing improvements to the Middle Fork Snoqualmie River Road for the purpose of enhancing operational safety and consistency of the road to access National Forest Lands (DJ&A, P.C. 2008). Part of the project included an inventory of stream crossings, including descriptions and photographs of culverts and bridges. The report also provided descriptions of roadway that encroached into the river floodplain or floodway, or were inundated during the December 2006 50-year discharge event, or required bank stabilization. Thirteen reaches were listed as potential problem areas; one had been inundated during December 2006, and three required bank stabilization. The stream crossing assessment also provided an inventory of the active streams crossing the Middle Fork Snoqualmie River Road within the project limits; fish presence and habitat suitability were documented (Mason Bruce & Girard 2004). Fish were observed or assumed present in 14 of 26 streams and species observed included cutthroat trout, sculpin, and longnose dace. Four culverts were identified where fish passage should have been possible but the condition of the culvert for fish passage was poor and needed improvement. Culvert design recommendations included culvert type and size and suggested that culverts should be oversized to accommodate the bankfull width and that the invert of the culvert should be below the natural streambed elevation grade to accommodate natural stream bottom.

Public Education

Final implementation of the SRGFEP will include increasing public awareness of the fishery resource and the efforts that have been made to maximize resident and sea-run trout resources in the Snoqualmie River Basin. This may include developing pamphlets or constructing kiosks to promote game fish resources and to educate the public on game fish life history and recreational fishing opportunities in the Snoqualmie River. Local fisheries enhancement groups and volunteers may be beneficial in helping to lower costs and to maximize a sense of stewardship.

Trophic Interactions

Although the SRGFEP does not specifically outline plans to study trophic interactions, some of this data can be collected opportunistically while addressing other research questions. Diet data in particular is very sparse and should be collected during this study. Stomach contents were analyzed for 11 trout in the North Fork plus 3 trout from a nearby beaver pond (Kurko et al. 1980). Not surprisingly, diets primarily consisted of aquatic insects, but shorthead sculpin and a juvenile trout were eaten by several of the larger trout, and one cutthroat trout from the beaver pond had consumed a number of snails (**Table 17**). It was suspected that had more large trout been analyzed, small fish would have been observed more frequently in the diet (Kurko et al. 1980). More recently, of six cutthroat trout caught by angling in the North Fork above the confluence of Lennox Creek, one had consumed a sculpin (USFS 2007). Sculpin diets were not analyzed but some diet overlap with trout was likely. Given their high abundance in the North Fork, sculpin may have a significant effect on river ecology (Kurko et al. 1980). A measure of food availability was obtained from benthic samples collected in June (Kurko et al. 1980). Aquatic invertebrate densities ranged from 272 to 1600 insects/m^2 across seven sampling stations, with mayflies (*Ephemeroptera* spp.) comprising between 46.8 and 82.7 percent (**Table 18**).

CONCLUSIONS

Implementation of the SRGFEP will result in a large-scale inventory of the trout resources in the Snoqualmie River that will facilitate continued management of the resource as a healthy, wild trout fishery. Data gaps are present in almost all the research tasks listed in the Plan. Topics with the fewest data gaps are the habitat surveys and mapping and background environmental data portions of the Plan. Topics with the most glaring data gaps include behavioral data such as instream movement and spawning behavior, and a rigorous age and growth analysis for each salmonid species including mountain whitefish.

<u>Relative Trout Abundance</u> – Density and abundance estimates are outdated and surveys did not always differentiate among trout species. Whereas the Jackson and Jackson (1993) surveys and USFS surveys throughout the 1990s provided useful fish/mile counts based on snorkel observations, new species-specific density estimates should be obtained from more rigorous mark-recapture techniques.

<u>Trout Distribution</u> – Trout distribution was well documented in the North Fork in 1979-84, and was assessed in the other forks based on limited angling efforts in the early 1980s (Middle Fork) and in 1990 (Middle and South forks). The most recent species composition data has come from USFS snorkel surveys, however species identification (especially between rainbow and cutthroat trout) can be difficult without direct capture methods. Trout distribution and species composition needs to be reassessed in each fork and in the major tributaries to the forks using data collected with a variety of fisheries techniques.

<u>Trout Movement</u> – Trout movement data is virtually non-existent. Radiotagging efforts are needed to assess whether trout exhibit extensive instream or among-fork movements

including seasonal transitions to summer feeding stations, overwintering areas, and spawning sites. This data will be useful to evaluate the interconnectedness of the trout populations among the forks and the extent to which each fork should be managed as a separate fishery.

Trout Reproductive Life History – Trout reproductive life history data is largely absent and has primarily been limited to a few ancillary observations during studies focused on other research questions. Data gaps include current spawning distribution, habitat preference, spawning duration, and egg/alevin incubation periods. This data should be obtained from spawning surveys, radiotagging, and capping redds, and can be used by managers to maximize trout reproductive success by protecting trout during critical spawning periods.

Age and Growth Studies – Scale samples have been collected on several occasions from electrofishing and angling efforts but published age and growth data are minimal. Rigorous age and growth analyses are needed for each salmonid species including mountain whitefish. Current population age structure, mortality rates, and age at maturity are also critical for evaluating existing management of the resource including size restrictions on harvestable trout.

Creel Census – Creel surveys varying from opportunistic spot checks to extensive scientific creel surveys were conducted in 1969 (North Fork and Middle Fork), 1979 (North Fork), 1984 (all three forks), and 1990 (South Fork). New surveys are needed to assess the current status of the fishery and to evaluate regulations affecting angler harvest and effort.

Background Environmental Data Monitoring – The Washington State Department of Ecology is currently conducting a study monitoring temperatures in the Snoqualmie River watershed. Stream thermographs from 2006 indicate that further research is needed to assess the effect of higher temperatures on trout in the Middle Fork. Additional measurements of stream temperature, turbidity, discharge, and other water quality parameters are recorded at monitoring stations operated by various agencies.

Habitat Surveys and Mapping – Extensive habitat surveys and mapping were conducted in the North Fork and in the upper mainstem between 1979 and 1983, and USFS stream habitat surveys were conducted as recently as 2007 in the North Fork, 1996 on the

Middle Fork, and 1998 in the South Fork. The detail and extent of these surveys is beyond the scope of this project and allocating effort to this aspect of the Plan is largely unwarranted.

Habitat Enhancement – Very little habitat enhancement has been conducted on the Snoqualmie River. A log of sites where habitat disturbance could be negatively affecting fish (e.g., landslides or sites with excessive sedimentation from logging operations) should be kept while conducting research and enhancement recommendations should be provided to Puget Sound Energy and other government entities upon completion of the Plan.

Public Education – As the project nears completion, a pamphlet should be developed and posted on the WDFW website promoting the fishery resource in the Snoqualmie River. The potential for constructing kiosks or placing signs at strategic locations in the watershed should also be evaluated. The final report should be made available to the public and results presented at local angling clubs.

Trophic Interactions – Although the SRGFEP does not specifically outline plans to study trophic interactions, some of this data can be collected opportunistically while addressing other research questions. Diet data in particular is very sparse and should be collected during this study.

Sea-run Cutthroat Trout – Quantitative information for coastal cutthroat trout in the Snoqualmie River below the falls is minimal. Although the majority of the time and effort in this project will be directed above Snoqualmie Falls, some effort should be allocated to collection and analysis of sea-run cutthroat trout in the river below the falls. At a minimum, snorkeling should be conducted to characterize relative abundance and general distribution of sea-run cutthroat trout.

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Table 1.-Density, biomass, fork length, weight, and species composition of trout in the North Fork Snoqualmie River estimated in early September 1979 from electrofishing seven block netted stations (from Kurko et al. 1980). Rivermiles (RM) were approximated from Kurko et al. 1980, Figure 6.

Block net Station (Rivermile)	Fish/mile	Fish/m^2	g/m^2	Mean fork length (mm)	Length range (mm)	Mean weight (g)	Weight range (g)	Species Composition
1 (RM 21)	2050±100	0.20±0.010	2.17±0.11	88	41-207	11.0	<1-54	99% cutthroat trout 1% brook trout
2 (RM 18.8)	1811±325	0.09±0.016	0.40±0.07	66	37-129	4.5	<1-21	85% cutthroat trout 15% brook trout
3 (RM 16.3)	923±538	0.02±0.014	0.28±0.16	82	48-190	12.1	1-82	67% rainbow trout 22% cutthroat trout 11% brook trout
4 (RM 14.7)	567±6	0.01±0.000	0.20±0.00	93	46-173	16.0	1-68	65% rainbow trout 23% cutthroat trout 12% brook trout
5 (RM 13.4)	1900±100	0.05±0.003	1.29±0.07	116	40-244	25.7	<1-157	91% rainbow trout 9% cutthroat trout
6 (RM 11.5)	4774±1355	0.09±0.026	1.51±0.43	86	34-204	16.4	<1-89	99% rainbow trout 1% brook trout
7 (RM 6.7)	2708±84	0.05±0.002	0.84±0.04	83	39-271	15.9	<1-260	100% rainbow trout

Table 2.-Densities of trout and mountain whitefish (# fish/mile) estimated from snorkeling twelve reaches along the North Fork Snoqualmie River during July 24-October 4, 1979 (adapted from Sweeney et al. 1981).

	Number of fish/mile			
Rivermile	0-3" Trout	3-9" Trout	>9" Trout	Whitefish
0.3-1.8	31	261	89	407
3.3-4.5	33	244	81	0
9.2-10.1	23	74	42	0
12.2-13.3	54	637	25	0
13.3-13.7	8	147	8	0
13.7-14.6	17	165	4	0
14.6-15.6	13	161	9	0
15.6-16.4	15	132	2	0
16.4-17.3	6	65	6	0
17.3-18.2	30	187	13	0
18.2-19.1	79	206	13	0
19.1-20.0	160 trout/mile observed; sizes were not specified for this reach.			

Table 3.-Summary of electrofishing surveys in the North Fork and mainstem of the Snoqualmie River in 1983. Fork length (mm) was recorded for all fish except cottids. From Dames & Moore 1985, Table 2.

