Upper South Fork Nooksack River Effectiveness Monitoring

Assessment and Recommendations

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LIST OF ATTACHMENTS

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BACKGROUND

The mission of the Lummi Natural Resources Department is to enhance, manage, and protect the natural resources into perpetuity for the benefit of the Lummi people in accordance with the policies and procedures of the Lummi Nation

The Upper South Fork Nooksack River flows mostly through forested mountainous terrain and is inhabited by all five species of Pacific Salmon, as well as bull trout, rainbow trout and steelhead and cutthroat trout. The Lummi Nation Natural Resources (LNNR) Department has been working to construct river restoration projects in the Upper South Fork Nooksack since 2001 to benefit Chinook salmon, which are an important cultural species and are listed as threatened under the Endangered Species Act (ESA). The Upper South Fork (upstream of Skookum Creek) contains 44% of the lineal length of spawning distribution and 24% of the lineal length of freshwater habitat for South Fork Nooksack Early Chinook (WRIA 1 SRB, 2005). Additional restoration work is planned for 2019 and beyond, so in order to optimize the design and implementation of future restoration work, and to identify any needs for adaptive management of current projects, the LNNR hired Natural Systems Design, Inc. (NSD) to develop a large-scale effectiveness monitoring program to assess project effectiveness for their projects located between RM 12.5 to RM 30.

INTRODUCTION

The Effectiveness Monitoring Program in the South Fork Nooksack River from River Mile (RM) 12.5 to RM 30 is a large-scale monitoring effort to evaluate physical and biological project responses over 17.5 miles of river. This large area required the use of both remote sensing data and field data collection. Data collection efforts were directly tied to the specific project objectives, which are in turn, driven by the limiting factors identified in the WRIA 1 Salmonid Recovery Plan (WRIA 1 SRB 2005).

This Effectiveness Monitoring Program was designed to accomplish three goals:

1. Evaluate project effectiveness for completed projects and establish baseline data for evaluation of planned projects.
2. Assess the relative effectiveness of projects and their contribution to habitat conditions in the study reach.
3. Make recommendations for future design improvements and potential project locations.

The monitoring program focuses on the eleven completed and planned restoration projects conducted by LNNR within the South Fork Nooksack River between RM 12.5 and RM 30 (Table 1; Figure 1).

Table 1. Completed, current, and planned restoration projects conducted by Lummi Nation Natural Resources in the Upper South Fork Nooksack River.

PROJECT	RIVER MILE	CURRENT PHASE
River Mile 30	29.9-30	Completed 2007
Elk Flats	22.6-22.9	Final Design Stage, planned for construction in 2020
Camp 18	21.1-22.6	Phase 1 built in 2019, Phase 2/3 at Preliminary Design Stage
Larson's Phase 1	19.8-20.6	Completed in 2001

PROJECT	RIVER MILE	CURRENT PHASE
Larson's Phase 2	19.7-21.1	Completed 2014-2015
Fobes Reach	18.3-19.5	Initial phase completed 2010
Cavanaugh Island	16.6-17.0	Initial phase completed 2012
Upper Cavanaugh-Fobes Phase 2	16.6-19.5	Adaptive management for Fobes and Cavanaugh Island projects. Preliminary design stage completed
Skookum Edfro Phase 1	13.9-14.3	Completed 2016-2017 as adaptive management to the Skookum Reach project
Skookum Edfro Phase 2	14.4-15.4	Completed 2018
Skookum Reach	13.6-14.2	Completed 2010

Figure 1. Locations of restoration projects within the Upper South Fork Nooksack River conducted by Lummi Nation Natural Resources. Cavanaugh-Fobes combines those two project areas and Larson's Phase 1 is co-located with Larson's Phase 2.

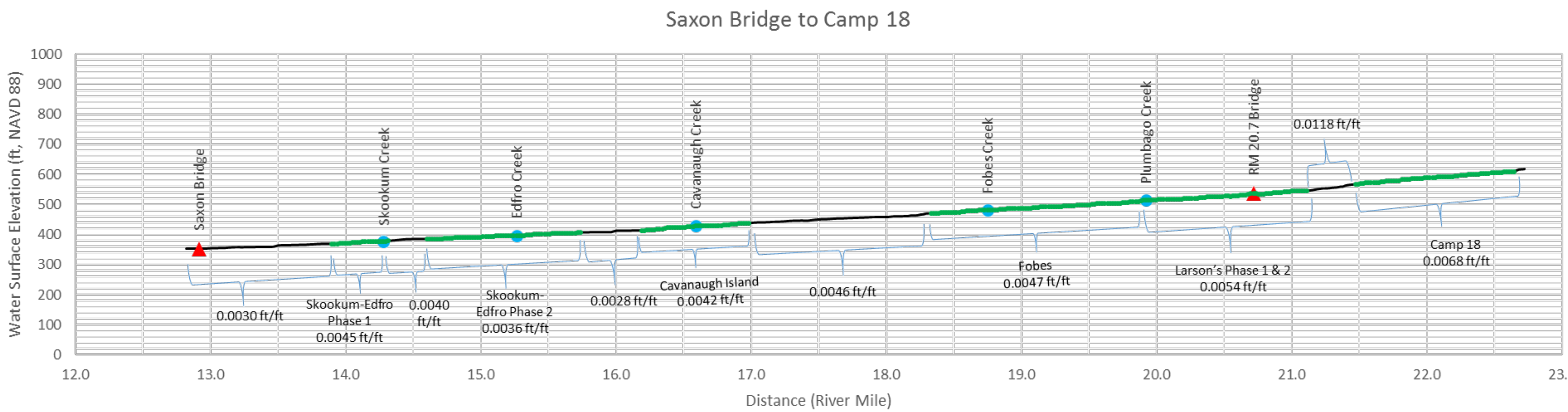
WATERSHED SETTING AND GEOMORPHIC CONTEXT

The South Fork Nooksack River is located in Whatcom and Skagit Counties, WA, and is a major tributary of the Nooksack River which flows into Bellingham Bay in Puget Sound. The headwaters of the South Fork begin in the Twin Sisters area of the Cascade Mountains, roughly 10 miles southeast of Mt. Baker – the tallest point in the Nooksack Watershed. The watershed experiences a Mediterranean precipitation regime (wet winters, dry summers) typical of Western Washington (USFS 2006 as cited in Brown and Maudlin, 2007). Stream flow is driven primarily by rainfall with a spring-snow melt signature and infrequent rain-on-snow events, which produce the largest floods. Much of the Upper South Fork Nooksack River flows through forested terrain within a narrow valley, although confinement decreases in the lower reaches. Steep sidewalls are present in the upper reaches and a rapid occurs at RM 25.5, which likely limits juvenile upstream migration. The feature at RM 25.5 is considered a partial barrier to upstream migration by spawning fish, depending on logjam volume and orientation in the canyon and flows (J. Klacan, 2020, pers. comm.). Some years it is passable for Chinook spawners but use has decreased in recent years. Spawner surveys above RM 25 from 1986 through 2018 (except 1987-1998) detected 29 redds in 1986, 1 redd in 2000, 1 redd in 2002, 8 redds in 2005, 1 redd in 2007, 1 redd in 2010 and 1 redd in 2017 (WDFW, LNR, NNR data, unpublished). Steelhead are generally able to negotiate the barrier (M. Maudlin, 2019, pers. comm.). The streambed is mostly cobble and boulders in the upper reaches and includes more gravels and sands in the Larson's Bridge vicinity. This change in sediment size may be due to a large outwash of gravel that occurs near Larson's Bridge. Riparian vegetation consists of conifers in the upper reaches and mixed deciduous and coniferous in the lower reaches. Disturbance in the watershed is mostly due to timber harvest, as most of the land in the upper watershed is owned by private timber companies and the Washington Department of Natural Resources. Commercial timber harvest began in the watershed around 1900 with the advent of railroad logging. The LNNR Hatchery operates near Skookum Creek in the study area and there is limited development.

The river valley below RM 30 is bounded by erodible Pleistocene glacial terraces and glaciolacustrine deposits, as well as some outcroppings of more resistant Mesozoic metasedimentary rocks (WA DNR, 2016). Because of the erodible nature of the glacial deposits, there are numerous mapped mass-wasting (i.e. landslide) deposits throughout the basin. The upper reaches of the mainstem above RM 30 are also filled with glacial deposits, but the underlying geology is comprised of more resistant lithologies, such as Twin Sisters Dunite (Mesozoic ultramafic) and less resistant rocks, such as the Bell Pass mélange (heterogeneous metamorphic). Exposure of bedrock is limited to canyon areas and occasional outcrops where the river has eroded away the glacial fill. High elevation tributaries, such as Howard Creek, Cavanaugh Creek, and Skookum Creek, all flow through erodible glacial deposits and numerous mapped landslides (especially in Howard Creek). The erodible nature of these deposits leads to a high sediment supply.

There are several slope breaks within the longitudinal profile of the Upper South Fork Nooksack River which influence sediment transport dynamics and channel morphology (Figure 2). The upper reaches, between RM 26-32, have a relatively consistent slope (~0.0146 ft/ft) which is interrupted by the McGinnis and Howard Creek confluences around RM 28.5. In that location, the slope steepens which indicates an increase in sediment transport capacity – possibly in response to the high sediment loads of Howard Creek. The slope is consistent below the Howard Creek confluence until the canyon reach at RM 25.5. This reach is a steep (0.0445 ft/ft) and confined rapid, which is passable to bull trout and summer steelhead, but is sometimes a barrier to Chinook. When this rapid is passable, only a small portion of the population uses the area upstream. This may be due to the small size of the current population and the current quality of upstream spawning habitat. In previous years, this reach was known to produce higher numbers of Chinook with 25 redds identified in 1986, although only 2 redds have been detected in the last 10 years.

The likely backwater (and subsequent sediment deposition) produced by the canyon reach constriction also impacts channel morphology. The upstream reach contains some examples of a multi-threaded anabranching system with wide gravel bars, although these areas are limited. Downstream of the canyon, the channel has a plane-bed morphology with large substrate and few large gravel bars. That morphology continues along a consistent slope through the Elk Flats and Camp 18 project reaches, until a slope break near RM 21.0 at the start of the Larson's Phase 2 project reach, where the channel flattens from an average slope of ~0.01 to ~0.005 ft/ft. Gravel bars increase below this point and the channel trends again towards a multi-threaded anabranching morphology. This morphology is seen through the Larson's and Fobes project reaches where there are large gravel bars and multiple active channels. There is another canyon directly downstream from the Fobes reach at RM 18.0, which likely also increases sediment deposition upstream. Downstream of that canyon, gravel bars are again lacking through the Cavanaugh Island reach and the channel returns to a single-threaded morphology. There is another canyon directly downstream from the Cavanaugh Island project which separates it from the Skookum project reaches. However, there is not a major grade break through this reach and the single thread channel morphology persists until the Saxon Bridge, except for the side channels at Edfro and Skookum Creeks.



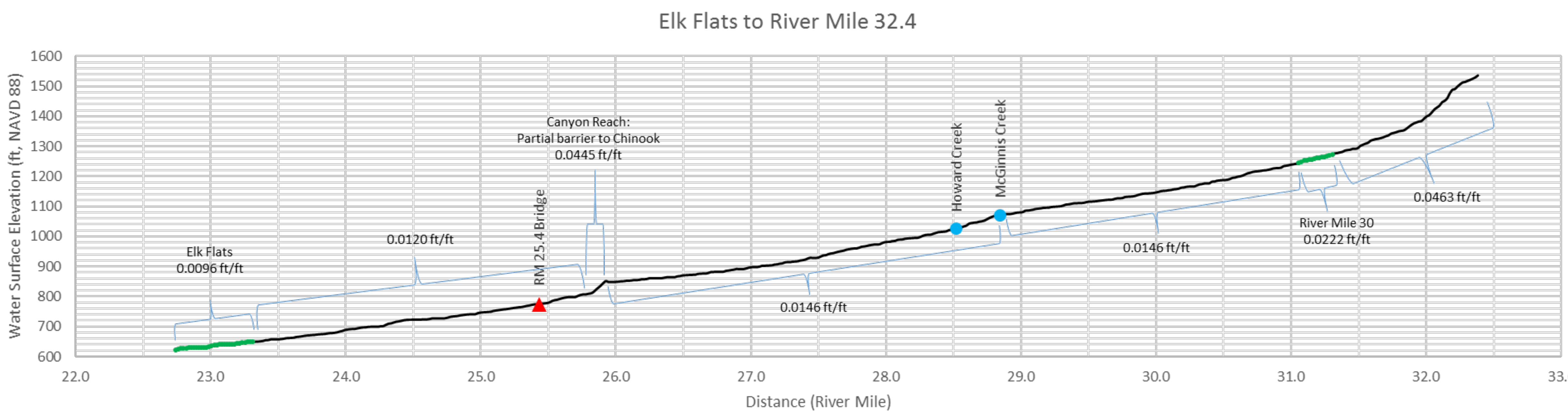


Figure 2. **Longitudinal profile of the Upper South Fork Nooksack River. The profile is based off water surface elevations derived from the 2017 LiDAR Digital Elevation Model (DEM).**