Station/	Date	Number		Length (mm)			Density[a]		
Species	Sampled	Captured	Measured	Mean	Min	Max	Fish/m^2	Fish/km	Fish/mile
A_1 North Fork	9/23/83								
Weyco Site (RM 5.3)									
Rainbow trout		19	17	104.2	54	181	0.044±0.02	932±463	1497±743
Cottids		68	68	52.6	28	102	(b)	(b)	(b)
A_3 North Fork	10/13/83								
Ernie's Grove (RM 1.1)									
Rainbow trout		1	1	62	--	--	(b)	(b)	(b)
Cutthroat trout		1	1	128	--	--	(b)	(b)	(b)
All trout		--	--	--	--	--	0.004±0.002	76±45	122±72
Large scale sucker		2	2	87.5	82	93	(b)	(b)	(b)
Cottids		156	156	79.6	31	166	0.32±0.05	6609±1107[c]	10614±1634[c]
Brook lamprey		5	5	124.0	65	142	(b)	(b)	(b)
B_1 Snoqualmie	10/7/83								
Mainstem									
Railroad Bridge to confluence of South Fork									
Cutthroat trout		10	10	115.6	58	150	0.016±0.01	995±620[c]	1599±996[c]
Mountain whitefish		3	3	88.3	85	90	(b)	(b)	(b)
Cottids		32	32	66.5	29	125	(b)	(b)	(b)
Brook lamprey		29	29	110.8	45	160	0.04±0.01	2755±764[c]	4425±1227[c]

(a) Plus or minus twice the standard error (Zippin 1958).
(b) Catch distribution precluded population estimates.
(c) Based on effective length of stream sampled (length of area sampled x percent of stream cross section represented).

Table 4.-Snorkel survey results in the North Fork Snoqualmie River. Surveys in 1983 were conducted using continuously moving divers covering long reaches of stream while 1984 surveys used very slow moving or stationary divers to thoroughly census short reaches of stream. It was concluded that trout densities were greatly underestimated in the 1983 survey, during which stream temperatures were reduced. From Dames & Moore 1985, Table 4.

	Stream Length Surveyed	Date	Total Trout Seen	Percent Coverage	Fish (Trout)/ Mile
1983					
Reach 1	0.6 mile	10/15/83	16	0.3	89
Wagner Bridge to Campground					
Reach 2	0.7 mile	10/14/83	18	0.2	129
(above A_1 RM 5.3)					
Reach 3	0.8 mile	10/06/83	0	0.2	0.0
Ernie's Grove to North Fork Bridge					
Reach 4	1.0 mile	10/06/83	3	0.05	60
Mainstem (South Fork confluence to Railroad Bridge)					
1984					
Reach 1a	100 yd	10/02/84	62	100	1091
Wagner Bridge	100 yd	10/03/84	48	100	845
Reach 1b	150 yd	10/02/84	2	100	24
USGS Gage	150 yd	10/03/84	3	100	35
Reach 1c	100 yd	10/02/84	36	100	634
Spur 10 Bridge	100 yd	10/03/84	33	100	581
Reach 2a	100 yd	10/02/84	106	100	1866
(Above A)	100 yd	10/03/84	139	100	2446

Table 5.-Summary of electrofishing and snorkel surveys in the North Fork Snoqualmie River, 1979-1984. From Dames & Moore 1985, Table 5. Surveys were conducted by Dames & Moore (D&M) or by the Washington Department of Game (WDG).

Station[a]	Survey Distance	Temp. (°C)	Fish/mile	Fish/m^2	Mean Fork Length (mm) (Range)	Species Composition	Lifestage Composition (Percent)	Year[b]	Survey Organi-zation
RM 6.0 (snorkel)	100 yd	13	2156	NA	NA	Rainbow	Juv. 40% Adult 60%	1984	D&M
RM 6.0-5.3 (snorkel)	0.7 mile	8.3	129	NA	NA	Rainbow	Adult 100%	1983	D&M
RM 5.3-5.5 (snorkel)	0.2 mile	7.2	10	NA	NA	Rainbow	Adult 100%	1983	D&M
RM 5.5 (electrofishing)	--	NA	1497	0.044	NA	Rainbow	NA	1983	D&M
RM 5.2 (electrofishing)	--	NA	2708	0.05	(54-181) 83	Rainbow	NA	1979	WDG
RM 7.0 (snorkel)	100 yd	12.5	608	NA	(39-271) NA	Rainbow	Juv. 5% Adult 95%	1984	D&M
RM 9.4 (snorkel)	150 yd	12.1	30	NA	NA	Rainbow	Adult 100%	1984	D&M
RM 9.4-10.1 (snorkel)	0.9 mile	NA	139	NA	NA	Rainbow	Juv. 33% Adult 67%	1979	WDG
RM 11.5 (snorkel)	100 yd	13	968	NA	NA	Rainbow	Juv. 6% Adult 94%	1984	D&M
RM 12.0-13.1 (snorkel)	1.1 mile	NA	716	NA	NA	Rainbow Brook	Juv. 76% Adult 24%	1979	WDG
RM 11.5 (electrofishing)	--	NA	4774	0.09	86 (34-204)	Rainbow 99% Brook 1%	NA	1979	WDG

(a) River miles (RM) for WDG data adjusted to conform to system in use on North Fork Snoqualmie Project.
(b) Note that 1983 D&M surveys were conducted using continuously moving divers covering long reaches of stream while 1984 D&M surveys used very slow moving or stationary divers to thoroughly census short reaches of stream. 1984 D&M data reported are means of replicated surveys taken on consecutive days.

Table 6.-Summary electrofishing surveys in Calligan Creek and Deep Creek, two tributaries to the North Fork Snoqualmie River. Fork length (mm) was recorded for all fish except cottids. From Dames & Moore 1985, Table 1.

Station/	Date	Number		Length (mm)			Density[a]		
Species	Sampled	Captured	Measured	Mean	Min	Max	Fish/m^2	Fish/km	Fish/mile
Calligan Creek[c]	8/31/83								
Rainbow trout		31	31	144.4	41	225	0.13±0.06	864±423	1388±679
Cottids		106	0	--	--	--	0.49±0.11	3259±696	5234±1118
Deep Creek (below road)	8/31/83								
Rainbow trout		7	7	84.6	33	198	0.04±0.04	299±294	480±472
Cutthroat trout		1	1	216	--	--	(b)	(b)	(b)
Brook trout		4	4	137.5	78	218	0.02±0.01	138±55	222±88
All trout		12	12	--	--	--	0.07±0.04	482±279	774±448
Cottids		90	10	60.9	22	100	0.53±0.13	3643±859	5851±1380
Deep Creek (above road)	9/8/83								
Rainbow trout		1	1	138	--	--	(b)	(b)	(b)
Cutthroat trout		1	1	70	--	--	(b)	(b)	(b)
Brook trout		6	6	152.3	80	190	0.13±0.42	793±2636	1274±4234
All trout		8	8	--	--	--	0.10±0.06	650±348	1044±559
Cottids		12	7	69.1	32	93	0.17±0.10	1073±620	1720±995

(a) Plus or minus twice the standard error (Zippin 1958).
(b) Catch distribution precluded population estimates.
(c) Electrofishing took place in the vicinity of the lower bridge.

Table 7.-Species composition and length frequency distribution for fish collected by R.W. Beck and Associates (August 1985) and Ott Water Engineers (Fall 1984) in the Black Canyon reach of the North Fork Snoqualmie River. Adapted from R.W. Beck and Associates (1985).

	0-3 inch	3-7 inch	> 7 inch
R.W. Beck and Associates			
Rainbow trout	0	0	4
Cutthroat trout	0	0	10
Unidentified trout	2	54	16
Percent of all trout	2.3%	62.8%	34.9%
Ott Water Engineers			
Rainbow trout	19	52	13
Cutthroat trout	0	3	2
Unidentified trout	1	5	1
Percent of all trout	20.8%	62.5%	16.7%

Table 8.-Densities of trout (# fish/mile) estimated from snorkel surveys and electrofishing surveys at four sites in the vicinity of the Twin Falls hydroelectric project. Study sites included a bypass site approximately 1,000 ft upstream of the project's tailrace, two sites selected for habitat enhancement (upper boulder and lower boulder), and a control site (adapted from Twin Falls Hydro Company 2006). Surveys were not conducted in 1989, 1992, and 1993. The project began operation December 1989 with a minimum flow in the bypass reach of 75 cfs in Aug-Apr and 150 cfs in May-Jul. A year-round minimum flow of 75 cfs was established in 1996.

	Snorkel Survey Densities (#fish/mile)				Electrofishing Densities (#fish/mile)			
Year	Bypass	Upper boulder placement	Lower boulder placement	Control	Bypass	Upper boulder placement	Lower boulder placement	Control
1984	2103.8	184.8	880.0	1665.2		184.8	985.6	
1985	2508.0	34.3	176.0	812.3	3097.9	52.8	211.2	1056.0
1986	895.1	18.5	165.4	353.4	870.4	52.8	281.6	852.9
1987	1567.5	97.7	140.8	678.3	1365.4	211.2	281.6	1502.8
1988	1196.3	26.4	165.4	731.1	878.6	26.4	140.8	1787.1
1990	1435.5	113.5	186.6	1494.6	1464.4	211.2	281.6	3371.1
1991	1307.6	79.2	352.0	1462.2	878.6	211.2	352.0	1380.9
1994	2392.5	139.9	397.8	1165.7	3242.3	132.0	492.8	609.2
1995	2256.4	422.4	271.0	946.3	2223.4	686.4	704.0	731.1
1996	899.3	224.4	274.6	418.3	684.8	290.4	668.8	446.8
1997	1629.4	95.0	218.2	203.1	2198.6	369.6	387.2	406.2
1998	1637.6	237.6	362.6	243.7	2029.5	660.0	1091.2	1056.0
1999	1443.8	245.5	316.8	324.9	1765.5	554.4	1267.2	365.5
2000	961.1	124.1	130.2	597.0	1027.1	316.8	387.2	731.1
2001	1183.9	105.6	257.0	394.0	2107.9	316.8	528.0	487.4
2002	1608.8	176.9	397.8	702.6	1542.8	396.0	739.2	852.9
2003	1291.1	87.1	95.0	406.2	994.1	211.2	140.8	487.4
2004	1608.8	79.2	271.0	893.5	1196.3	211.2	211.2	568.6
2005	1773.8	211.2	257.0	662.0	2198.6	369.6	211.2	203.1

Table 9.-Densities of trout (# trout/km) by size group estimated in August 1992 from snorkel surveys in the three forks of the Snoqualmie River. Trout (all species combined) were estimated by expanding snorkel lane counts to total surveyed area; numbers in each pass are expanded estimates rather than actual counts (from Jackson and Jackson 1993).

Total length (cm)	1st pass	2nd pass	Mean	Mean trout/km	Mean % total
Upper North Fork (RM 16.3-18.4)					
<15	40	--	40	11.6	51.3
15-22	34	--	34	9.9	43.6
23-30	3	--	3	0.9	3.8
31-38	0	--	0	0.0	0.0
> 38	1	--	1	0.3	1.3
Total	78		78	22.7	
Middle North Fork (RM 6.85-9.44)					
<15	13	--	13	3.1	4.2
15-22	91	--	91	21.9	29.4
23-30	146	--	146	35.1	47.1
31-38	45	--	45	10.8	14.5
> 38	15	--	15	3.6	4.8
Total	310		310	74.5	
Lower North Fork (RM 0.25-2.42)					
<15	219	93	156.0	44.7	17.3
15-22	477	434	455.5	130.5	50.6
23-30	205	262	233.5	66.9	25.9
31-38	39	63	51.0	14.6	5.7
> 38	1	8	4.5	1.3	0.5
Total	941	860	900.5	258.0	
Upper Middle Fork (RM 63.05-64.95)					
<15	210	--	210	64.4	37.1
15-22	308	--	308	94.5	54.4
23-30	42	--	42	12.9	7.4
31-38	6	--	6	1.8	1.1
> 38	0	--	0	0.0	0.0
Total	566		566	173.6	

Table 9.-Concluded.

Total length (cm)	1st pass	2nd pass	Mean	Mean trout/km	Mean % total
Middle Middle Fork (RM 54.9-56.8)					
<15	173	183	178.0	57.4	20.5
15-22	504	508	506.0	163.2	58.3
23-30	144	197	170.5	55.0	19.6
31-38	8	16	2.0	3.9	1.4
> 38	0	4	2.0	0.7	0.2
Total	829	908	868.5	280.2	
Lower Middle Fork (RM 45-46.75)					
<15	13	13	13.0	4.6	5.4
15-22	104	121	112.5	40.0	46.4
23-30	66	104	85.0	30.3	35.0
31-38	23	28	25.5	9.1	10.5
> 38	5	8	6.5	2.3	2.7
Total	211	274	242.5	86.3	
Upper South Fork (RM 16.7-18.1)					
<15	30	--	30	14.4	42.8
15-22	16	--	16	7.7	22.9
23-30	18	--	18	8.6	25.7
31-38	6	--	6	2.9	8.6
> 38	0	--	0	0.0	0.0
Total	70		70	33.6	
Middle South Fork (RM 8.2-10.7)					
<15	459	--	459	114.2	35.6
15-22	516	--	516	128.4	40.1
23-30	226	--	226	56.2	17.6
31-38	84	--	84	20.9	6.5
> 38	3	--	3	0.8	0.2
Total	1288		1288	320.5	
Lower South Fork (RM 0.3-2.6) Not surveyed because of time constraints.					

Table 10.-Fish observed during snorkel surveys in the North Fork (1993), the Middle Fork (1996 and 1990) and the South Fork (1998, 1991, and 1990). Data are from USFS stream habitat surveys (USFS 1998b, 1993, 1991a, 1990a, 1990b and Cascades Environmental Services 1997). Reaches increase numerically moving upstream.

	Cutthroat trout		Rainbow trout		Brook trout		Unidentified		Whitefish	
Reach	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.
North Fork – 1993 (RM 8.0-13.1)										
1	No numbers reported									
2	--	--	50	50	--	--	--	1	--	--
3	--	--	23	34	--	--	--	3	--	--
4[(a)]	--	--	38	65	--	--	--	--	--	--
5	--	--	43	46	--	--	--	18	--	--
6	--	--	21	24	--	--	--	3	--	--
Middle Fork – 1996 (RM 60.5-81)										
1	15	32	5	40	--	--	--	--	11	2
2	Rainbow trout, cutthroat trout, brook trout, mountain whitefish, and sculpin spp.									
3	Cutthroat trout and brook trout.									
Middle Fork – 1990 (RM 45.9- 61.0)										
1[(b)]	--	--	7	--	4	1	--	--	156	50
2[(b)]	--	--	56	60	--	--	--	--	--	--
3[(b)]	--	--	--	--	10	1	--	--	--	--
South Fork – 1998 (RM 17.9-30.6)										
1	4	15	5	14	3	21	3	2	--	--
2	8	31	--	--	--	2	--	6	--	--
3	2	5	--	5	--	--	--	--	--	--
4	20	8	1	2	--	--	5	2	--	--
5[(c)]	4	2	--	1	--	--	4	1	--	--
6	2	--	--	--	--	--	1	1	--	--
7	Not snorkeled									
8	Not snorkeled									
9	2	--	--	--	--	--	--	1	--	--
10	3	--	1	--	--	--	--	1	--	--
11	--	--	--	--	--	--	--	1	--	--

(a) One unidentified adult sculpin observed.
(b) Sculpin (adult/juvenile): Reach 1 (148/49), Reach 2 (15/15), and Reach 3 (6/2).
(c) Two unidentified species of sculpin were observed at RM 25.74.

Table 10.-Concluded.

Reach	Cutthroat trout Adult	Cutthroat trout Juv.	Rainbow trout Adult	Rainbow trout Juv.	Brook trout Adult	Brook trout Juv.	Unidentified Adult	Unidentified Juv.	Whitefish Adult	Whitefish Juv.
South Fork – 1991 (RM 24.2-27.0)										
1	11	7	1	--	--	--	1	--	--	--
2	15	7	--	1	1	--	5	--	--	--
South Fork – 1990 (RM 17.3-24.2)										
1	--	--	33	53	17	1	1	6	--	--
2	1	--	81	105	4	2	--	1	--	--

Table 11.-Fish observed during snorkel or electrofishing surveys in Lennox Creek (North Fork tributary; 1990), the Taylor River (Middle Fork tributary; 1992), the Pratt River (Middle Fork tributary; 1992), Carter Creek (South Fork tributary; 1991), and Quartz Creek (Taylor River tributary; 1991). Data are from USFS stream habitat surveys (USFS 1992a, 1992b, 1991b, 1991c, and 1990c). Reaches increase numerically moving upstream.

	Cutthroat trout		Rainbow trout		Brook trout		Sculpin[a]		Whitefish	
Reach	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.	Adult	Juv.
Lennox Creek – 1990 (RM 0.0-5.5) electrofishing survey.[b]										
1	25	17	2	2	--	40	40	64	--	--
2	13	39	--	--	--	2	40	63	--	--
3	This reach not surveyed.									
4[c]	13	44	--	--	--	2	0	4	--	--
5	6	15	--	--	2	4	28	16	--	--
Taylor River – 1992 (RM 0.0-6.7) snorkel survey.										
1	2	--	11	--	--	--	--	--	2	10
2	11	8	13	3	--	--	--	--	--	--
3	8	4	10	15	--	--	--	--	--	--
4	4	2	5	16	--	--	--	--	--	--
Pratt River – 1992 (RM 0.0-7.42) snorkel survey.										
1	9	--	7	14	--	--	--	--	--	--
2	4	--	16	19	--	--	--	--	--	--
3	14	--	32	59	--	--	--	--	--	--
4	7	--	11	53	--	--	--	--	--	--
Carter Creek – 1991 (RM 0.0- 0.6) electrofishing survey.										
1	3	3	--	1	--	--	--	--	--	--
Quartz Creek – 1991 (RM 0.0- 3.0) electrofishing survey.										
1[d]	--	--	0	1	--	--	4	10	--	--
2	--	--	--	--	--	--	3	3	--	--

(a) Recorded as "non-game" species in the Lennox Creek survey, and likely were sculpin.
(b) Data for the Lennox Creek survey was recounted from the raw data sheets and should be considered approximate.
(c) Counts from reach 4 were from snorkel observations.
(d) Three juvenile fish were recorded as Chinook salmon.

Table 12.-Snorkel observations made in July 1990 from the mainstem above Snoqualmie Falls to the lower reaches of the three forks [adapted from Puget Sound Power & Light Company (1991)]. With the exception of Kimball Creek, site numbers increased from upstream to downstream within each fork or mainstem area surveyed. Additional observations from one and eight weeks after backwater levels were raised are included in Puget Sound Power & Light Company (1991).

Site	Cutthroat <3 in	Cutthroat >3 in	Rainbow <3 in	Rainbow >3 in	Whitefish <3 in	Whitefish >3 in	Sucker	Other
Middle Fork								
1	--	--	--	--	--	1	--	--
2	4	--	--	--	--	--	2	--
North Fork								
3	22	--	--	3	--	3	18	--
4	--	--	--	--	4	--	--	--
Mainstem								
5	19	--	--	--	5	2	5	--
6	--	--	--	--	--	--	1	--
7	24	5	--	--	--	--	7	--
8	--	6	--	--	--	--	--	--
9	--	3	--	--	--	--	--	1
10	2	1	--	--	--	--	--	--
11	--	--	--	--	--	--	1	--
12	--	--	--	--	--	--	1	--
South Fork								
13	--	67	--	--	--	--	187	--
14	--	75	--	--	--	--	20	--
15	--	50	--	--	--	--	17	--
16	--	6	--	--	--	--	1	--
17	--	29	--	--	--	--	1	--
18	--	29	--	--	--	--	2	--
Kimball Creek								
19	--	--	--	--	--	--	--	--
20	--	--	--	--	--	--	--	1

Table 13.-Season-long effort and catch success from creel surveys conducted on the North, Middle, and South Forks of the Snoqualmie River (adapted from Pfeifer 1985).

	Anglers Checked	Hours/ Trip	Mean Catch/ Hour	Mean Fish/ Angler	% RB	% CT	% EB	Total Catch	Total Angler Days
North Fork									
1969	194	2.96	0.846	2.51	91.3	4.8	3.7	9860	3936
1979	2648[a]	4.23	0.676	2.86	--	--	--	--	--
1984[b]	34	1.59	0.833	1.23	77.8	15.6	6.7	5615	2823
Middle Fork									
1969	89	4.39	0.510	1.87	75.3	24.7	--	12443	7777
1984[b]	46	1.41	0.169	0.24	54.5	45.5	--	1153	3519
South Fork									
1984[b]	50	1.18	0.698	0.82	24.4	58.5	--	8083	3519
1990[c]	44	No fish were retained. 20% fishing with bait or illegal gear.							