HABITAT CONTEXT

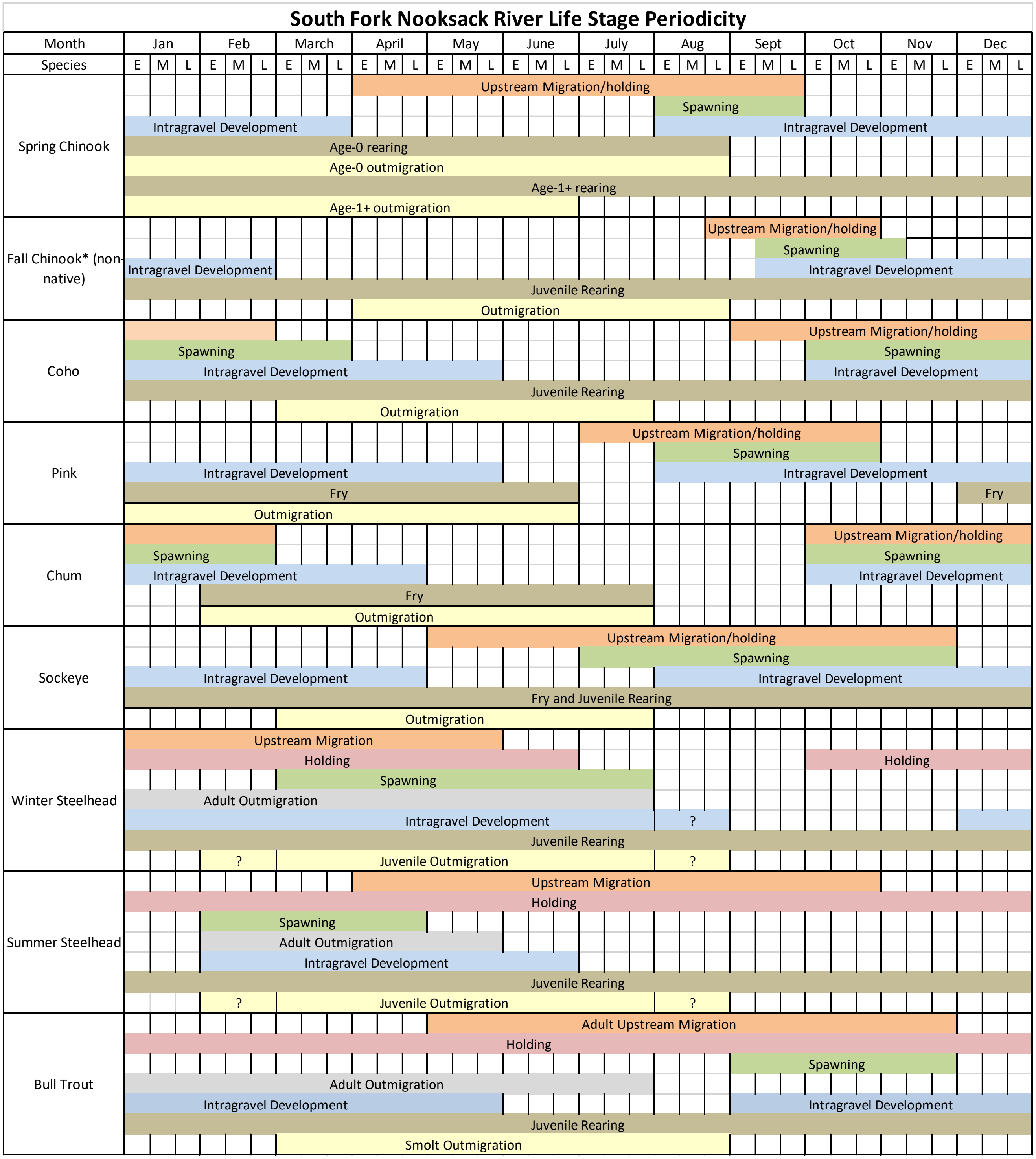
Three salmon species have been listed as threatened under the federal ESA and are of high priority in the Upper South Fork Nooksack. These include spring Chinook salmon (*Onchorhynchus tshawytscha)*, summer steelhead trout (*O. mykiss*), and bull trout (*Salvelinus confluentus*). The habitat in the study area includes a large portion (44%) of the spawning for the South Fork Nooksack population of early Chinook (based on EDT model results; WRIA 1 SRB, 2005). This fact underscores the importance of this reach in maintaining the population of fish in this region. The South Fork also provides habitat for coho (*O. kisutch)*, pink (*O. gorbuscha*), and chum (*O. keta)* (WRIA 1 SRB, 2005).

The life history of salmonid use in the South Fork Nooksack is presented in Table 2 (adapted from EPA, 2016 and Anchor Environmental, LLC. 2003). The South Fork Nooksack spring Chinook population is native and considered essential to the recovery of the threatened Puget Sound Chinook Evolutionarily Significant Unit (ESU) (64 FR 14308, Mar.24 1999). Spring Chinook enter the South Fork in April and upstream migration and holding occurs through September. Spawning occurs from August through September. Intra-gravel development occurs from August through March. Rearing may occur throughout the year and outmigration occurs January through August. The overall number of spawners in the South Fork Nooksack River has increased in recent years due to the early success of the South Fork Chinook Rescue Program. The 2012 – 2017 escapement estimates for the South Fork were 116, 10, 22, 7, 319, and 145 natural-origin spawners for the South Fork Chinook population (Nooksack Co-managers, unpublished data).

Summer-run steelhead migrate upstream from April through October. Holding occurs year-round and spawning occurs February through April. Intra-gravel development occurs February through June. Juvenile rearing occurs throughout the year and the majority of outmigration occurs March through July.

Bull trout enter the South Fork and migrate upstream May through November. Holding occurs year-round and spawning occurs September through November. Intra-gravel development occurs September through May. Juvenile rearing occurs throughout the year. Adult outmigration occurs January through July and smolt outmigration occurs April through August.

Table 2. Salmonid life stage periodicity in the South Fork Nooksack River. Table adapted from EPA 2016. Coastal Cutthroat and Dolly Varden not shown. *Fall Chinook periodicity were adapted from Anchor Environmental, LLC. 2003 and were updated for the South Fork based on spawning ground surveys and genetic analysis of smolt trap samples (D. Kruse 2020 - personal communication). Upstream migration refers to time when salmonid enters the South Fork. Question marks (?) are months in which there is a question whether the species life stage occurs.



The primary limiting factors in the reach are elevated water temperature and lack of habitat diversity, with secondary factors of fine sediment and lack of key habitats (WRIA 1 SRB, 2005). Temperatures in the Upper South Fork are commonly above 16 degrees Celsius and temperatures nearing the lethal limit for salmonids have also been recorded, specifically during August and September, when spawning and egg incubation are occurring. There have been several deep-seated landslides in the basin that have contributed to the high levels of fine sediment, and lack of large wood in the system has led to simplified habitat conditions. There have also been landslides caused by roads and timber harvest practices in the basin. This may be a legacy effect of past timber harvest practices, rather than the current regulations. Deep complex pools (i.e., with woody cover) are largely lacking in the basin and are a target for restoration. Other key habitats noted as lacking are backwater pools, complex edge habitats and perennial side channels.

Life stages with the most limited productivity in the Upper South Fork include egg incubation, fry, pre-spawn holding and migration, spawning, and overwintering juveniles (WRIA 1 SRB, 2005). Pre-spawn mortality of South Fork Nooksack Early Chinook has been noted in recent years and an emphasis on cool water refuge was identified as an objective for many of the projects in this study.

The limiting habitat factors and life stages identified in the WRIA 1 Salmonid Recovery Plan have been (and are) a major focus of restoration efforts in the Upper South Fork Nooksack River. They have been used to guide restoration projects within the river and focus them towards achieving common objectives. Because of this, objectives such as pool creation, decreasing water temperature, increasing habitat diversity, and increasing large wood frequency are consistent between projects, even though they may have been phrased differently. One consistent definition used in setting project objectives is to create *primary pools,* which has been defined as **a pool that covers the majority of the mainstem channel** (Hawkins et al. 1993). Project objectives in the Upper South Fork Nooksack were generally comparable with the limiting factors identified for the basin. Fine sediment was identified as a less frequent project objective, due to the fact that the need to address fine sediments was linked to specific locations of landslides, which were only addressed by certain projects. We employed consistent, basin wide assessment techniques to quantify the influence that restorative actions in the project area have had on these limiting factors.

REACH SCALE ASSESSMENT

Field and remote sensing assessment techniques were utilized to evaluate restoration projects in the Upper South Fork in context with their stated objectives, the thematic limiting factors outlined above, and geomorphic processes present in the river. The field methods were designed to be as objective and repeatable as possible in order to remain consistent in the evaluation process across projects and to facilitate future monitoring. The field methods used to survey habitat conditions in 2018 and 2019 are based upon Pleus et al. (1999), and Schuett-Hames et al. (1999). These are the same protocols used in the 2005 habitat surveys and are used consistently across the basin for other habitat surveys by both the Lummi Tribe and the Nooksack Tribe. The results from this work can also be used to establish 2018 and 2019 conditions for future effectiveness monitoring efforts.

Methods

Background data review

The analyses and effectiveness monitoring conducted by this project relied on previously collected, compiled, and analyzed data to establish baseline conditions from which to compare current conditions against. This background data was provided to NSD by LNNR and included existing GIS files, topographic (LiDAR and other) survey data, historical aerial photographs and maps, stream gage and weather station data, stream temperature data, spawning survey data, fish use data, habitat survey data, substrate data, and supporting literature (i.e. the Recovery Plan, reach assessments, and Basis of Design reports for past projects). This included data from a 2002 forward looking infrared (FLIR) survey that identified areas of cool water that were a main focus of many restorative actions. These FLIR data were critical to evaluating the temperature objectives that are present in most of the projects reviewed.

Objectives for each of the completed and proposed restoration projects within the study area were also compiled by LNNR and provided to NSD. These objectives were used to evaluate the effectiveness of each project (i.e. were the objectives met? If not, why?) and were based on project specific documentation. A data gaps analysis was conducted and submitted to LNNR identifying additional background or existing conditions data necessary to fully evaluate each objective.

Geomorphic Field Assessment

An interdisciplinary team from NSD (Leif Embertson, Jen O'Neal, Susan Dickerson-Lange, Scott Katz, and Evan D'Oro) conducted a field assessment of the project areas on June 26-27th 2018. Average flow at the USGS Saxon Bridge Gage was 450 cfs over this time period. Generally, field sampling for habitat surveys is conducted during low flow, so these observations may differ from those of the habitat surveys. The goal of the field work was to assess the existing geomorphic conditions of the project areas and fill any data gaps in order to evaluate the project-by-project objectives. The field survey was conducted between RM 22.75 within the Elk Flats project reach and the downstream end of Skookum Edfro Phase 1 reach at RM 13.9. Project areas were accessed by boat from the Larson's bridge to Skookum Creek (Day 1) and from the floodplain in the Elk Flats reach down to Larson's Bridge (Day 2). Upstream reaches were difficult to access with the current road access and private land holdings, so areas upstream of RM 22.75 were reviewed using LiDAR and aerial photographs for this assessment.

The field data collection efforts during the assessment focused on the following observations and measurements:

- Channel morphology and reach descriptions
- Pool depths and locations
- Side channel inundation frequency and inlet/outlet condition
- Sediment observations, including pebble counts in several locations
- Riparian condition, dominant species and size classes

Habitat Surveys

Habitat surveys were conducted in late summer 2018 and 2019 to collect spatially explicit channel units, large wood perimeters and locations, surface substrate characteristics, and riparian vegetation data. In 2018, Lummi Natural Resources and Nooksack Tribe staff members collected data on a portion of the study area for comparison with pre-project data. Habitat surveys were completed in September 2019 by staff from Lummi Natural Resources, Nooksack Tribe, and Natural Systems Design. Flow at the USGS Saxon Bridge Gage was 362 cfs, on average, during June 28, 2018 surveys and 85 – 167 cfs during September 4 - 12, 2019 surveys. Methodology generally followed protocols from the Timber Fish and Wildlife Monitoring Program Habitat Unit Survey and Large Wood Survey (Pleus et al. 1999, Schuett-Hames et al. 1999).

Channel units were mapped using a GeoExplorer Trimble unit and identified by channel unit type at unit corners, classifying habitat criteria using a pre-built data dictionary. Pools were measured for maximum depth and tail-out depth, to generate residual pool depth statistics. Depths were measured with stadia rods. For each channel unit, percent cover by the three dominant cover types was visually estimated and recorded. Additionally, the dominant and subdominant substrate on the channel floor was visually estimated by channel unit.

The large wood survey inventoried key pieces and log jams. Key pieces are defined as large wood with a volume greater than 9 m^3. Volume was determined in the field using length and diameter measurements and a table to convert those dimensions to volume. For log jams, the number of key pieces present in the jam was recorded. Additional attributes for log jams and key pieces were also collected (Table 3). The attributes included relative location in the channel, GPS location, if the wood appeared stable or not, functional attributes, and if the jam was natural or an engineered log jam (ELJ). The data collected during the large wood survey were used to update digital files of wood locations developed using LiDAR and aerial photos.

Table 3. Large wood attributes.

ATTRIBUTES	RELATIVE LOCATION	ABSOLUTE LOCATION	STABLE	FUNCTIONS	TYPE	KEY PIECES
Potential Values	Edge low flow channel	Latitude	Yes	Split low flow	Natural	# of key pieces
	Center low flow channel	Longitude	No	Split high flow	ELJ	
	Mid-channel bar			Channel deflection		
	Lateral bar			Channel avulsion		
	floodplain			Sediment storage		
	Side channel			Pool formation		
				Fish cover		

Thermal refuges of water at least 2°C colder than ambient conditions were mapped. Areas tested for thermal refuges included pools, groundwater seeps, tributaries, and side channels. The ambient water temperature was established by measuring the temperature 20 ft upstream of suspected refuges. Attributes collected for refuges were GPS locations and approximate dimensions - length, width, and depth.

Snorkel Surveys

Snorkel surveys were conducted in seven reaches of the Upper South Fork Nooksack River in early August 2018. Average flow at the USGS Saxon Bridge Gage was 130 cfs over this time period.