(a) Number of anglers checked and number of fish caught were estimated totals from Kurko et al. 1980; raw, unexpanded data not available (Pfeifer 1985).
(b) Qualifications for estimated total catch and angler days are in Appendix V of Pfeifer (1985).
(c) Pfeifer 1990, unpublished report.

Table 14.-Snoqulmie River creel data from the 1940s. Data were copied opportunistically from a box of historical records. Additional data may be archived in Olympia (J. Mattila, personal communication). Cutthroat trout (CT); rainbow trout (RB).

Date Checked	No. of Anglers	No. of each species of fish taken	Average size (in or lbs)	Time of day checked
South Fork Snoqualmie River				
5/27/45	43	243 CT	6-8 in	AM
5/25/47	125	195 CT, 195 RB	6-10 in	AM
5/22/49	40	108 RB, 36 CT	7-10 in	PM
Snoqualmie River				
5/27/45	3	25 RB, 25 CT	8-14 in	PM
5/25/47	10	None	--	PM
6/1/47	7	8 RB	7-9 in	AM
6/15/47	10	None	--	PM
6/21/47	5	2 Steelhead	6-7 lbs	PM
6/22/47	7	1 Steelhead	4 lbs	PM
6/23/47	7	1 Steelhead	7 lbs	AM
6/26/47	4	None	--	PM
6/28/47	2	None	--	PM
7/2/47	6	None	--	PM
7/5/47	4	None	--	PM
6/5/48	4	None	--	PM
5/22/49	1	1 Steelhead	16”	AM

Table 15.-Water quality data from the U.S. Army Corps of Engineers North Fork Snoqualmie River sampling program (from Sweeney et al. 1981).

Date	Water Temp. Cent.	Conductivity at 25° C micromho	pH	DO MG/L	DO Satur. percent	Turbidity Trbidmtr Hatch FTU	Phenolphth-alien alk MG/L
North Fork Snoqualmie at upper NF Bridge (Station 4: 47 39 49.0 121 34 13.0 4)							
7/20/79	14.0	14	6.95	9.2	94.0	--	--
7/24/79	13.0	16	--	9.9	99.1	--	--
8/21/79	14.5	20	--	10.4	107.7	--	9
9/18/79	12.4	36	--	10.3	101.9	0.1	8
10/16/79	10.0	28	--	10.2	94.9	0.2	8
11/14/79	3.9	12	--	12.8	102.7	0.4	7
2/22/80	2.6	11	6.60	14.0	109.1	0.3	4
3/26/80	3.0	12	6.80	14.5	114.5	0.4	4
5/14/80	6.7	10	6.70	11.0	97.3	0.4	4
6/20/80	8.9	15	6.61	11.8	107.2	0.2	2
Lennox Cr. above mouth at County Road Bridge (Station 3: 47 39 34.0 121 48.0 4)							
7/20/79	15.4	11	6.91	9.5	100.0	--	--
7/24/79	13.4	12	--	10.2	102.9	--	--
8/21/79	14.6	17	--	10.9	113.1	--	7
9/18/79	12.2	30	--	10.8	106.4	0.1	7
10/16/79	9.3	20	--	11.0	100.3	0.1	6
11/14/79	2.6	14	--	13.8	107.1	0.1	6
2/22/80	2.0	8	6.60	14.6	111.9	0.3	4
3/26/80	1.8	11	6.80	15.2	116.4	0.3	4
5/14/80	5.6	--	6.60	--	--	0.5	1
6/20/80	9.0	10	6.45	11.9	108.7	0.4	1
Sunday Cr. above mouth at County Road Bridge (Station 2: 47 39 15.0 121 39 22.0 4)							
7/20/79	16.6	12	6.10	9.1	98.0	--	--
7/24/79	14.6	14	--	9.5	98.0	--	--
8/21/79	14.9	15	--	10.6	110.4	--	6
9/18/79	13.7	28	--	10.2	103.5	0.1	6
10/16/79	10.8	20	--	10.1	95.5	0.2	6
11/14/79	6.2	15	--	12.4	105.2	0.2	4
2/22/80	3.7	11	6.60	13.8	110.4	0.3	4
3/26/80	3.3	10	6.70	14.2	112.8	0.7	4
5/14/80	7.2	--	6.60	--	--	0.5	1
6/20/80	11.0	16	6.40	11.2	106.8	0.6	4

Table 15.-Concluded.

Date	Water Temp. Cent. Water	Conductivity at 25° C micromho Conductivity	pH	DO MG/L	DO Satur. percent DO	Turbidity Trbidmtr Hatch FTU Turbidity	Phenolphth-alien alk MG/L Phenolphth-
N. Fk Snoqualmie at Wagner Bridge (RM 12.1) (Station 1: 47 39 29.0 121 40 44.0 4)							
7/20/79	18.4	22	6.55	9.0	101.0	--	--
7/24/79	15.1	22	--	9.5	98.6	--	--
8/21/79	15.6	34	--	10.8	113.4	--	13
9/18/79	14.5	36	--	10.1	103.9	0.3	17
10/16/79	10.5	40	--	10.6	98.9	0.7	18
11/14/79	5.9	44	--	11.8	99.0	2.6	13
2/22/80	4.0	20	--	14.2	113.7	1.4	10
3/26/80	3.7	20	7.20	14.4	114.9	1.9	16
5/14/80	6.7	--	6.90	--	--	3.0	8
6/20/80	13.5	34	6.85	11.2	109.9	1.4	18
Beaver Pond							
7/20/79	16.0	54	--	8.1	--	--	--

Table 16.-Habitat measurements for snorkel survey sites selected in the upper, middle, and lower reaches of the three forks of the Snoqualmie River, August 1992 (from Jackson and Jackson 1993).

	No	Total length (m)	Average length (m)	% of total	No/km
Upper North Fork (RM 16.3-18.4)					
Pools	8	190.5	23.8	17.8	2.4
Riffles	18	300.5	16.7	40.0	5.4
Runs	19	2870.6	151.1	42.2	5.7
Middle North Fork (RM 6.85-9.44)					
Pools	16	74.5	4.7	20.5	4.8
Riffles	19	545.0	28.7	24.4	5.7
Runs	25	1550.5	62.0	32.1	7.5
Pocket water	12	1013.5	84.5	15.4	3.6
Chutes/Cascades	6	166.7	27.8	7.7	1.8
Lower North Fork (RM 0.25-2.42)					
Pools	7	578.5	82.6	17.9	2.0
Riffles	11	566.6	51.5	28.2	3.2
Runs	17	1798.0	105.8	43.6	4.9
Pocket water	4	541.3	135.3	10.3	1.1
Upper Middle Fork (RM 63.05-64.95)					
Pools	18	1241.2	69	31.6	5.5
Riffles	20	1080.8	54	35.1	6.1
Runs	17	858.6	50.5	29.8	5.2
Pocket water	2	78.3	39.2	3.5	0.6
Middle Middle Fork (RM 54.9-56.8)					
Pools	8	771.4	96.4	21.6	2.6
Riffles	12	1073.2	89.4	32.4	3.9
Runs	9	444.6	49.4	24.3	2.9
Pocket water	8	772.6	96.6	21.6	2.6
Lower Middle Fork (RM 45-46.75)					
Pools	9	767.9	85.3	29.0	3.2
Riffles	10	611.8	61.2	32.3	3.6
Runs	12	1427.2	118.9	38.7	4.3

Table 16.-Concluded

	No	Total length (m)	Average length (m)	% of total	No/km
Upper South Fork (RM 16.7-18.1)					
Pools	13	339.6	26.1	26	6.2
Riffles	12	256.6	21.4	24	5.7
Runs	21	1185.3	56.4	42	10
Pocket water	1	27.4	27.4	2	0.5
Chutes/Cascades	2	65.2	32.6	4	1.0
Enhanced Riffle	1	216.7	216.7	2	0.5
Middle South Fork (RM 8.2-10.7)					
Pools	23	870.6	37.9	22.3	5.7
Riffles	35	1471.5	42.0	34.0	8.7
Runs	33	1325.3	40.2	32.0	8.2
Pocket water	12	352.0	29.3	11.7	3.0
Lower South Fork (RM 0.3-2.6) Not surveyed because of time constraints.					

Table 17.-Stomach contents of trout caught in the North Fork Snoqualmie River and in beaver pond 6 (adapted from Kurko et al. 1980). Trout were caught between July 21 and August 26, 1979 by hook and line, with exception of the one rainbow trout and the 215 mm brook trout that were caught by electrofishing. Adult (Adt), Nymph (Nym), Pupae (Pup), Larvae (Lva).

		Fork length	Fish	Pleco-ptera		Diptera			Tricho-ptera		Ephem-eroptera		Coleo-ptera		Ortho-ptera		Gastro-poda
Species	Location	(mm)		Adt	Nym	Adt	Pup	Lva	Adt	Lva	Adt	Nym	Adt	Lva	Adt	Lva	
Cutthroat	RM 19.1	≈ 190	--	1	--	--	--	--	--	--	--	--	--	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	1	1	--	--	1	--	2	--	1	1	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	--	1	--	--	--	--	--	--	--	3	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	--	3	--	--	5	--	1	--	3	--	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	--	--	--	1	--	--	1	--	--	--	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	--	1	1	--	--	--	3	--	--	--	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	1	--	3	--	3	--	--	--	2	--	--	--	--	--
Cutthroat	RM 19.1	≈ 190	--	--	--	--	--	--	--	4	--	--	1	--	--	--	--
Rainbow	RM 11.2	270	1[a]	--	--	--	--	--	--	8	--	--	--	--	--	--	--
Brook	RM 17.3	215	1[b]	--	--	--	--	--	--	24	--	--	--	--	--	--	--
Cutthroat	RM 16.4	186	1[c]	--	--	1	--	--	--	--	--	--	1	--	1	--	--
Cutthroat	Beaver Pd	266	--	--	--	--	--	--	--	--	--	--	--	--	--	--	20
Brook	Beaver Pd	225	--	--	--	--	--	--	--	6	--	--	1	--	--	--	--
Brook	Beaver Pd	197	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--

(a) juvenile trout (40mm).
(b) shorthead sculpin (30mm)
(c) shorthead sculpin (29mm), ALSO 2 Ants (Hymenoptera).