The surveys were conducted to evaluate the potential response of restoration projects on fish populations and behavior. Surveys were conducted in August, because turbidity is lower and visibility higher during this time of year. In August, juvenile spring Chinook are rearing and outmigrating and adults are migrating upstream, holding, and spawning (Table 2). Juvenile summer steelhead are rearing in August and there may be some juvenile outmigration at this time. Adult bull trout are migrating upstream and holding and juveniles are also rearing and outmigrating in August. The surveys did not target all life stages of all species and represent a snapshot of fish use in the Upper South Fork. The survey was conducted in Elk Flats, Camp 18, Larson's, Fobes, and Cavanaugh Island project areas, as well as one control area upstream from Elk Flats (Figure 3). The control reach extended downstream from the bridge at RM 25 and consisted mostly of riffle habitat with a few pools at the top and bottom of the reach. Reach extents were defined by the bounds of existing or planned restoration actions, except for Camp 18 Upper, which was cut shorter than anticipated due to time constraints (Figure 3) and the control reach. Reach boundaries were identified and established in the field using a handheld GPS unit and GIS Pro software on an iPad, which included previously downloaded aerial imagery and a KMZ file with existing and planned restoration project extents. Snorkel reaches ranged from 606 to 2,184 meters in length. Future surveyors can locate start and finish points of the surveys using GPS coordinates.

Figure 3. Extent of 2018 snorkel surveys. TOS = Top of Site, BOS = Bottom of Site.

Each reach was surveyed by three snorkelers, except for Cavanaugh (where only two snorkelers were used due to staffing constraints). Snorkelers started at the upstream end of the reach and worked downstream using predetermined snorkel lanes and constant communication to ensure that the entire river area was surveyed. Disconnected off-channel areas (including side channels and isolated pools) were snorkeled, but tributaries were not. Snorkelers were briefed on in-water safety and did not snorkel unsafe areas (e.g. areas with high velocity, or where flow was directed into logjams that could trap a snorkeler).

Snorkelers recorded every fish observed in the reach. Data collected for each fish included species, size class, habitat structure associations, and channel unit type. All salmonids were identified to species, while suckers, sculpin, and dace/cyprinids were not. Size classes were binned into five categories based on fork length: 0-60mm, 60-120mm, 120-250mm, 250-500mm, and >500mm. Habitat structures and channel types noted included natural wood, placed wood, natural boulder, and placed boulder as structures, natural off-channel, and created off-channel as channel types. Wood must have been at least 0.1m wide by 1m long, and boulders must have had an intermediate axis of at least 256mm to qualify (Wolman, 1954). Placed wood and boulders were intentionally added to the reach as a part of restoration actions, while created off-channel included any off-channel area that was created or significantly enhanced by restoration actions. Off-channel areas included backwaters, alcoves, side channels, beaver ponds, and any other water feature disconnected from the mainstem river. Fish were determined to be using a habitat structure if they were taking cover around the structure or spending time in the structure's zone of hydraulic influence (i.e. the eddy or lower velocity area downstream of the structure). Multiple structure associations were recorded if a fish was using multiple structures (e.g. one fish could be labeled as both natural off-channel and placed wood). All data were collected using underwater dive slates and waterproof paper and were entered into Microsoft Excel after completion of field work.

Additional data at each reach included starting time, ending time, starting water temperature, ending water temperature, in-water visibility on a scale of 0 (visibility is too poor to snorkel) to 3 (perfect visibility), and field notes, which included a general description of reach conditions and any information on why certain areas of the reach were or were not surveyed. Due to overall time and project budget constraints, not all project areas were surveyed, and individual channel units were not delineated or spatially referenced. Channel unit types were noted for each fish.

Topographic Data and Landform Analysis

Topographic data used in this project were provided by LNNR and consist of a topobathymetric LiDAR digital elevation model (DEM) collected on October 9th and December 8th, 2017, from RM 31 to RM 13. Collection between RM 31 to RM 22.5 occurred on October 9th and from RM 22.5 to RM 13 on December 8th, due to weather concerns. Because of this, the flow (and thus depth) between the collection days was different. Flow at the USGS Saxon Gage was 220 cfs on October 9th and 690 cfs on December 8th. This will be discussed further in the hydraulic model section of this document. The DEM was converted to the WA State Plane – North Coordinate System from UTM in order to remain consistent with other projects being conducted in the reach.

A relative elevation model (REM) was developed to assess the current geomorphic conditions present at the site (including channel and floodplain features), evaluate the response of project actions on channel morphology, and identify future restoration opportunities throughout the study area. The methods used for this analysis were adapted from Jones (2006) and utilized the LiDAR DEM and water surface raster. A REM is a tool that depicts elevations of floodplain features relative to the water surface elevation of the channel at the time when the 2017 LiDAR was collected. A topographic plane of the water's surface at the time of LiDAR collection was developed (water surface raster). This surface was then mosaicked on top of the topobathymetric bare-earth DEM to effectively "fill the channel" with water and establish a reference plane with a slope consistent with the local channel gradient. The water surface plane was extended across the entire valley and subtracted from the bare earth DEM using raster calculator in ArcGIS to establish a relative elevation for each pixel of the bare earth DEM. The REM was used to identify geomorphic landforms, channel/floodplain morphology, and restoration opportunities within the project areas and river valley in general.

Hydraulic Model

A hydraulic model was developed for the Upper South Fork Nooksack River within the study area (RM 13-32) to calculate estimates of hydraulic parameters such as depth, velocity, and shear stress under existing conditions for both low flow and flood flow conditions. The model was developed using Hydronia's RiverFlow-2D plus GPU solver and the Aquaveo SMS v12.2 software interface. RiverFlow-2D is a two-dimensional finite-volume computer model that provides depth-averaged hydraulic parameters at centroids within a triangular mesh model domain. The model was calibrated using the water surface elevation (WSE) measured during the LiDAR flights and calculated from the provided depth raster. The model had to be calibrated for a combination of discharge levels (220 cfs and 690 cfs) because the LiDAR flight was conducted on two separate days (see section on topographic data above). Calibration was conducted by varying channel and side channel roughness values (Manning's n) and resulted in a root mean square error of measured WSE *minus* modeled WSE of 0.53 ft and a mean residual error of -0.22 ft from a total of 197 calibration points spaced at 0.1-mile intervals throughout the model domain.

All modeled flow levels were based off of the USGS Saxon Gage (12210000) and split between major tributaries (Mainstem, Howard Creek, Plumbago Creek, Cavanaugh Creek, and Skookum Creek) based on drainage area. The model was run for flow levels of 220 cfs and 690 cfs (LiDAR flows) and the Q1 (3700 cfs) and Q2 (10500 cfs) which were calculated using Log-pearson curve analysis of the gage. From a habitat perspective, the 220 cfs flow level is a potential surrogate for summer flows (low flows are around 100 cfs) and the 690 cfs flow level for spring flows. Specifics pertaining to the model development (i.e. inflow partitioning, mesh spacing, roughness values, calibration) can be found in Appendix A. Results from the hydraulic analysis can be found in Appendices D-G.

Project Level Evaluation

As the initial unit of analysis each project area is discussed independently below to compare the data to the project objectives. For those projects that have been completed, and for which pre- and post-project data were available, we provide a conclusion for each objective as to whether it was met, partially met, not met, or not enough data to conclude. Additional information on reach setting is also provided, as well as recommendations for the project, in terms of outcomes, or future implementation.

River mile 30

The River Mile 30 project area is located between RM 30 and RM 29.9 along the Upper South Fork Nooksack River. The project is the most upstream project constructed by LNNR on the river and was completed in 2007. The project sought to address the limiting factors of *elevated fine sediment* and *low habitat diversity* through the removal of a failing bridge across the South Fork, pull-back of artificial bridge approach fill in the floodplain and channel, abandonment of approximately 2,000 feet (625 m) of forest road, and the placement of four engineered log structures (NNR and LNR 2020). The logjam structures consisted of logs cabled together into an open box shape and then filled with rock ballast. The structures were designed to settle into the bed of the channel as local scour undercut them. The focus of the restoration was to isolate the channel from a stream-adjacent landslide upstream of the bridge abutment, create scour pools, and sorting gravel to provide areas for spawning. The main objectives of the project were:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
River Mile 30	1. Alleviate scour impacts of the right bank landslide immediately upstream of the bridge imprint	elevated fine sediment
	2. Increase spawning use of the reach	none
	3. Increase channel type and unit diversity	low habitat diversity
	4. Increase instream habitat complexity through large woody debris (LWD) loading	low habitat diversity
	5. Create catchments for finer substrate	elevated fine sediment
	6. Improve floodplain connection throughout the reach.	low habitat diversity
	7. Abandon spur road to the site, closing it to vehicle traffic	elevated fine sediment

Reach Description

This reach was not visited during the field reconnaissance or snorkel surveys due to budget constraints and level of prioritization by LNNR and thus, the following section is based solely on remote sensing analysis.

The River Mile 30 project reach extends from RM 30 to RM 29.9 and contains a steep plane bed morphology dominated by boulders and an average slope of 0.02 ft/ft (Figure 4). The reach is constrained by the hillslope on both sides of the valley and the river corridor is ~250 ft wide at the widest point. There is a landslide scarp along the right side of the valley that was contributing sediment to the reach. The landslide is currently vegetated and appears to have stabilized since construction in 2007, although that was not the main focus of the project. A gravel bar / inset floodplain terrace has formed at the toe of the landslide and is 2 ft above the low flow water surface. This feature is inundated at the Q1 flow level and is therefore, un-vegetated. There is a 4-6 ft high terrace along the left side of the valley that is not inundated at the Q2 flow level. The eroding bank upstream of the bridge abutment appears to have been stabilized.

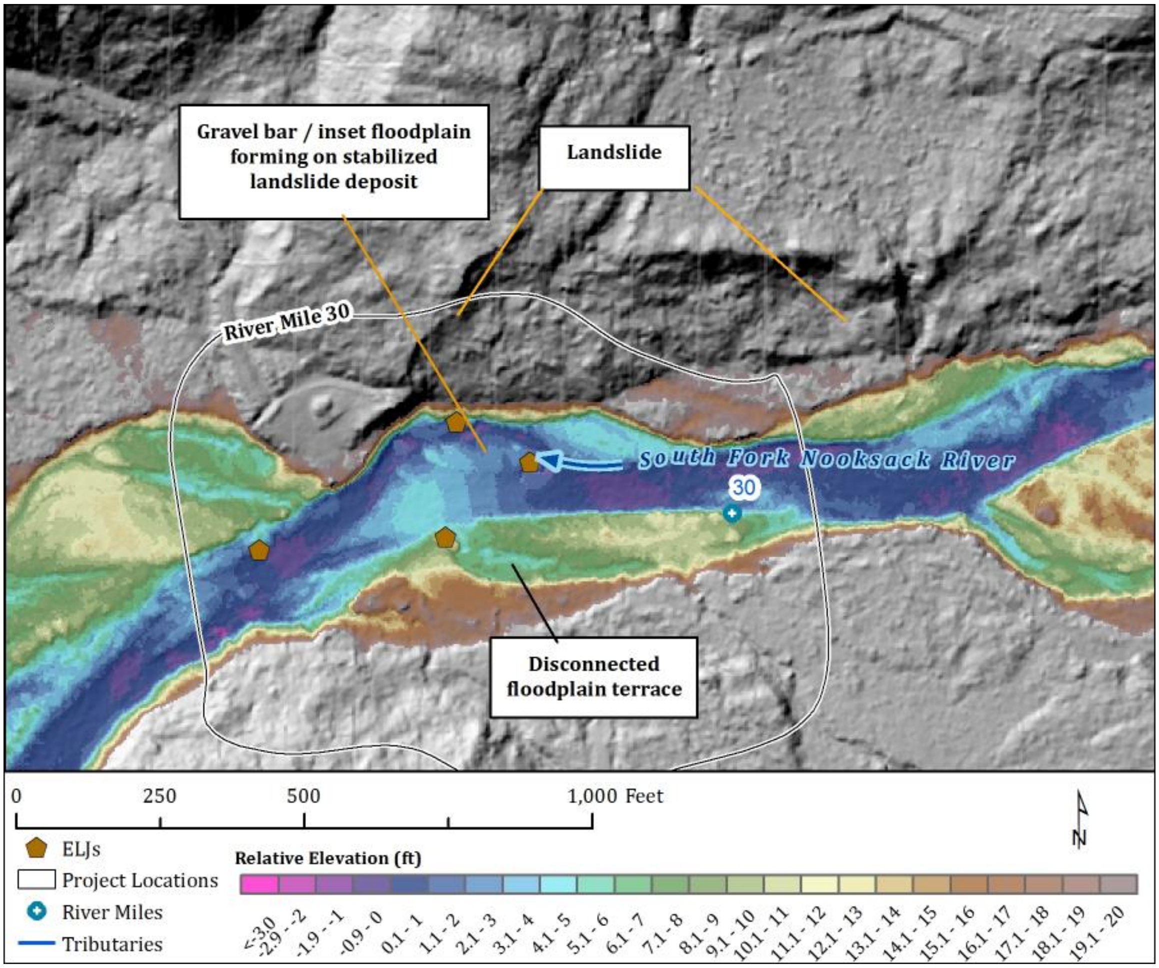


Figure 4. Relative elevation model (REM) for the RM 30 reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

The River Mile 30 project reach contains high velocity habitat and few instances of stable wood and pools (Appendix C- RM 30, Appendix D: RM 30-Depth and Appendix E: RM 30-Depth). The reach primarily consists of riffle units (55%) and contains only 5% slow velocity habitat (Figure 5 and Figure 6). This is not surprising given the steep slope. There are 4 logjams within the reach with a total structure area of 8,355 ft^2. The reach also contains two pools with an average residual pool depth of 2.25 ft, and neither met the deep pool classification of 3.28 ft. One pool is associated with an ELJ and the other occurs at the downstream end of the landslide deposit on the right bank (Table 4 and Figure 8).

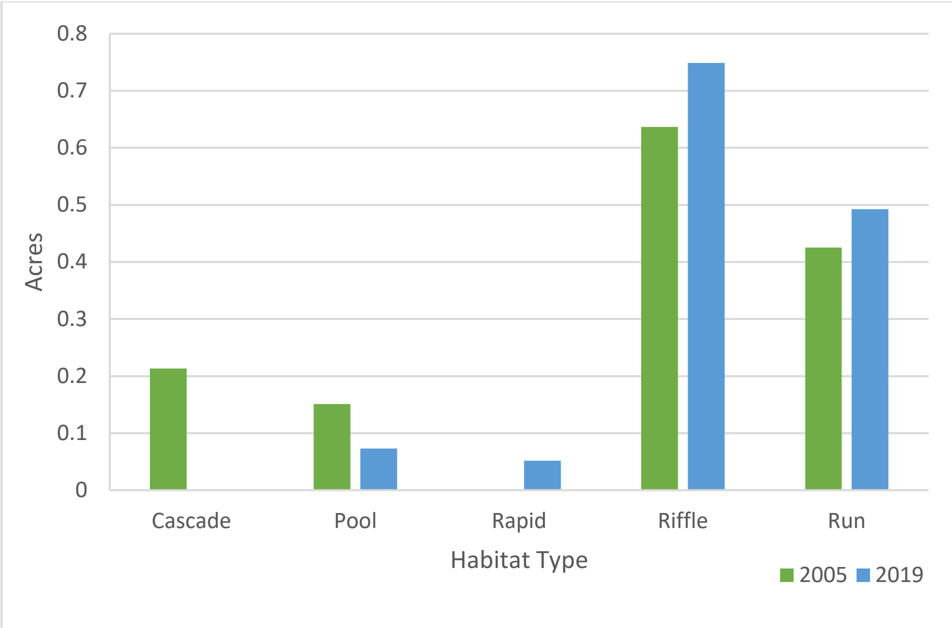


Figure 5. **Channel unit area for the River Mile 30 project reach from the 2005 and 2019 field surveys.**

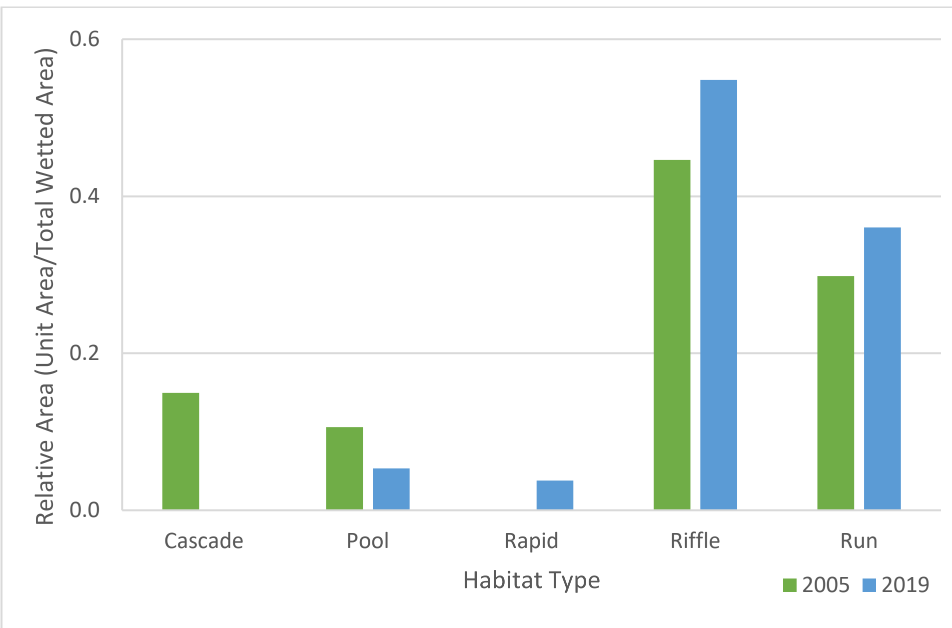


Figure 6. **Channel unit distribution for the River Mile 30 project reach from the 2005 and 2018-19 field surveys.**

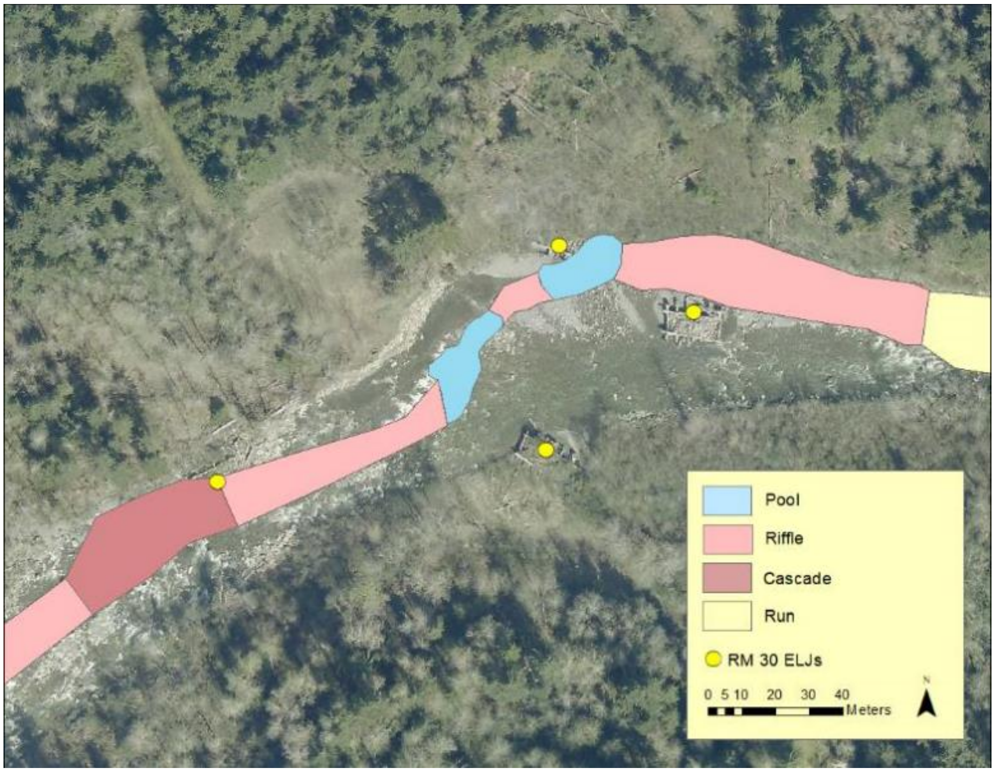


Figure 7. Channel unit map for the River Mile 30 project reach from the 2005 field surveys. (LNR 2005 data, photo from 2016, Source: NNR and LNR 2019).

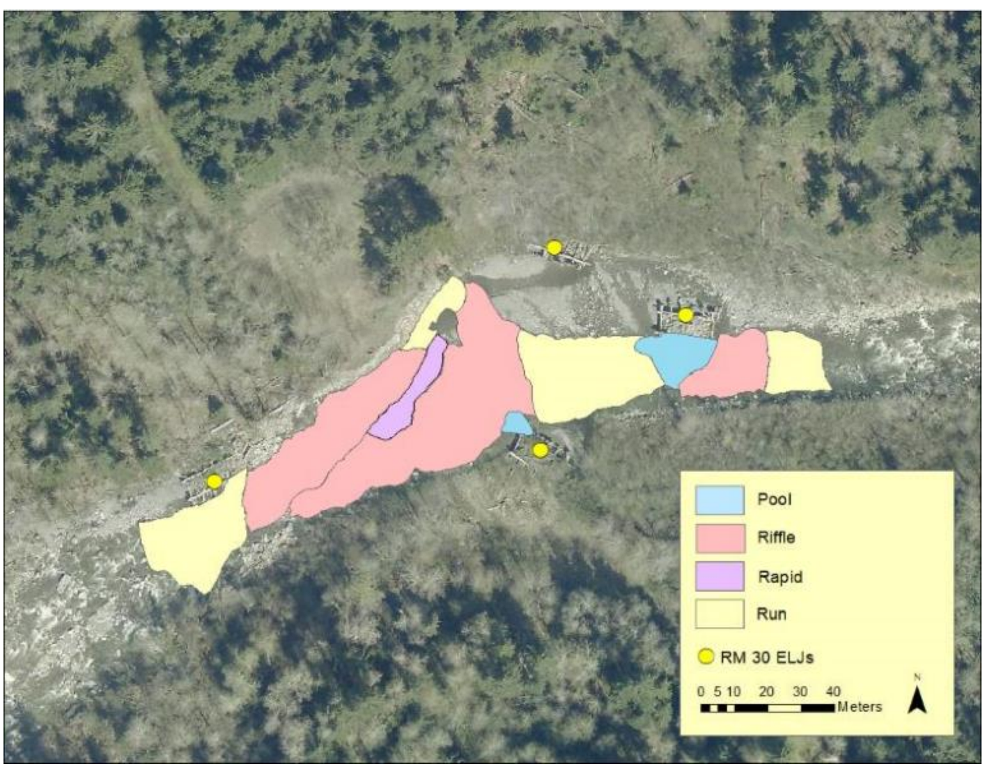


Figure 8. Channel unit map for the River Mile 30 project reach from the 2018-19 field surveys. (LNR 2019 data, photo from 2016, Source: NNR and LNR 2019).

Table 4. Pre-restoration (2005) and post-restoration (2019) pool parameters for the River Mile 30 restoration project (construction completed in 2007). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth > 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	2	2 (2)
Primary Pools (ELJ)	2	1 (1)
• Deep Pools (ELJ)	2	0 (0)
Secondary Pools (ELJ)	0	1 (1)
• Deep Pools (ELJ)	0	0 (0)

Monitoring Metrics

Project metrics for the RM 30 project reach were evaluated by comparing pre-project and post-project data in the context of the objectives. The level of achievement for each objective (achieved, partially achieved, not achieved, or not assessed) are summarized below.

Objective 1 – Alleviate scour impacts on the right bank landslide immediately upstream of the bridge imprint

This objective has been achieved. The majority of the slope is stabilized and is vegetated, as shown by Google Earth imagery, from before and after project implementation.

Objective 2 – Increase spawning use of reach

This objective has not been achieved. There have been zero chinook redds observed within this project reach following the 2007 restorative actions, or in any years of spawner survey data (1986, 1999-2018), although this project reach is not surveyed every year. This reach is above the constricted cascade near RM 25.5, which is a partial fish passage barrier to Chinook, depending on logjam volume and orientation in the canyon and the flows. In previous years, this reach had a higher level of use by spawning Chinook, but only three redds have been detected above RM 25 since 2007, one in 2007, one in 2010, and one in 2017 (WDFW, LNR, NNR data, unpublished). Sufficient data were not available to assess changes in substrate size before and after project implementation.

Objective 3 – Increase channel type and unit diversity

Channel unit numbers have increased in the reach although the diversity has remained at four unique channel units within the reach. The number of habitat units has increased from 6 in 2005 (pre-project) to 10 in 2019 (post-project) (NNR and LNR 2019) (Figure 7 and Figure 8) and there seems to have been a transition from riffle habitat to more run habitat (Figure 5 and Figure 6) although the number of pools is still relatively low. There are two pools identified in the reach in both the 2005 and 2019 data sets, although interim monitoring in 2009 and 2011 showed increases in pools near the structures and an increase in braiding relative to the original single-thread main channel (LNR 2009a, Maudlin and Coe 2011). The overall slope of the reach may prevent significant slow water habitats from forming (Figure 2).

Objective 4 – Increase instream habitat complexity through large woody debris loading

In the pre-project setting, there were no logjams noted in the project area. In 2019, 8,355 ft^2 of wood cover was identified, with 4 placed ELJs still present. These log jams, however, have not recruited significant quantities of large wood and thus, are not increasing wood loading within the reach. There is some engagement of log jams at low flow, but many are not engaged. So, while the number of channel units has increased, and the amount of wood loading has increased, it is not clear that the ELJs are actively contributing to increased habitat complexity at the low flow. This objective was somewhat achieved by the project.

Objective 5 – Create catchments for finer substrate

It appears from Google Earth aerial photos that fine sediments are accumulating in the lee of the ELJs - particularly the two directly in the vicinity of the right bank landslide deposit. This objective has been achieved, although measurements of the use of finer substrate in specific areas for spawning have not been collected.

Objective 6 – Improve floodplain connection throughout the reach

This objective has been achieved. Comparisons between 2006 and 2017 LiDAR indicate development of inset floodplain along the right bank in the area where the landslide occurred and the ELJ was placed. Channel area has expanded in this location as the flows occupy the inset floodplain more frequently.

Figure 8 also shows floodplain connection to the north and west of the upstream log structures, an area which was not connected in the pre-project condition Thus, the restorative actions have been successful at increasing floodplain connectivity in the narrow available floodplain that exists in the steep reach.

Objective 7 – Abandon spur road to the site, closing it to vehicle traffic

This objective has been achieved. The spur road bridge has been removed and the road has been abandoned, as shown in Google Earth images, from before and after restoration. The area was re-vegetated in 2014, and 2019 field surveys found that the plantings are doing well. Previous monitoring reports (Brown and Maudlin 2007, Maudlin and Coe, 2011) did not describe the post project status of the road removal, other than it was part of the project and was designed to increase floodplain width.

Table 5. River Mile 30 Project objectives and success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Alleviate scour impacts of the right bank landslide immediately upstream of the bridge imprint	Sediment source reduction	**Met**- the majority of the unstable slope is stabilized.
Increase spawning use of the reach	Salmon abundance	**Not Met**- no spawning has been observed in the project reach.
Increase channel type and unit diversity	Habitat unit diversity	**Met**- increase in habitat units from the project.
Increase instream habitat complexity through large woody debris (LWD) loading	LWD Loading	**Partially Met**- increase in the number of logjams in the reach; habitat diversity not compared to target values. There were 8,355 square feet of in-water wood surveyed in 2019.
Create catchments for finer substrate	Spawning gravel retention	**Met**- fine sediment is accumulating around the logjams.
Improve floodplain connection throughout the reach.	Floodplain reconnection	**Met**- small floodplain has developed adjacent to active channel area.
Abandon spur road to the site, closing it to vehicle traffic	Sediment source reduction	**Met**- road abandonment was effective.