Table 18.-Densities of aquatic invertebrates (#/m^2) collected in North Fork Snoqualmie River, June, 1979 (from Kurko et al. 1980). Invertebrates were collected with a Mundie sampler at six sampling stations interspersed between approximately RM 6.6 and RM 20.2 plus one station in Lennox Creek (station 2).

	Sampling station						
	1	2	3	4	5	6	7
	#/m^2 (%)	#/m^2 (%)	#/m^2 (%)	#/m^2 (%)	#/m^2 (%)	#/m^2 (%)	#/m^2 (%)
Ephemeroptera	1272.5 (80.3)	483.4 (51.8)	161.1 (46.8)	966.7 (60.4)	188.9 (69.3)	533.4 (82.7)	527.8 (61.6)
Plecoptera	161.2 (10.2)	194.5 (20.8)	127.8 (37.1)	177.7 (11.1)	44.4 (16.3)	44.5 (6.9)	44.4 (5.2)
Trichoptera	28.0 (1.7)	5.6 (0.6)	5.6 (1.6)	38.9 (2.4)	5.6 (2.1)	--	16.8 (1.9)
Diptera	66.7 (4.2)	244.6 (26.2)	5.6 (1.6)	377.9 (23.7)	27.8 (10.2)	50.1 (7.8)	216.7 (25.3)
Coleoptera	5.6 (0.4)	--	--	38.9 (2.4)	5.6 (2.1)	5.6 (0.9)	16.7 (2.0)
Collembola	5.6 (0.4)	--	--	--	--	--	--
Oligocaeta	--	--	27.8 (8.1)	--	--	--	16.7 (2.0)
Unknown	44.4 (2.8)	5.6 (0.6)	16.7 (4.8)	--	--	11.1 (1.7)	16.7 (2.0)
TOTAL	1584.0 (100)	933.7 (100)	344.6 (100)	1600.1 (100)	272.3 (100)	644.7 (100)	855.8 (100)

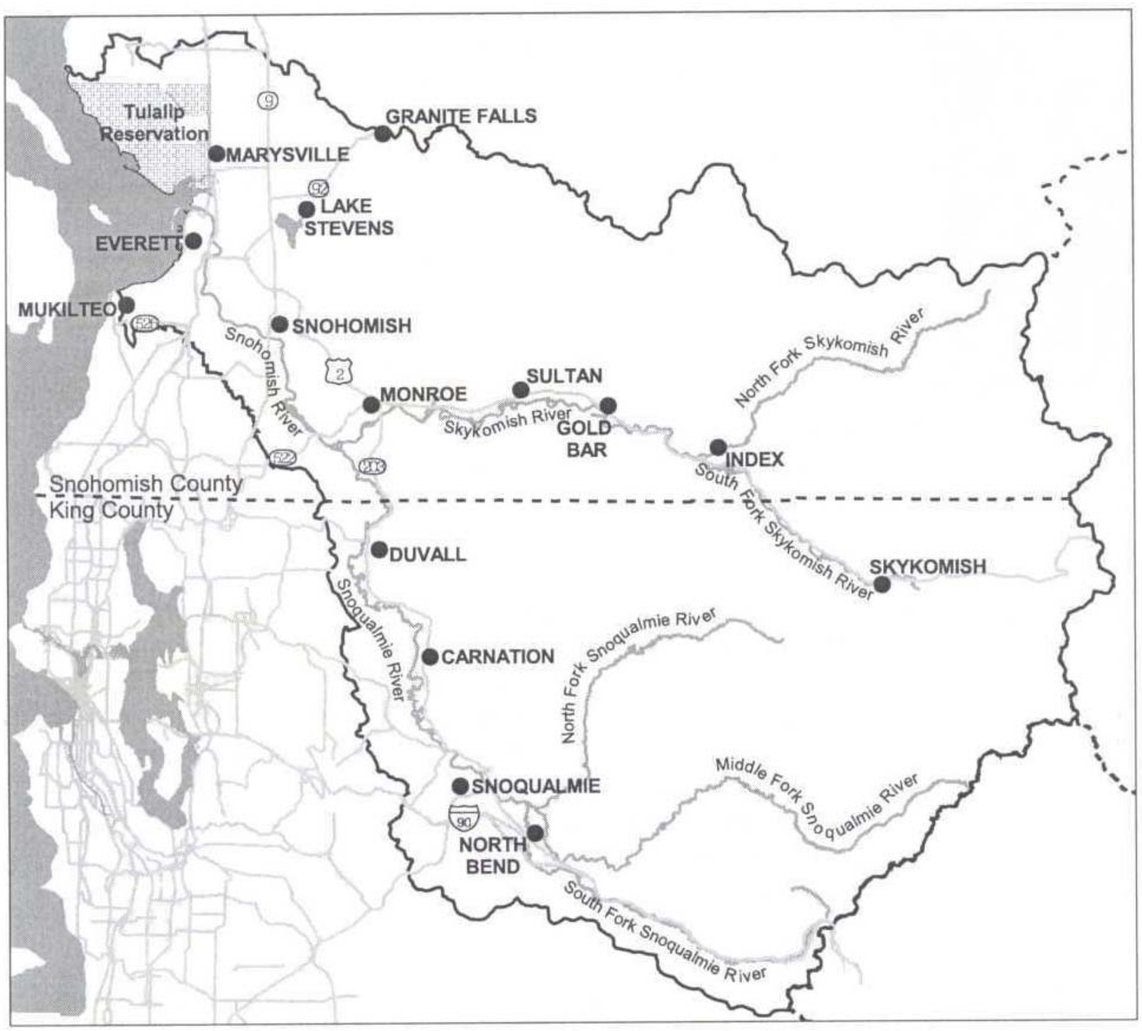

Figure 1.-Map of the Snohomish River Basin including the Snohomish, Skykomish, and Snoqualmie rivers and associated forks. From Snohomish Basin Salmon Recovery Forum (2005).

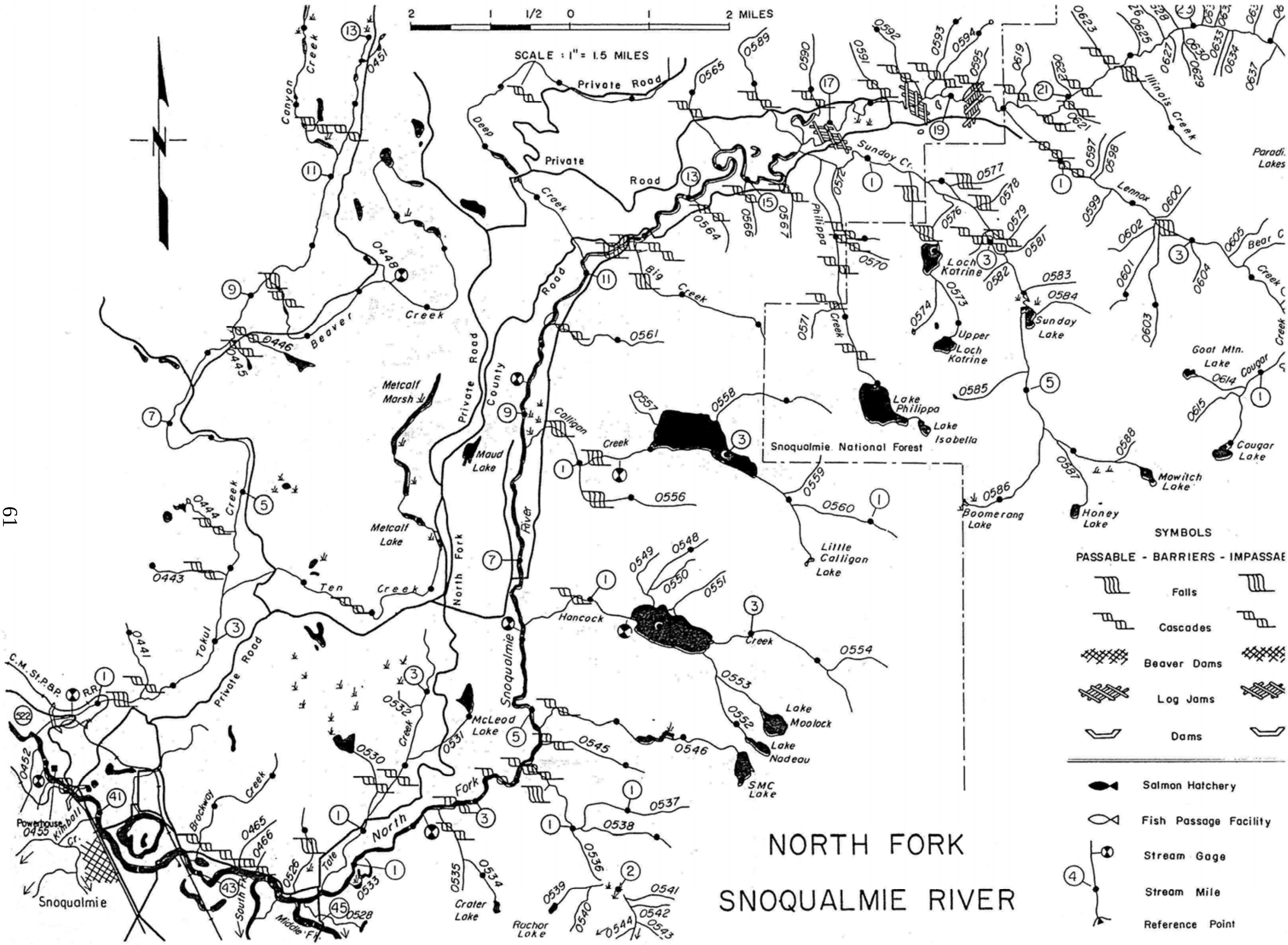

Figure 2.-Map of the North Fork Snoqualmie River including tributaries lakes, impassible migration barriers, and river miles (from Williams et al. 1975).