Recommendations

This project has been effective at achieving its objectives and the objectives were generally reasonable given the geomorphic context of the reach (Table 5). Increasing spawning use may not have been reasonable due to the drop at RM 25 and increasing habitat diversity significantly is difficult given the channel gradient in the reach. The reach is steep, high in the watershed, and confined by the valley walls along both sides. The primary goal of the project was to stabilize an eroding bank upstream of a bridge abutment that was removed during the project. The ELJs constructed in this project have succeeded in this objective and are creating a small inset floodplain in their place. Because the valley is so narrow in this location, the log jams are highly engaged with flood flows and thus, have been effective at trapping sediment. However, because of the valley constrictions, there is a low amount of available area for additional floodplain habitat to form. This project is an example of how a focused project objective (reduce sediment load from landslide) can be achieved.

Elk Flats

The Elk Flats project area is located between RM 22.9 and RM 22.6 along the Upper South Fork Nooksack River. The project is currently in the **final design stage** (Geoengineers, 2020) and is planned for construction in summer 2020. This project is targeted at addressing the habitat limiting factors of *Elevated Fine Sediment*, *Low Habitat Diversity,* and *High Water Temperature* through the placement of engineered log structures, floodplain grading, and riparian planting. An additional focus for the overall project is to restore flow into the floodplain at the 2-year discharge. The main objectives of the project are:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Elk Flats	1. Reduce the fine sediment content in downstream riffles within five years.	elevated fine sediment
	2. Reconnect the main channel to the floodplain by encouraging development of side channels into the floodplain. Floodplain connectivity will be indicated by side channel inundation on the left floodplain at the 2-year flow event assumed to be 7,280 feet per second (cfs).	low habitat diversity
	3. Facilitate floodplain connectivity to reduce channel incision and encourage long-term channel bed aggradation and increased bed load storage within the reach.	low habitat diversity
	4. Increase the large woody material (LWM) function and abundance in the channel by adding 18 logjams.	low habitat diversity
	5. Create up to 18 effective, sustainable pools with in-stream woody cover.	low habitat diversity and high water temperature

Reach Description

The Elk Flats project area is in a high energy reach with plane-bed morphology, large substrate (boulders and cobble), and an average slope of 0.0096 ft/ft, with the steepest section just upstream of the landslide (Figure 9 and Figure 10 and Appendices B-H: Elk Flats). There is a landslide along the right bank near RM 22.7 where the river is constrained by a high left bank terrace and a glacial deposit along the right valley wall. The downstream end of the reach is characterized by rapids, as the river becomes constrained by a resistant terrace along the left bank and a landslide on the right bank.

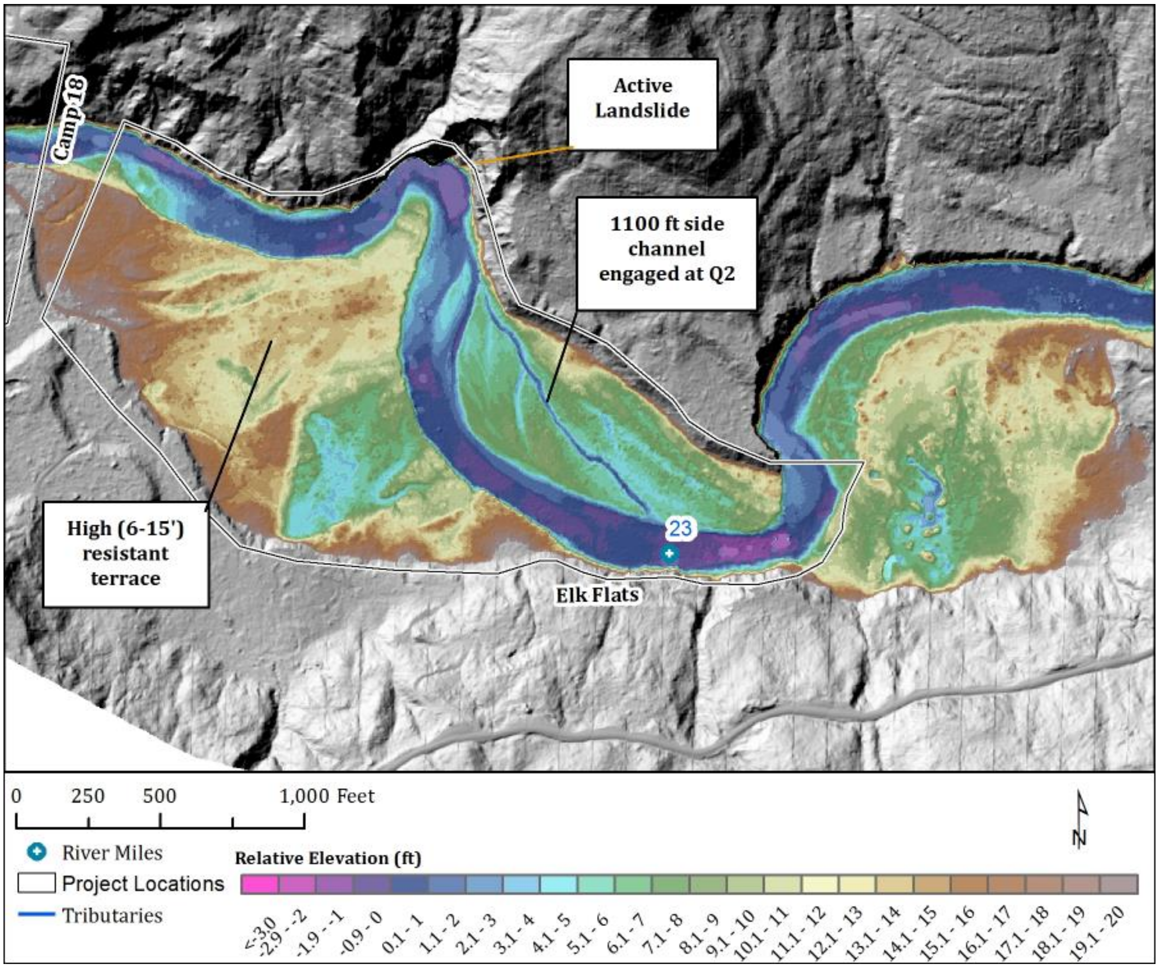


Figure 9. Relative elevation model (REM) for the Elk Flats reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

Figure 10. Downstream view of Elk Flats site near RM 22.75. Flow is into the page and the photo was taken on 6/27/18.

There are two side channels within the project reach – a 350-ft right bank channel near RM 22.75 that is engaged at the Q1 flow level and a ~1100-ft right bank channel near RM 23 that is engaged at the Q2 flow level. Besides those features, the floodplain is not engaged anywhere else within the reach (See Appendices F-G: Elk Flats). The floodplain surrounding the side channel is roughly 4-8 ft above the low flow water surface and is heavily forested. Historically, the main channel has periodically cut across the left bank floodplain at RM 22.7 and project engineers found evidence of scroll marks and relict channels in the 2013 LiDAR surface analysis and relative water surface elevation analysis (GeoEngineers 2020). The left bank floodplain showed no signs of engagement during the 2018 field visit and can be as much as 10-15 ft above the low flow water surface. The high elevation of the left bank floodplain terrace limits the potential for connectivity and forming an anabranching planform, although the terrace was overtopped in the November 2015 high flows. Bar growth on the right bank may progressively push flow toward the left bank terrace in the future. This terrace is primarily forested but, contains a large meadow near RM 22.7.

The Elk Flats reach has low habitat diversity, a lack of stable large wood, and likely has elevated water temperatures due to a lack of deep pools. The reach contains no in-stream wood and four total pools with an average residual depth of 5.6 ft, although one pool has a residual depth of 14 ft, which skews the average. The remaining three pools have an average residual depth of 2.8 ft. Two of the pools are defined as primary pools. One of the primary pools is located near the right bank meander bend and the other in the downstream portion of the reach (Table 6). The two secondary pools are associated with boulders scattered throughout the reach which provide the main sources of cover present in the reach.

Fast water units make up 86% of the reach, and pools make up the remaining 14%. (Figure 12 and Figure 13). The channel unit distribution underscores the low habitat diversity within the reach – something that the restorative actions are designed to address.

Figure 11. 2019 Habitat unit map for Elk Flats. Data from LNR and Aerial imagery from USDA NAIP 2017.

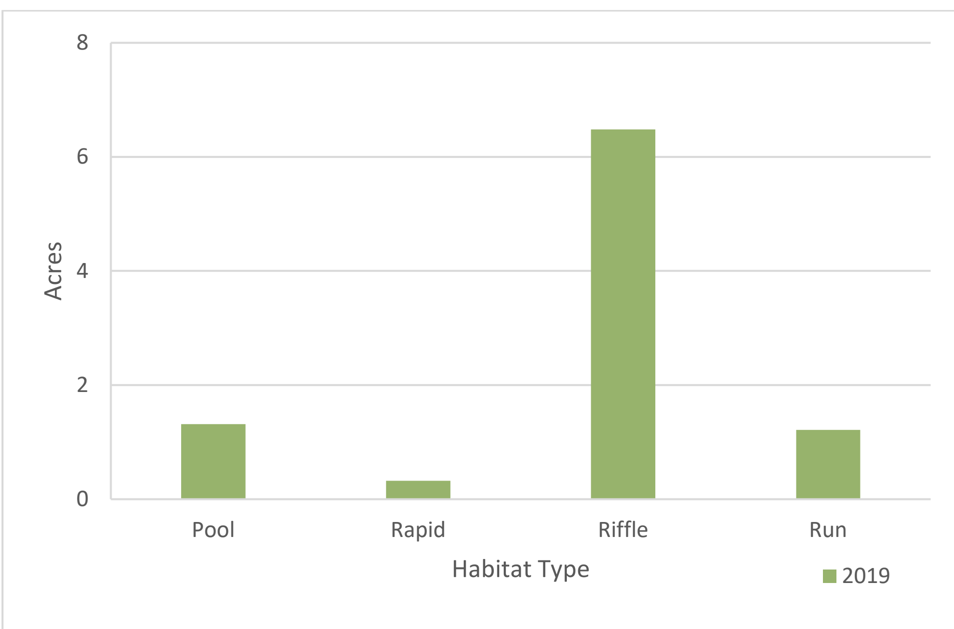


Figure 12. Channel unit area for the Elk Flats project reach from the 2018-19 field data.

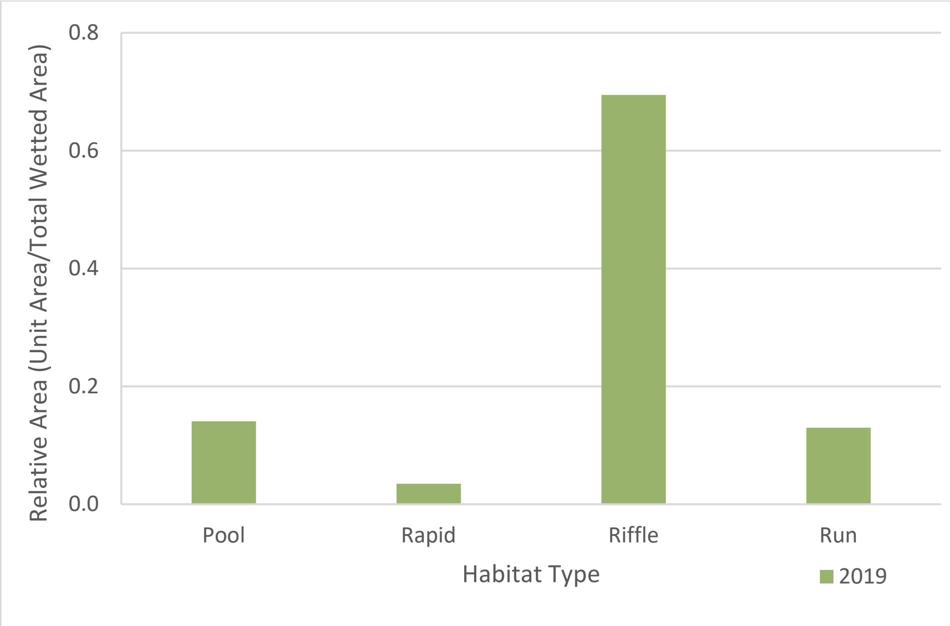


Figure 13. Channel unit distribution for the Elk Flats project reach from 2018-19 field data.

Table 6. Pre-restoration (2019) pool parameters for the Elk Flats restoration project. Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth > 3.28 ft (1m)).

POOL PARAMETER	2019
Total Pool Count	4
Primary Pools	2
• Deep Pools	2
Secondary Pools	2
• Deep Pools	0

The fish observed in the Elk Flats project area were dominated by *O. mykiss*, which are better adapted to a wider range of habitat types than Chinook salmon. Additionally, higher proportions of *O. mykiss* use habitat areas without structure (wood or boulders) and this reach has low levels of wood in the pre-project condition. There were a few Chinook observed at the site, as well as a few Mountain Whitefish (Figure 14). The level of fish use observed in the Elk Flats project area was moderate to low compared to other reaches surveyed, making it a good option for potential restoration actions. The site is also near the upper limit of spawning for the small population of Chinook in the South Fork, so the potential for juvenile use by Chinook may be quite low. Further, by the time of the August snorkel surveys, some of the early Chinook would have already outmigrated, although this would be the same across all projects. The structure use in Elk Flats was mostly at boulders located in the reach with some limited use of natural wood (Figure 15).

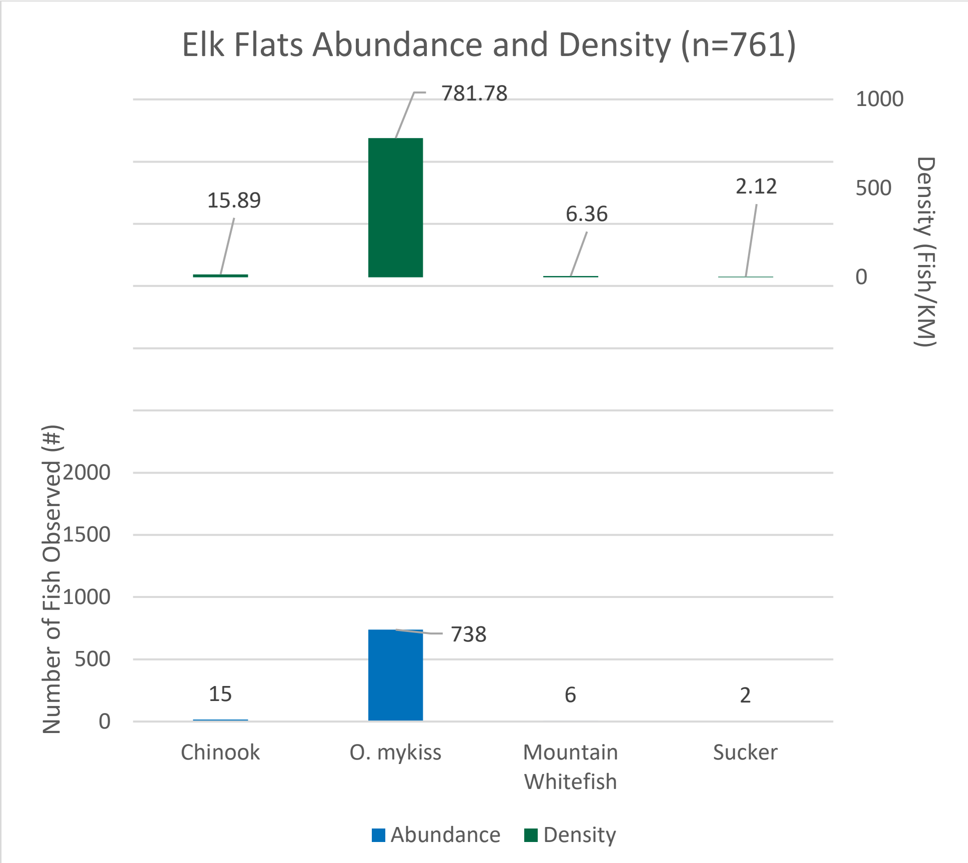


Figure 14. Snorkel survey results by species within the Elk Flats project area (August 6, 2018).

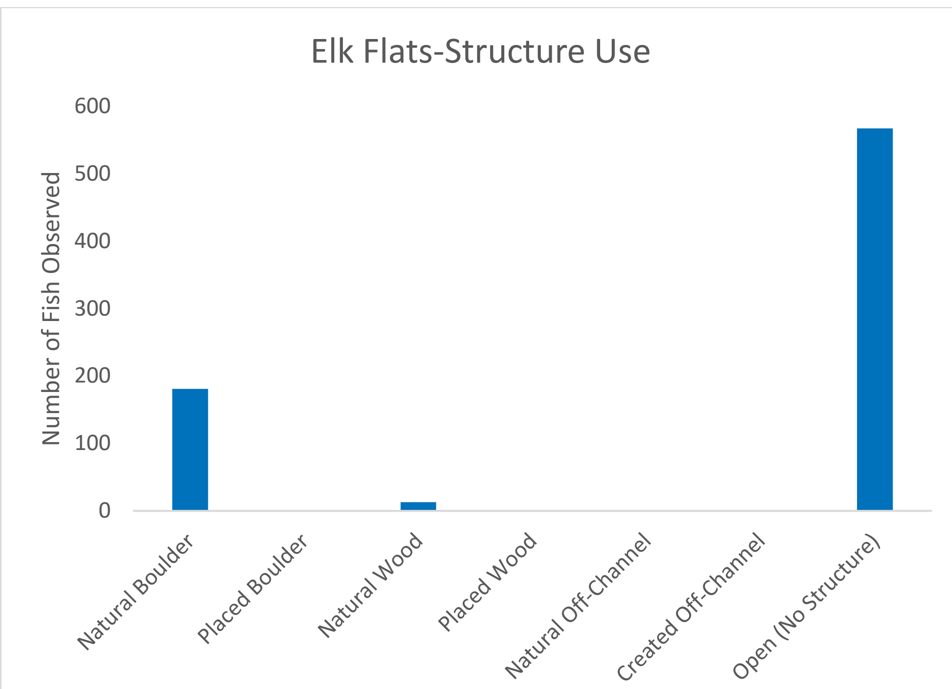


Figure 15. Observed structure use from the Elk Flats project area (August 7, 2018).

Monitoring Metrics

Elk Flats is currently in the preliminary design stage and thus, has no post-project data to evaluate project effectiveness. A discussion of each project metric follows.

Objective 1 – Reduce the fine sediment content in downstream riffles within five years.

Fine sediment was not the dominant or subdominant substrate in downstream riffles during 2019 habitat surveys. However, substrate embeddedness was not measured nor pebble counts conducted, so presence of fines have not been well documented. We recommend conducting pebble counts in downstream riffles prior to project implementation to allow for pre and post restoration changes.

Objective 2 – Reconnect the main channel to the floodplain by encouraging development of side channels into the floodplain. Floodplain connectivity will be indicated by side channel inundation on the left floodplain at the 2-year flow events assumed to be 7,280 cubic feet per second (cfs).

There is currently 350 ft of side channel engaged at the Q1 flow level and an additional 1120 ft of side channel engaged at the Q2 flow level. Reconnecting the left bank floodplain by encouraging development of side channels is an achievable metric, however it may take significant channel bed aggradation for it to occur, especially if engagement at the annual flow level is desired. The left bank floodplain is between 6 and 10 ft above the low flow water surface and proposed conditions hydraulic modeling of the project indicates that the surface is not engaged under the 2-year event which is higher than the annual flow. Channel bed aggradation (caused by the proposed ELJs) will need to occur to reduce the difference between water surface elevations and the floodplain surface significantly in order to reconnect the left floodplain perched approximately 6 - 10 feet above the current water surface. The dense placement of the proposed structures and their associated reductions in shear stress appear capable of aggrading the bed, but whether the elevation increases enough for the left floodplain to be activated at the Q2 should be monitored.

Objective 3 - Facilitate floodplain connectivity to reduce channel incision and encourage long-term channel bed aggradation and increased bed load storage within the reach.

The dense placement of the proposed ELJs are predicted to increase bed-load storage within the reach through reductions in sediment transport capacity. This will likely encourage long-term channel bed aggradation and facilitate floodplain connectivity through reductions in channel incision (i.e. raising the bed elevation). Thus, this objective is achievable with the proposed design.

Objective 4 – Increase the large woody material (LWM) function and abundance in the channel by adding 18 logjams.

Increasing large wood function and abundance is an achievable metric in this project reach. Due to the steeper slope in this reach, we recommend using high factors of safety to ensure logjam stability. There is no instream wood in the reach currently, which indicates that large wood processes are impaired. Long-term investment in the establishment of healthy riparian forests should also be included as part of the project to allow for sustainable levels of wood recruitment.

Objective 5 – Create up to 18 effective, sustainable pools with in-stream woody cover.

There are currently 4 pools within this reach (5.7 pools per mile), with an average residual depth of 5.6 feet. One of the pools is noted as being formed by a logjam. The average percent cover across all pools is 47.5%, which would allow for adequate hiding cover in most pools within the reach. Elk Flats has the second lowest number of pools per mile of all of the reaches sampled, so could certainly benefit by the creation of more pools with cover, although the steeper gradient in the reach may limit the amount of slow water habitat that can be created and maintained over time (currently, 69% of the reach is riffle habitat). This objective could be met by additional placement of wood to create additional pools with cover.

Conclusions/Recommendation

Future restoration work within the Elk Flats project reach should consider the valley-scale geomorphic setting to define project expectations and goals – especially those related to floodplain connectivity. The river flows against a valley wall (either left or right) throughout most of the reach which limits the amount of available floodplain to which connectivity can be restored. The downstream portion of the reach is a plane-bed rapid as the river is confined between the high (>10') left bank terrace and the right bank valley wall. This channel morphology limits the extent of channel/island formation in this portion of the reach and could pose issues to ELJ stability. Furthermore, the majority of the left bank floodplain is elevated high above the current water surface which further limits the feasibility of connection. The right bank floodplain terrace between RM 23 and RM 22.75 provides the greatest restoration opportunity – especially because it contains an 1120' long side channel that is currently engaged at the Q2 flow.

Restoration activities can provide benefits to habitat – especially by focusing on the limiting factors that the project is attempting to address (elevated fine sediment, low habitat diversity, and high water temperature). Habitat diversity is likely to increase following the restorative actions, however due to the lack of available floodplain and the channel slope, there is a limit to the degree of slow water habitat that can be created and proposed objectives should be scaled to what is achievable in the channel setting.

Camp 18

The Camp 18 project area is located directly upstream from Larson's Phase 2 between RM 22.6 and 21.1 along the South Fork Nooksack River. The first of three phases of the project was constructed in 2019 and the overall project intended to address the limiting factors of *Low Habitat Diversity* and *High Water Temperatures* through the placement of engineered log structures, engineered log riffles, whole trees, and riparian planting. The report details pre-project conditions based on 2017 topobathymetric LiDAR and 2018 field surveys. The main objectives of the project are:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Camp 18	1. Increase key habitat quantity and quality through primary pool creation, by creating up to six primary pool habitat units within five years through the placement of engineered logjam structures.	lack of key habitat and high water temperature
	2. Improve thermal refugia in areas of known cool water through primary pool creation, by creating at least six primary pool habitat units within five years, in areas of cool water refuge through the placement of ELJs.	high water temperature
	3. Increase off-channel rearing habitat by reconnecting floodplain and side channel through the addition of flow obstructions that deflect flows and raise local water elevations. Minimal side channel excavations may be considered to improve connectivity.	low habitat diversity

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
	4. Promote the development of stable hard points in the river channel to split flow, encourage side channel development and formation of forested islands.	low habitat diversity
	5. Promote bed aggradation and bed fining (reduction in median grain size) through reach-scale shear stress partitioning (accomplished by increasing hydraulic roughness within the channel), install log reinforced riffles, channel spanning log jams to aggrade the bed and reconnect floodplain.	low habitat diversity
	6. Use engineered wood placements to create stable hard-points (#4), increase hydraulic roughness (#5), and increase the spatial density of habitat complexity (#1 & 3) by increasing cumulative length of channel edge and the range of hydraulic and textural conditions within the channel (fast, slow, deep, shallow water and coarse to fine sediment in close proximity).	low habitat diversity

Reach Description

The Camp 18 project area is a high energy reach with a plane-bed morphology, a high degree of in-channel boulders, and an average slope of 0.0068 ft/ft (Figure 16 and Appendices B-H: Camp 18). The river is constrained between two high terraces (>20 ft above low flow water surface) from the upstream end at RM 22.6 to RM 22. The river abuts a high bank sediment source along the left bank near RM 21.75 where the river interacts with a glacial terrace. Another resistant high bank prevents further migration along the left bank near the downstream end of the reach at RM 21.4. The reach also contains poorly sorted sediment within gravel bars – particularly in the vicinity of the left bank sediment sources.

Figure 16. Downstream view of Camp 18 site near RM 22. Flow is into the page. Photo was taken on 6/27/18.

There is a narrow (~100 ft wide) inset floodplain along the right bank at the upper end of the reach between RM 22.3-22.0 with two small side channels that are predicted to be engaged at the Q1 flow level (Figure 17). The floodplain surface, however, does not get inundated at the Q2 flow level despite being 2-4 ft above the low flow water surface. This area is forested primarily with deciduous trees. Increasing connectivity to this surface through placement of ELJs is an objective of the project and will help increase habitat diversity within the project reach.

The right bank floodplain widens significantly between RM 22.0-21.5 to ~1000 ft wide at the inside of the meander bend. There are several side channel and relict channel features throughout this surface, which is 4-6’ above the low flow water surface. The primary side channel near RM 21.9 is engaged at the Q1 flow and several other channels and some of the floodplain surface is engaged at the Q2 flow level (Appendices F-G: Elk Flats). This terrace is also forested. There is a higher right bank floodplain terrace (4-10’ above the low flow water surface) at the downstream end of the reach and an inset floodplain feature along the left bank that is 2-4’ above the low flow water surface. Only a side channel within the left bank inset floodplain is predicted to be engaged at the Q2 flow level. Increasing connectivity to this floodplain surface and side channels is a primary objective of this project as it will increase habitat diversity and likely reduce water temperatures. The formation of an inset floodplain and engagement of the wide right bank floodplain terrace demonstrates that this reach has a high restorative potential because its geomorphic tendencies trend towards floodplain formation and connectivity.