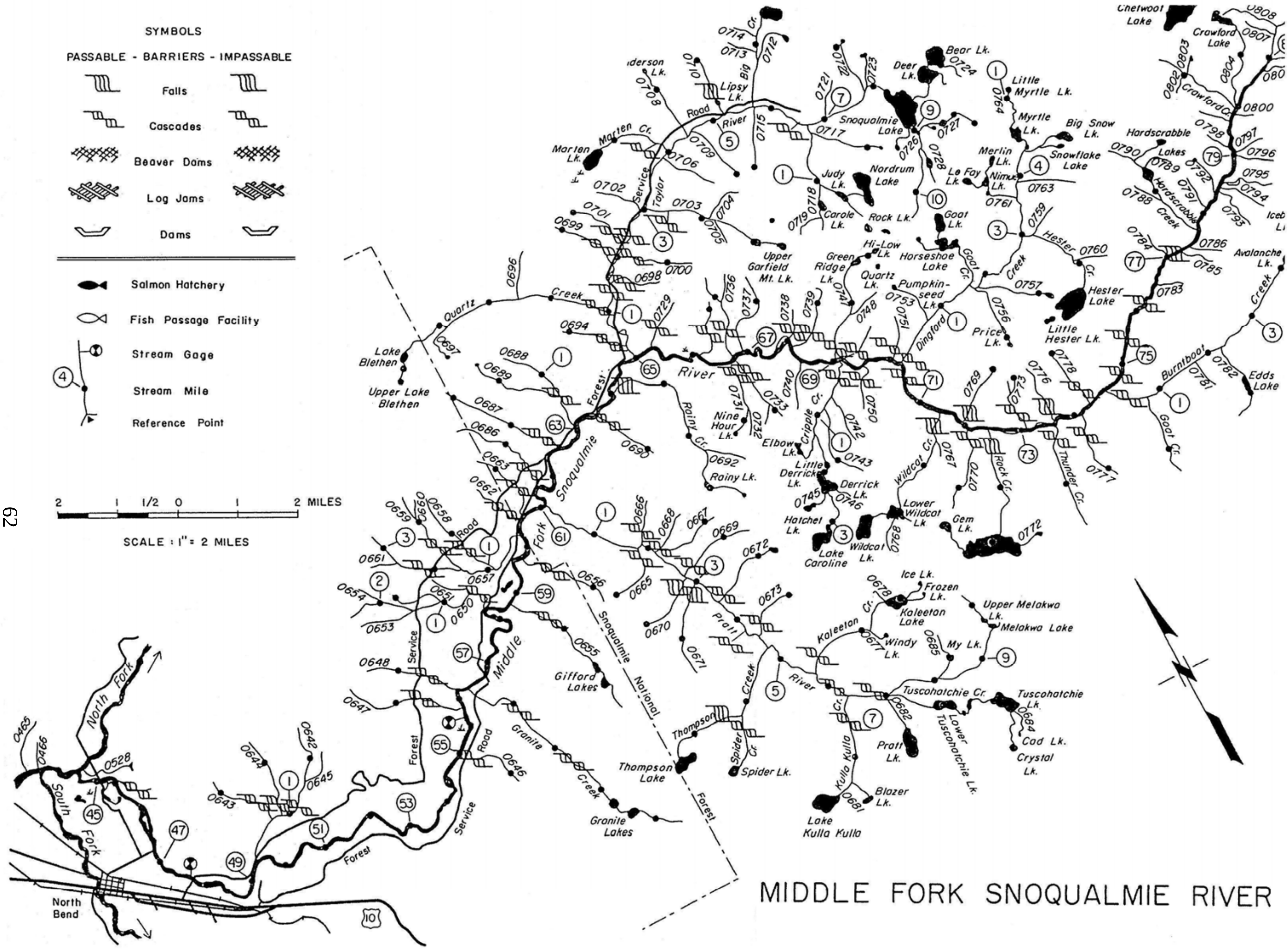

Figure 3.-Map of the Middle Fork Snoqualmie River including tributaries, lakes, impassible migration barriers, and river miles (from Williams et al. 1975). Middle Fork river miles start at RM 44.5.

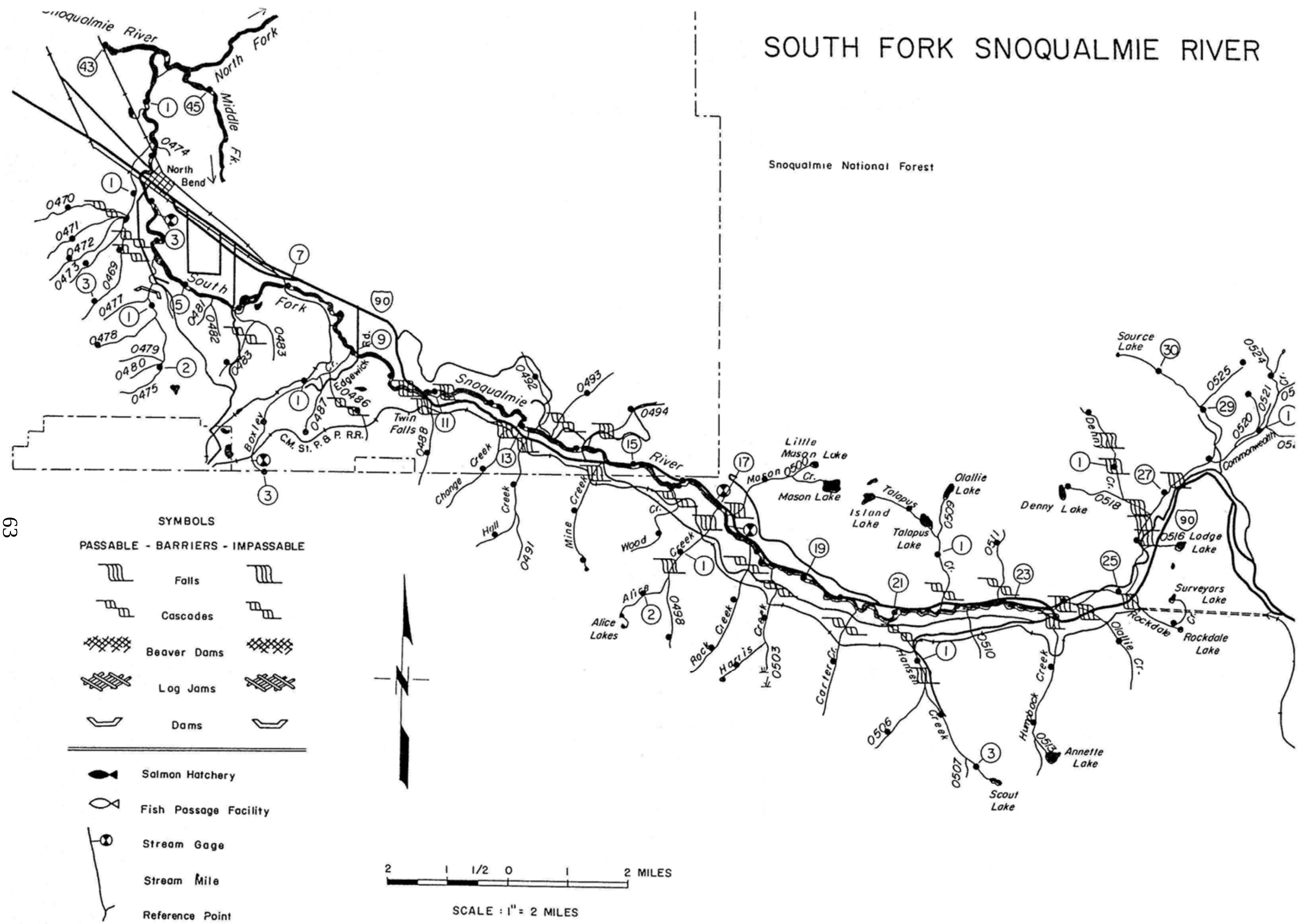

Figure 4.- Map of the South Fork Snoqulamie River including tributaries, lakes, impassible migration barriers, and river miles (from Williams et al. 1975).

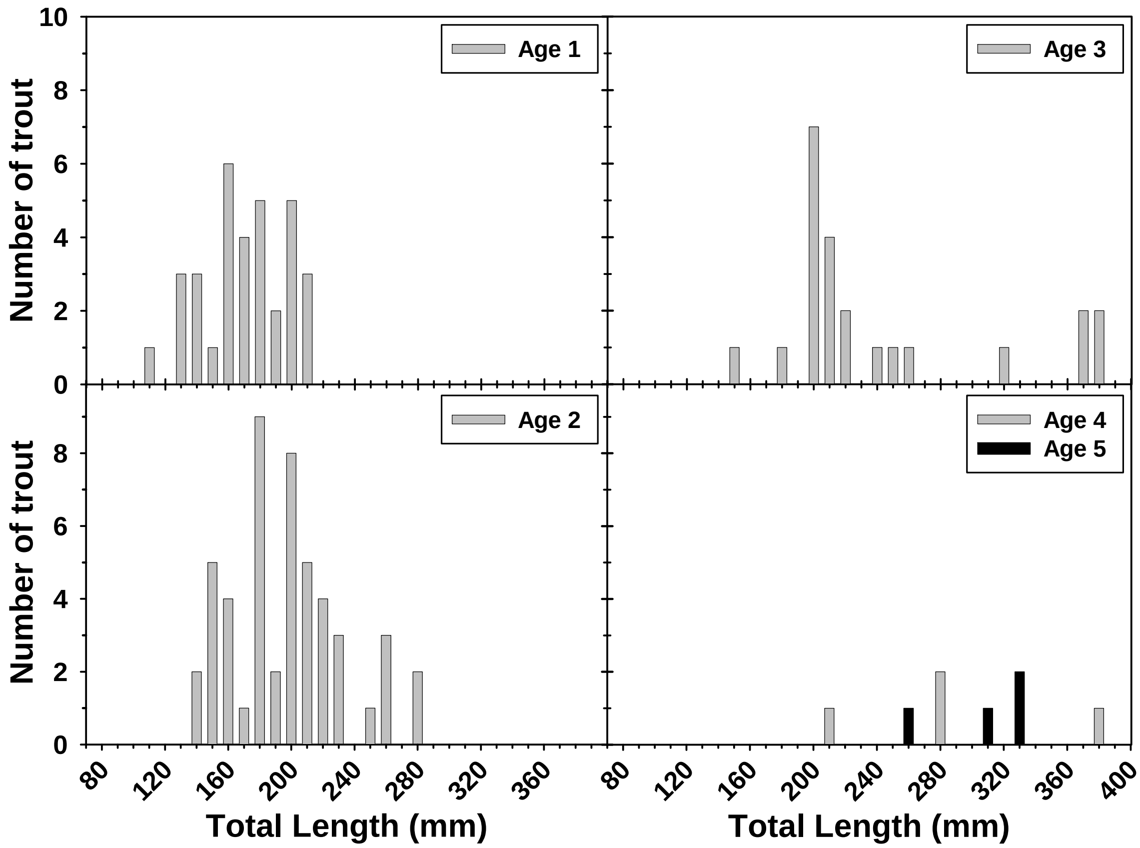

Figure 5.-Length frequencies (number of trout) by age for cutthroat trout collected by angling in the Middle Fork, 1981-1984 (adapted from Pfeifer 1990).