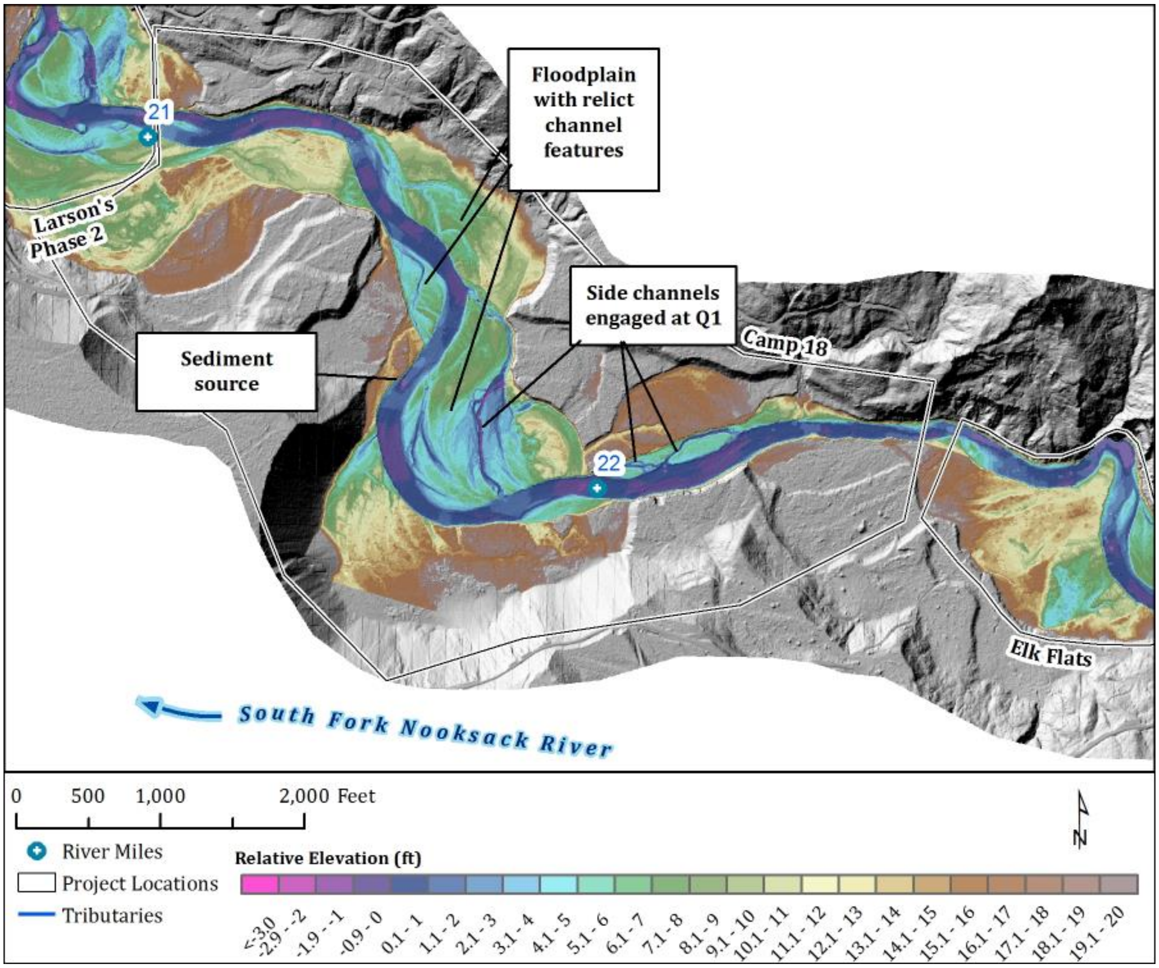


Figure 17. Relative elevation model (REM) of the Camp 18 Project Reach. The REM was developed using the 2017 Topobathymetric LiDAR DEM. Flow is to the left.

The Camp 18 reach has low habitat diversity and a lack of stable mid-channel wood. Pre-project data documented 3 logjams with an area of 4,549 ft^2. Habitat surveys were conducted in June 2018 and will be used to present the pre-project conditions.

In pre-project condition, the reach contained four total pools with an average residual depth of 4.9 ft and two primary pools (LNR Data 2018). The pools that were present were formed by a variety of sources – boulder, erosion resistant banks, and a tree stump. 93% of the reach was comprised of high-velocity channel units (riffle, run, and rapid) and only 7% were pools (Figure 18 and Figure 19). The channel unit distribution underscores the low habitat diversity within the reach pre-project – something that the restorative actions intend to address. The low habitat diversity is underscored by a low frequency of large wood with 3 log jams (2 jams/mile) mapped during pre-project conditions.

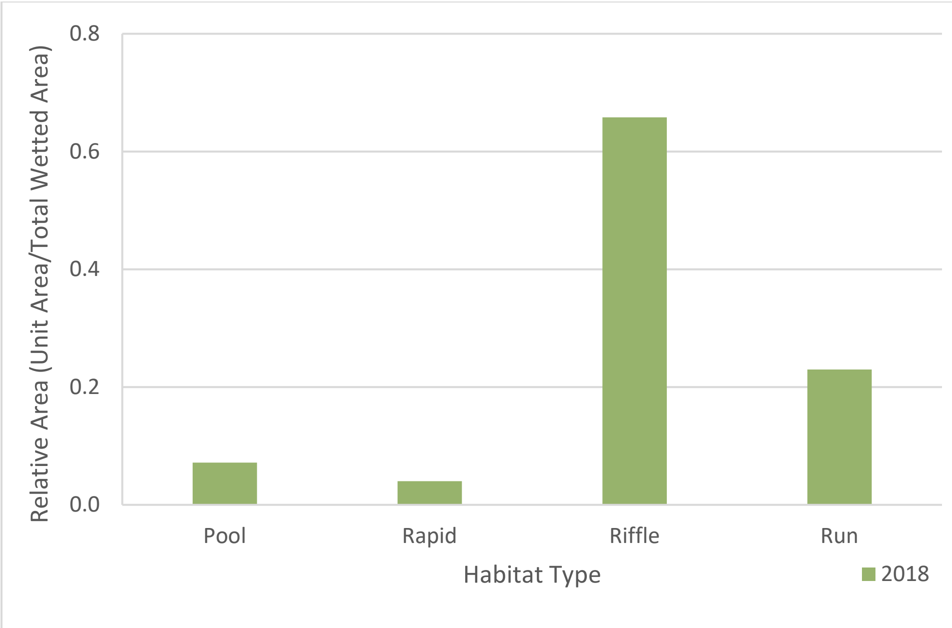


Figure 18. Channel unit distribution for the Camp 18 project reach from the 2005 field data.

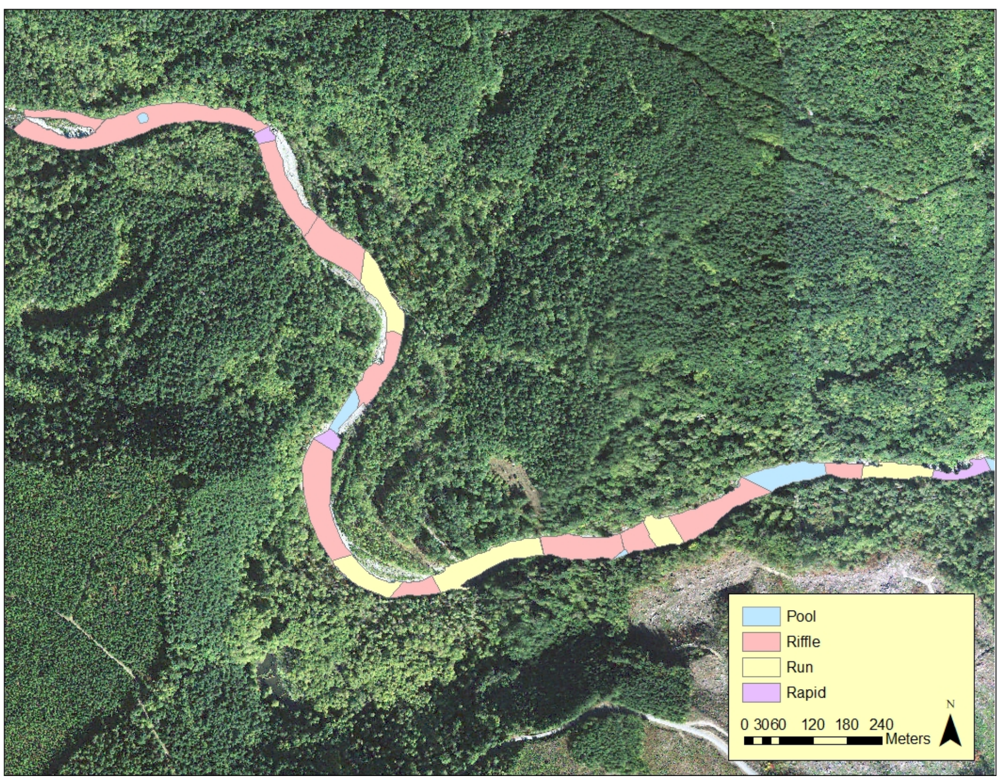


Figure 19. Channel unit map for the Camp 18 project reach from the 2018 field data. Aerial Imagery from 2017 NAIP.

Table 7. Pre-restoration (2018) pool parameters for the Camp 18 restoration project (Phase 1 construction was completed in 2019, but data are not presented here). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth ≥ 3.28 ft (1m)).

POOL PARAMETER	2018
Total Pool Count	4
Primary Pools	2
• Deep Pools	2
Secondary Pools	2
• Deep Pools	2

Fish observations in Camp 18 were largely dominated by *O. mykiss* with less than 5% suckers in the upper section and less than 5% Mountain Whitefish in the Phase 1 area (Figure 20 and Figure 21). Small numbers of Chinook juveniles (<10 fish) were also observed at the site. This site is at the upper extent of spawning for a small population of Chinook salmon, so there may be little opportunity for juveniles to populate the area. On average, 3% of all South Fork Nooksack Chinook redds have been detected in this project reach across all spawner survey years (1986, 1999 to 2018). The level of fish use observed at Camp 18 was relatively low, making this area a good choice for restoration because of the otherwise low-gradient morphology with plentiful floodplain connectivity opportunities and proximity to the high use spawning area just downstream in Larson's Phase 2. Surveys were conducted in August 2018, when some of the early Chinook juveniles have already outmigrated, although this is the same across all projects surveyed. Structure use was limited to several large boulders present in the reach (Figure 22 and Figure 23). Otherwise, observed fish were not associated with structure.

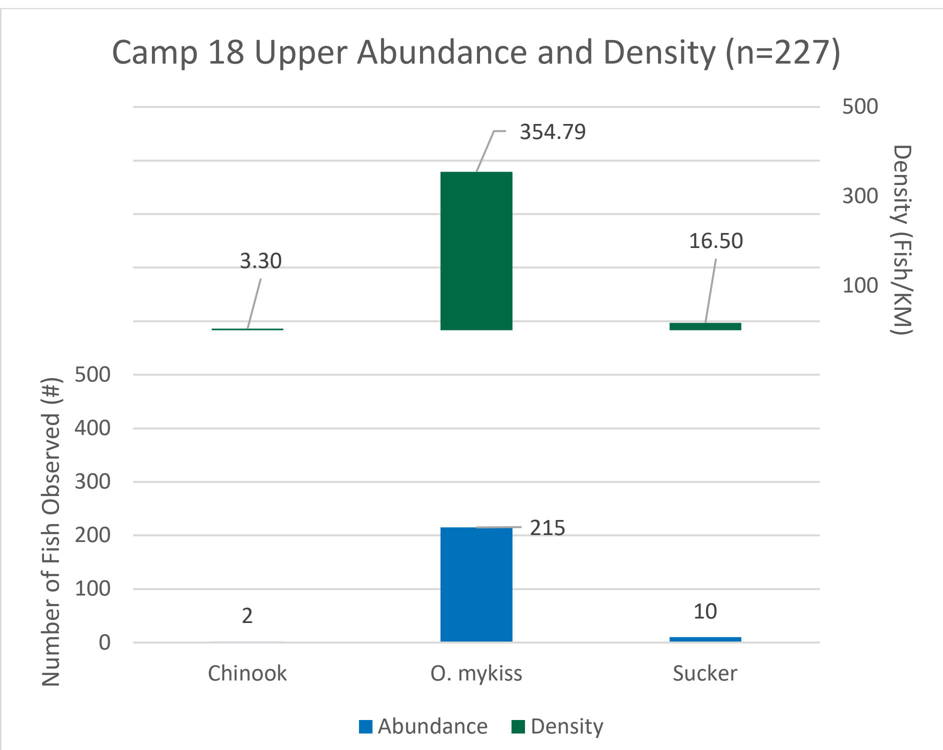


Figure 20. Snorkel survey results by species within the Camp 18 Upper project area (August 6, 2018).

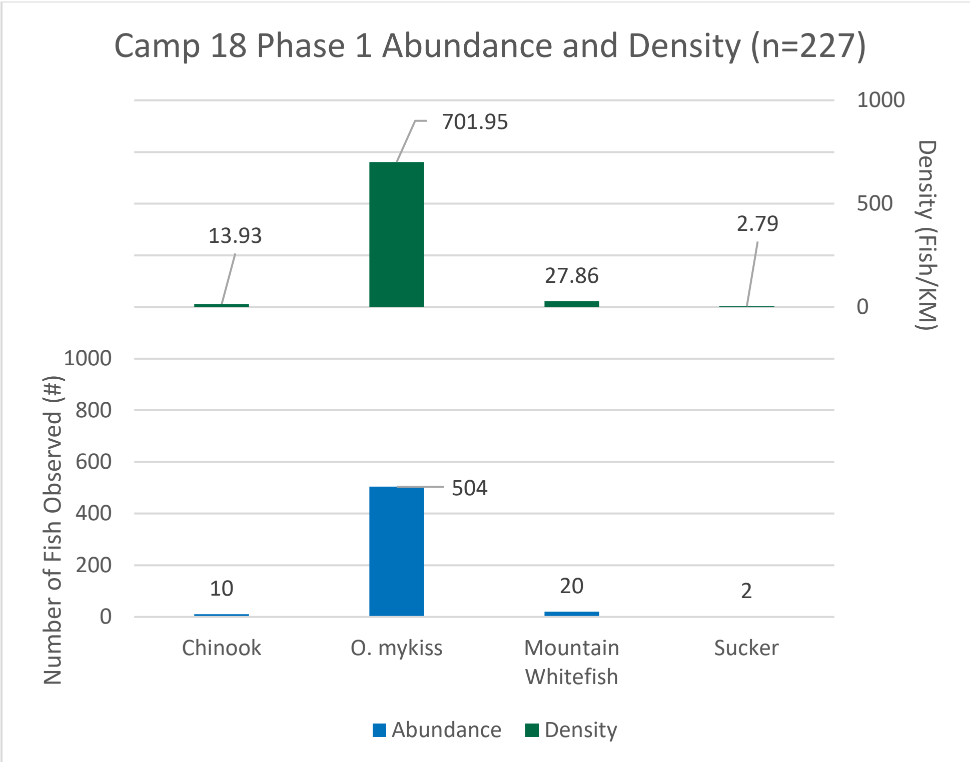


Figure 21. Snorkel survey results by species within the Camp 18 Phase 1 project area (August 7, 2018).