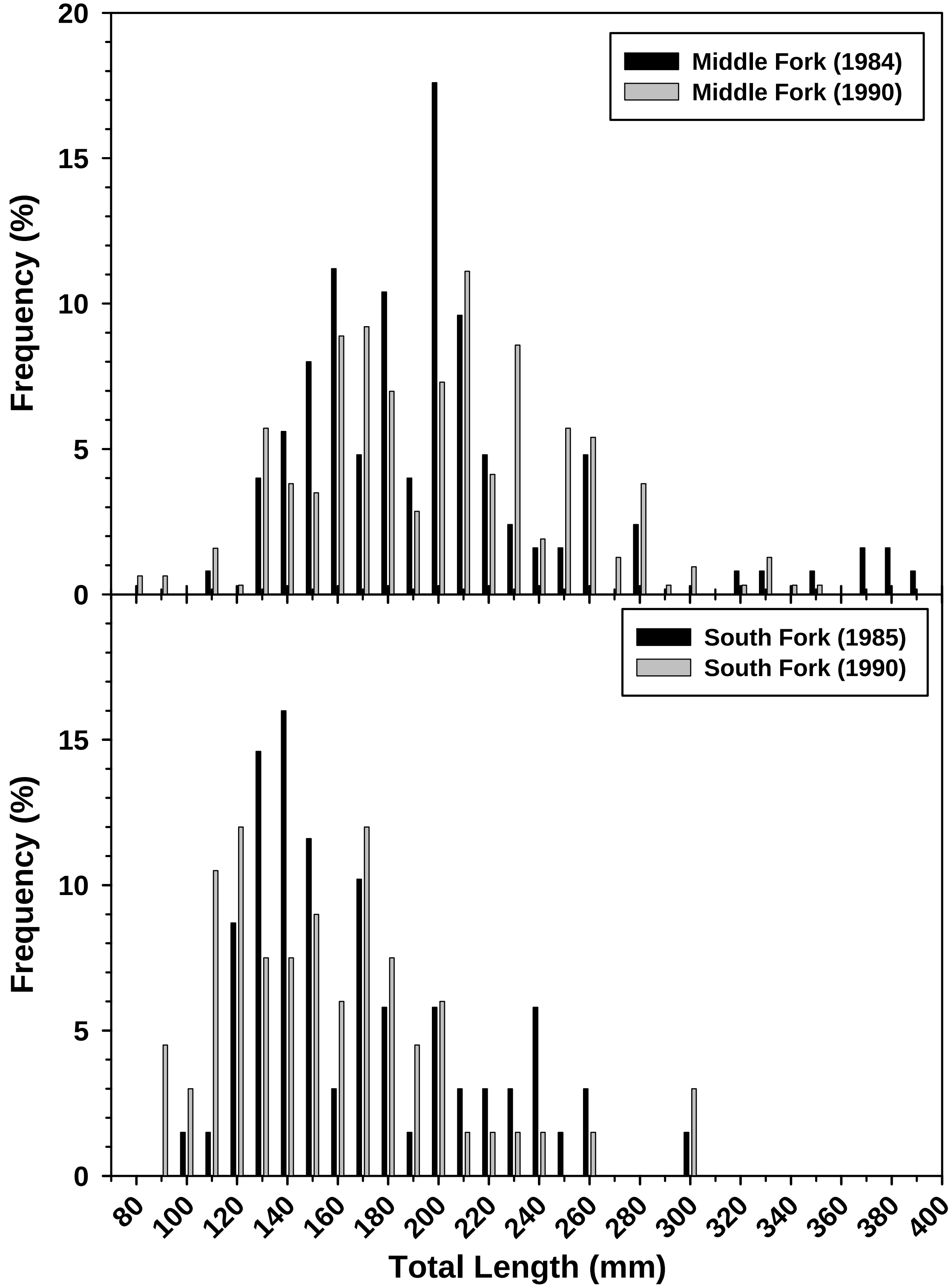

Figure 6.-Length frequencies (%) for cutthroat trout collected by angling in the Middle Fork and by electrofishing surveys in the South Fork (adapted from Pfeifer 1990).

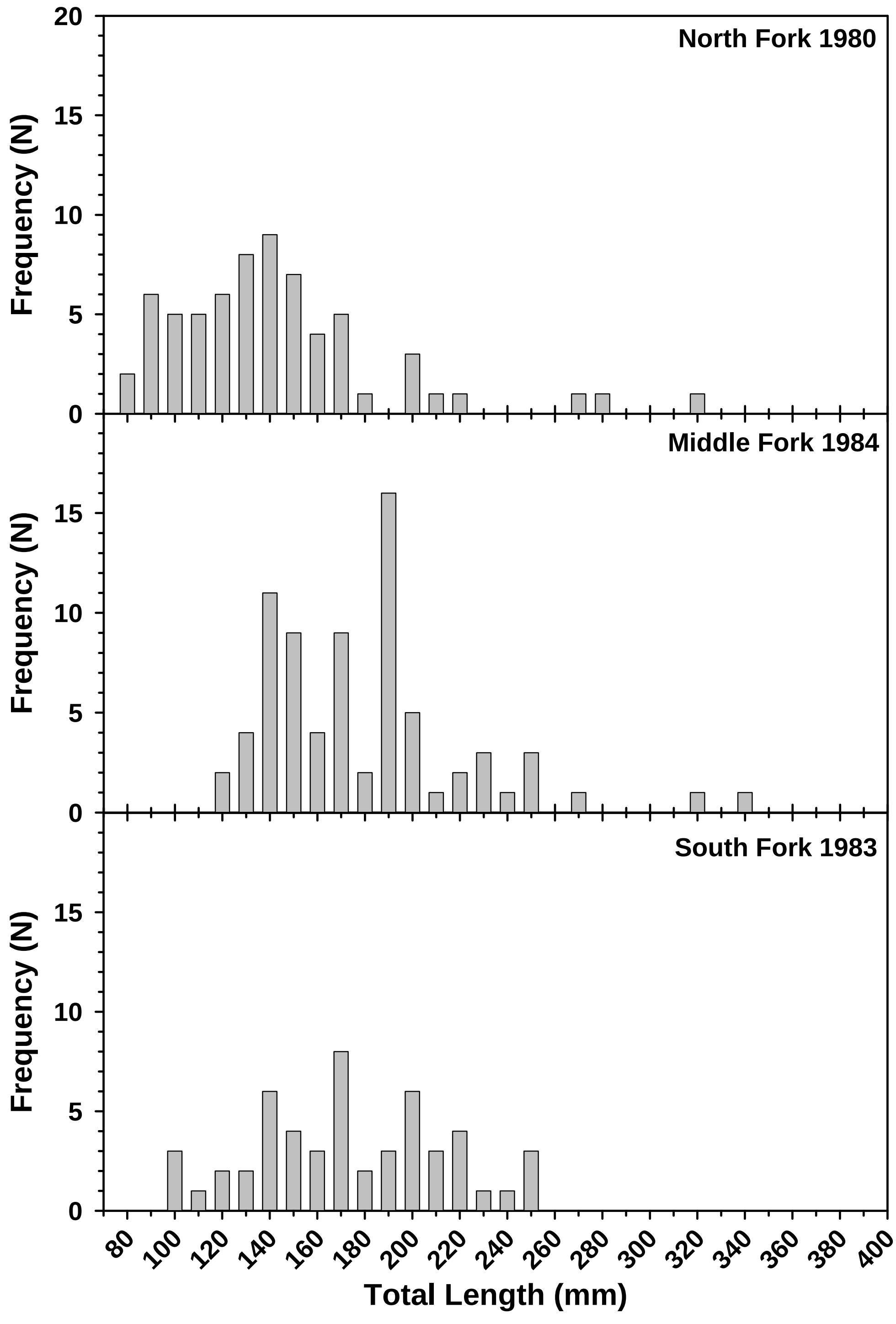

Figure 7.-Length frequencies (number of fish) for trout collected by electrofishing in the North Fork and by angling in the Middle Fork and South Fork (from Pfeifer 1985). It is possible that lengths of North Fork trout were not converted from fork length to total length for this figure (R. Pfeifer, personal communication).

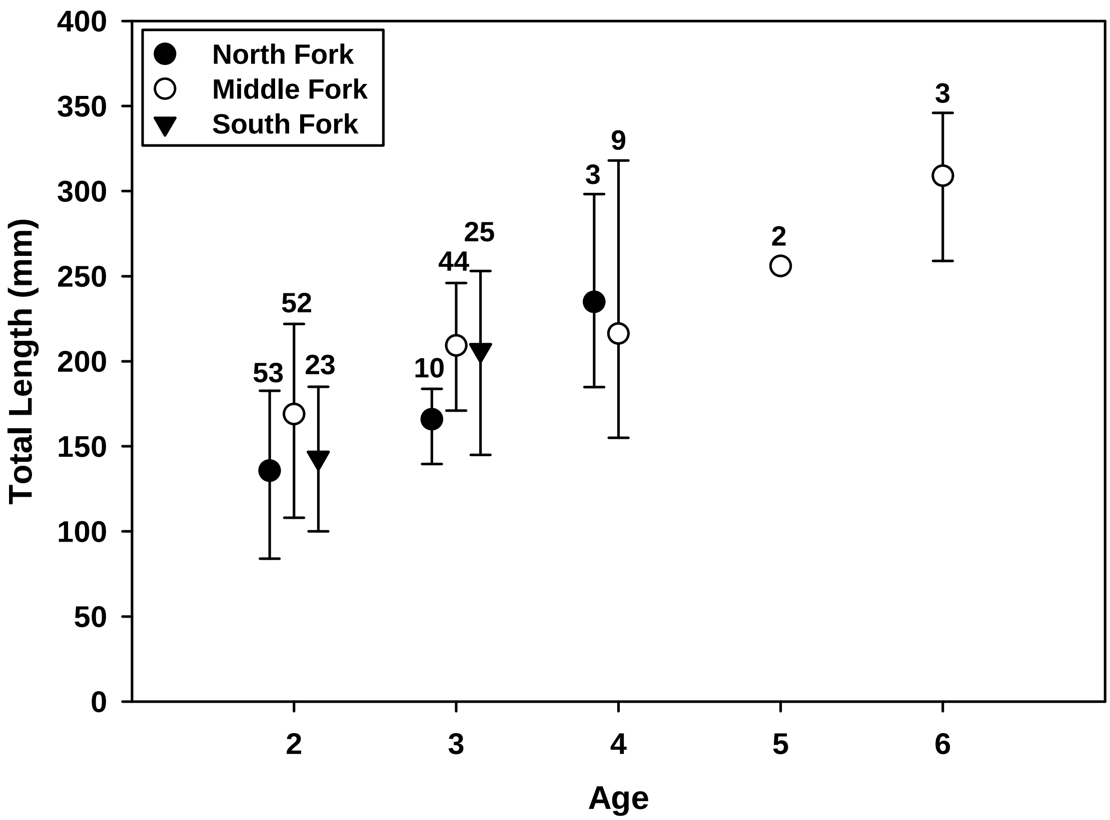

Figure 8.-Average total lengths (mm) at age for trout (cutthroat trout and rainbow trout combined) collected by electrofishing the North Fork and its tributaries and from angling in the Middle and South Forks. Adapted from Tables 4.2, 4.3, and 4.4 in Pfeifer (1985). Error bars represent min and max length observed and numbers represent sample size. Total lengths for North Fork trout were converted from fork lengths using a regression (TL = 1.050 FL) for cutthroat trout from the upper Yakima Basin (Trotter et al. 1999).

APPENDIX

Appendix Table 1.-Age and length data for cutthroat and rainbow trout collected by electrofishing in the North Fork Snoqualmie River and tributaries, 9/23/80–10/2/80. From Pfeifer (1985) Table 4.2. Scales were not taken from trout less than 80 mm (all Age I).

Water	Age	Ageable sample size (n)	Mean fork length (mm)	Range	Species	% RB	% CT
"GF" Creek	2	9	137.8	97 – 174	Ct	0.0	100.0
	3	3	175.0	-175-	Ct	0.0	100.0
Lennox Creek	2	9	129.3	80 – 171	Ct	0.0	100.0
Sunday Creek	2	4	115.0	106 – 125	Ct	0.0	100.0
	3	1	154.0	--	Ct	0.0	100.0
	4	1	176.0	--	Ct	0.0	100.0
Philippa Creek	2	7	131.3	121 – 147	Rb, Ct	28.6	71.4
	3	6	150.2	133 – 163	Rb	100.0	0.0
	4	2	247.5	211 – 284	Rb	100.0	0.0
North Fork above Lennox Creek	2	24	127.6	89 – 164	Ct	0.0	100.0
All Waters Combined[a]	2	53	129.2	80 – 174	Rb, Ct	3.8	96.2
	3	10	158.0	133 – 175	Rb, Ct	60.0	40.0
	4	3	223.7	176 – 284	Rb, Ct	66.7	33.3
All Tribs.	2	29	130.4	80 – 174	Rb, Ct	6.9	93.1
	3	10	158.0	133 – 175	Rb, Ct	60.0	40.0
	4	3	223.7	176 – 284	Rb, Ct	66.7	33.3

(a) t-tests showed no significant differences between river sections.

Appendix Table 2.-Age and length data for cutthroat and rainbow trout in the Middle Fork Snoqualmie River, 9/25/81 – 10/29/81. From Pfeifer (1985) Table 4.3.

River Section[(a)]	Age	Ageable sample size (n)	Mean fork length (mm)	Range	Species	% RB	% CT	% Ct/Rb
I	2	32	162.5	108 – 210	Rb, Ct	12.5	87.5	0.0
	3	24	218.6	171 – 279	Rb, Ct	4.2	95.8	0.0
	4	1	318.0	--	Ct	0.0	100.0	0.0
II	2	3	169.3	160 – 175	Ct/Rb, Ct	0.0	33.3	66.7
	3	2	203.5	197 – 210	Ct	0.0	100.0	0.0
Both Sections	2	35	163.1	108 – 210	Rb, Ct, Rb/Ct	11.4	82.9	5.7
Combined[(b)]	3	26	217.4	171 – 279	Rb, Ct	3.8	96.2	0.0
	4	1	318.0	--	Ct	0.0	100.0	0.0

(a) Section I = RM 0.0 to 20.3; Section II = RM 20.3 to 25.7.
(b) t-tests showed no significant differences between river sections.

Appendix Table 3.-Age and length data for cutthroat and rainbow trout in the Middle Fork Snoqualmie River, 7/29/84. From Pfeifer (1985) Table 4.3.

River Section[a]	Age	Ageable Sample Size (n)	Mean Fork Length (mm)	Range	Species	% RB	% CT
I	2	16	168.9	132 – 222	Ct, Rb	5.9	94.1
	3	16	196.5	135 – 246	Ct, Rb	11.1	88.9
	4	4	214.5	195 – 271	Ct, Rb	20.0	80.0
	5	1	257.0	--	Ct	0.0	100.0
	6	2	334.0	322 – 346	Ct	0.0	100.0
II	3	2	204.5	199 – 210	Ct	0.0	100.0
	4	1	231.0	--			
III	2	1	170.0	--	Ct	0.0	100.0
	4	2	192.0	190 – 194	Ct	0.0	100.0
IV	4	1	155.0	--	Ct[b]	0.0	100.0
	5	1	255.0	--	Ct[b]	0.0	100.0
	6	1	259.0	--	Ct[b]	0.0	100.0
All Sections Combined[c]	2	17	169.0	132 – 222	Ct, Rb	5.6	94.4
	3	18	197.4	135 – 246	Ct, Rb	10.0	90.0
	4	8	203.5	155 – 271	Ct, Rb	38.5	61.5
	5	2	256.0	255 – 257	Ct	33.3	66.6
	6	3	309.0	259 – 346	Ct	0.0	100.0

(a) Section I = RM 0.0 to 20.3; Section II = RM 20.3 to 25.7; Section III = RM 25.7 to 33.0; Section IV = RM 33.0 to 39.5.
(b) Text suggests these are Rb rather than Ct.
(c) t-tests showed no significant differences between river sections.

Appendix Table 4.-Age and length data for cutthroat and rainbow trout in the South Fork Snoqualmie River, 7/3/81– 8/14/81. All trout collected with hook and line. From Pfeifer (1985) Table 4.4.

River Section[a]	Age	Ageable Sample Size (n)	Mean Fork Length (mm)	Range	Species	% RB	% CT	% Rb/Ct
I	2	7	147.3	105 – 185	Rb, Ct, Rb/Ct	0.00	28.6	71.4
	3	5	217.0	145 – 240	Ct, Rb/Ct	0.00	60.0	40.0
II	2	9	119.4	100 – 165	Rb, Ct, Rb/Ct	33.3	33.3	33.4
	3	14	197.5	170 – 250	Rb, Rb/Ct	42.9	0.0	57.1
III	2	7	150.0	120 – 170	Rb, Ct, Rb/Ct	57.1	14.3	28.6
	3	6	218.8	195 – 253	Rb, Rb/Ct	16.7	0.0	83.3
All Sections	2	23	143.3	100 – 185	Rb, Ct, Rb/Ct	30.4	26.1	43.5
Combined[b]	3	25	206.5	145 – 253	Rb, Ct, Rb/Ct	28.0	12.0	60.0

(a) I: Mouth to Twin Falls (RM 10.8); II: Twin Falls to Exit 42 (RM 17.2); III: Exit 42 to Asahel Curtis Interchange (RM 23.4); IV: Asahel Curtis Interchange to source.
(b) t-tests showed no significant differences between river sections.

Appendix Table 5.-Summary of river spot electrofishing in the North Fork Snoqualmie River in 1979. From Kurko et al. 1980, Table 13. Either a Coeffelt model BP-1C (backpack) or a Coeffelt model VVP-2C (vvp) electroshocker was used.

Date	River mile	Shocking unit	Time (hr)	Fish Species	Number	Mean length (FL, mm)	Length range (FL, mm)	Mean weight (g)	Weight range (g)
7/3	9.2	backpack	--	rainbow fry	1	40	--	< 1	--
				shorthead sculpin	14	--	--	--	--
7/31	19.0	backpack	--	rainbow	1	117	--	81	--
				cutthroat	1	98	--	16	--
				shorthead sculpin	7	--	--	--	--
8/1	11.2	backpack	--	rainbow	8	143	74-270	58	5-272
				rainbow fry	10	40	--	< 1	--
				shorthead sculpin	39	79	72-90	5	3-8
8/1	11.6	backpack	1.0	rainbow	5	143	112-165	39	19-58
				rainbow fry	12	40	--	< 1	--
8/1	19.2	backpack	0.75	cutthroat	3	135	106-164	30	11-52
				cutthroat fry	5	66	64-68	2	--
				brook	1	130	--	21	--
8/2	17.5	backpack	1.5	cutthroat	5	137	86-238	43	11-138
				brook	1	215	--	115	--
				shorthead sculpin	45	--	--	--	--
8/9	11.6	vvp	1.2	rainbow	6	129	109-147	24	14-34
				rainbow fry	14	40	--	1	--
8/9	14.6	vvp	1.2	rainbow	6	113	103-125	17	13-19
				cutthroat	2	111	100-122	14	11-18
				shorthead sculpin	42	--	--	--	--
10/17	19.2	backpack	0.5	brook	14	81	59-170	10	2-62
				cutthroat	1	59	--	2	--