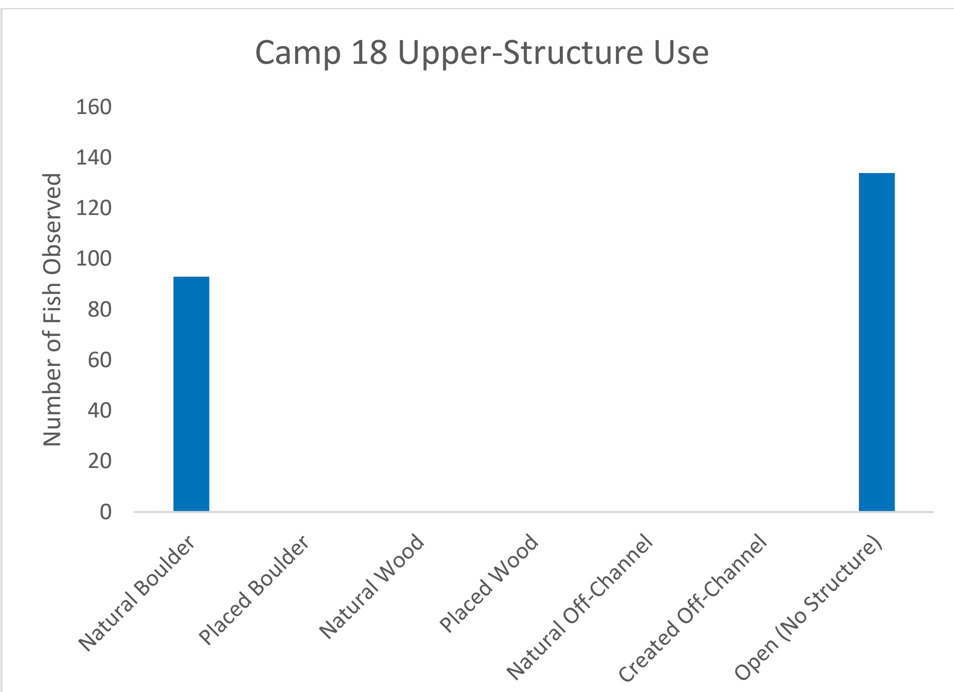


Figure 22. Observed structure use from the Camp 18 Upper project area (August 7, 2018).

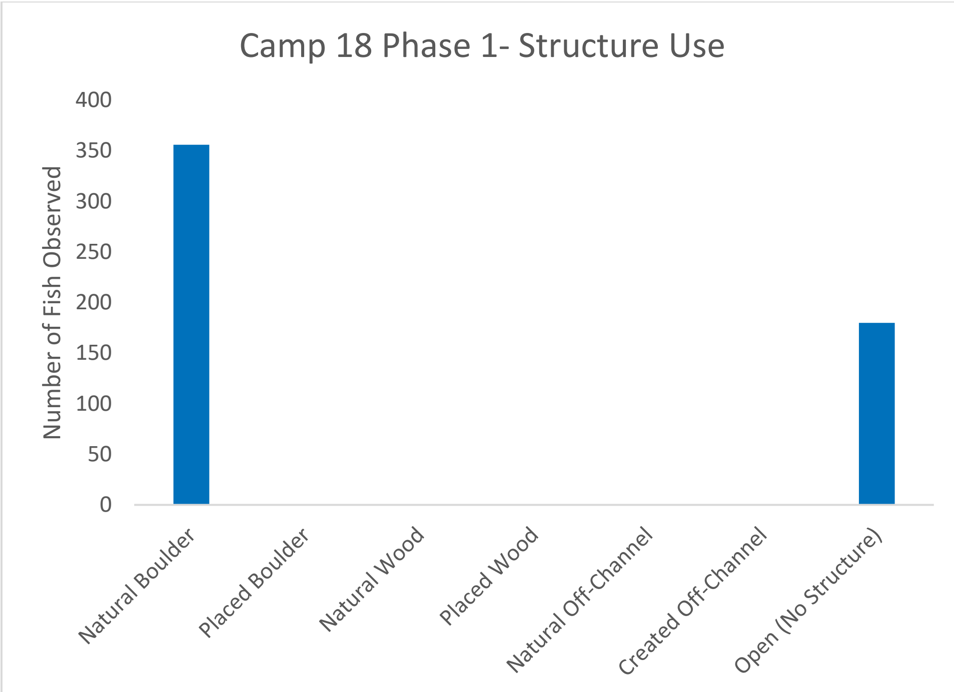


Figure 23. Observed structure use from the Camp 18 Phase 1 project area (August 7, 2018).

Monitoring Metrics

Camp 18 is currently in the preliminary design stage and thus, has no post-project data to evaluate project effectiveness. A discussion of each project metric follows.

Objective 1 – Increase key habitat quantity and quality through creating at least six primary pools within five years

In 2018, there were 2 primary pools in the Camp 18 project reach and 4 total pools. Adding an additional six pools is feasible in this reach; however, structures would need to be placed in the low flow channel main flow (not on the margins) and obstruct 50 to percent of the flow if primary pools are to be created.

Objective 2 – Improve thermal refugia in areas of known cool water by creating at least six primary pools within five years

Two primary pools were present in the Camp 18 reach, but they are not located in mapped cool water areas. There is a left bank tributary near river mile 21.7 that was mapped as a cold water refuge in 2002 FLIR data. Cold water refuge is defined as water that is 2°C colder than the mainstem flow (Torgersen et al. 2012). Effectiveness of pools in terms of providing potential thermal refuge can be increased, although the causes of thermal refuge are variable based on site specifics. Thermal refuge can be influenced by the depth of solar radiation penetration, isolation of water from flows that would cause mixing, and the difference between air temperature and water temperature (Ozaki 1994, Tate et al. 2006). Increasing depth in pools and providing pool habitat in areas separated from the mainstem flow could help increase the potential for thermal refuges to develop. Additionally, reviewing pool creation sites for cold water upwelling can also affect the ability to create thermal refuge (J. Helfield, pers. comm, 2019). The objectives of creating primary pools for spawner holding and the creation of thermal refuge could be separated so that each could be achieved. Since primary pools, by definition, span more than half the channel width, separating them from the main flow enough to maintain a temperature difference to qualify as a thermal refuge may not be attainable. Cold water refuges in the reach include seeps (RM 21.5) and tributaries (RMs 21.7, 21.8, 21.9), and an unclassified refuge at RM 22.1 (FLIR data, 2002, unpublished). These areas should be investigated for the creation of specific thermal refuges.

Objective 3 – Increase off-channel rearing habitat by reconnecting the floodplain and side channels

There is currently 2,780 ft of side channel engaged during the Q1 flow and 4,970 ft of side channel engaged during the Q2 flow. There is overbank flow from the longest of these side channels (right bank - RM 22) that begins to inundate the floodplain surface. The current degree of side channel and floodplain connectivity demonstrates the feasibility of increasing inundation frequency and duration through restorative actions, via the addition of flow obstructions such as logjams. Including a quantified target for this objective as each project phase is developed will make determination of achievement more apparent.

Objective 4 – Promote the development of stable hard points in the river channel

Pre-project data show that there were 3 logjams in the project with an area of 4,540 ft^2. The development of floodplain habitat and side channels in this reach, even without the presence of placed ELJs, demonstrates the feasibility for developing further channel and island features if more hard-points are added. However, due to the steep, high energy morphology of the reach, logjams must be large and stable enough to exert geomorphic influence for this to occur. Including a quantified target in this objective would make determination of achievement more apparent.

Objective 5 – Promote bed aggradation and bed fining

The median grain size measured within the reach from one pebble count on a mid-channel bar at the upstream end of the reach is 53 mm under current conditions (NSD field survey 2018). The pebble count contained a broad distribution of sediment sizes. No other specific sediment data were reported in the 2018-2019 field data. Further sediment characterization (Wolman, 1954) before project implementation is necessary to adequately assess current sediment conditions and should be included in any future habitat surveys or assessments of this reach. Sediment distributions should also be monitored using the same methods following restorative actions to monitor changes and detect if bed fining is occurring. There is likely enough sediment supply (e.g., high bank sediment sources) to aggrade the channel bed with log structures, and sediment storage at other projects (e.g., Larson's 2) has been achieved with log riffle structures. A quantified range for idealized substrate distribution would be helpful in terms of both design specifications for shear stress and determination of objective achievement.

Objective 6 – Increase spatial density of habitat complexity by increasing the range of hydraulic and textural conditions within the channel

The existing distribution of channel units is dominated by fast velocity habitat types such as riffles, runs, and rapids (Figure 18). Riffles currently compose 66% of the reach by area. A post-construction habitat survey should be conducted using the same methods as the 2018 habitat survey to monitor project effectiveness in increasing habitat area, the diversity of channel units (i.e. habitat complexity) and side channel formation. A clear, quantified definition of habitat complexity is needed in order to detect change in this metric and a clearer description of "hydraulic textural conditions" and the desired range should also be included in order to assess objective achievement.

Conclusions/Recommendation

The restoration objectives for the Camp 18 project are achievable within the valley-scale geomorphic context of the reach. The ability of the river to form and maintain floodplains and multi-threaded channel networks is demonstrated by the floodplain surfaces and side channels currently present within the reach. Despite the general lack of stable large wood, several side channels are engaged between the Q1-Q2 flow levels. The placement of large stable engineered logjams will further increase the frequency and duration of floodplain/side channel engagement, which will help the project achieve its objectives. Due to the relatively steep/high energy nature of the reach however, the obstructions must be large enough to have a significant longitudinal and lateral effect on hydraulic cs. Current habitat conditions can be improved, as they are currently dominated by simple, fast velocity channel units. Additional quantification and definitions should be added to objectives to make determination of achievement more apparent.

Larson's Phase 1 and Phase 2

The Larson's Phase 1 and Phase 2 projects are located directly downstream from the Camp 18 project reach and extend from RM 21.1 to 19.7 along the Upper South Fork Nooksack River. The Larson's Phase 1 project extended downstream of Larson's Bridge between RM 19.8 and 20.6 and was constructed in 2001. The Larson's Phase 2 project revisited the Phase 1 project to address additional habitat limitations in the reach and expand the area treated between RM 19.7 and 21.1. This report primarily focuses on the reach as it currently stands and addresses the Phase 1 actions to the extent possible, as the changes to channel morphology from the Phase 1 project are somewhat masked by the more recent work.

The Larson's Phase 1 project (also known as Larson's Bridge) included the construction of 6 engineered log jams, one of which was a 130m wood revetment placed at the toe of a landslide in the reach. This was one of the first large instream projects in the Nooksack watershed and was constructed in 2001. It was intended to address the limiting factors of *Low Habitat Diversity* and *Elevated fine sediment*. The main project objectives were identified in Maudlin and Coe (2011) and Maudlin (2001):

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Larson's Phase 1 (Larson's Bridge)	1. Relocate the thalweg away from the landslide.	elevated fine sediment
	2. Increase pool frequency, residual depth, and cover.	lack of key habitat and high water temperature
	3. Increase channel roughness.	N/A
	4. Increase secondary channel length.	low habitat diversity
	5. Reduce fine sediment originating in the reach.	elevated fine sediment
	6. Increase abundance of adult salmonids	N/A

The Phase 2 project was completed in 2014-2015 and was intended to address the limiting factors of *Low Habitat Diversity* and *High Water Temperature* through the placement of ELJs, engineered log riffles, and whole trees within the main channel, side channels, and floodplain areas. At the time of construction, the project included the largest number and area of ELJs constructed in the main flow of the channel with structures that blocked a majority of the flow (over 50%). The engineered log riffles retained sediment across the entire channel in some places – especially after additional wood wracked on the structure. The main objectives of the project were:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Larson's Phase 2	1. Create 3 thermal refuge areas for migrating salmonids by 2016 by co-locating 3 wood structures (and resultant pools) with known cool-water inputs.	high water temperature
	2. Enhance activation of 1.33 miles of side channel at the 1-year flow and above by 2020 through placement of wood structures in the mainstem that promote bed aggradation and local water surface rise.	low habitat diversity
	3. Enhance activation of 13.8 acres of floodplain at the 1-year flow and above by 2020 through placement of wood structures that promote bed aggradation and local water surface rise.	low habitat diversity
	4. Create 13 primary pool habitat units by 2016 through placement of wood structures.	low habitat diversity, lack of key habitat and high water temperature
	5. Reestablish an anabranching channel planform by 2020 by improving the stability of up to 5 existing mid-channel islands using wood structures.	low habitat diversity

Reach Description

The Larson's Phase 1 project extended downstream of Larson's bridge between RM 19.8 and 20.6 and has been described as a single thread channel (Maudlin 2001). At the time of a field survey in 2011, the right bank low-flow side channel at the upstream end of the project (RM 20.6) had been disconnected due to sediment deposition at the mouth (Maudlin and Coe 2011) and has remained disconnected. The logjam (#2) constructed in this side channel is also isolated from flow and is overgrown. Of the six log jams, 4 had primary pools associated with them at the time of the 2011 field survey. A large pool (11.2 ft residual depth and 13.8 ft maximum depth) was noted under Logjam #3 at the site, although some of the key pieces in this jam were noted as missing (Maudlin and Coe 2011). Logjam #3 had also formed a gravel tail out below the pool that was suitable for spawning. The landslide has been stabilized by the long log revetment (Logjam #5), which during the 2011 surveys, had filled the basin behind the structure and was revegetating with deciduous trees. At the time of the 2011 surveys, the structure had been deeply undercut by the river, creating a very large pool (21,108 m^2) and providing the greatest extent of woody cover in the South Fork (Maudlin and Coe 2011). Five of six structures showed signs of damage during the 2011 survey, but all were deemed functional.

The Larson's Phase 2 project area extends beyond the Phase 1 project from RM 19.7 to 21.1 and is separated by the Larson's bridge (Figure 25). The bridge is built on resistant geologic material and helps to create differences in geomorphic conditions both up and downstream (NSD, 2013). Upper Larson's (above the bridge) contains a high energy plane-bed morphology similar to the downstream end of

Camp 18. The river flows along a resistant geologic material on the left bank near RM 20.75 which creates a deep pool. The river then abuts bedrock on the right bank directly upstream from the bridge where there is another deep, primary pool. The reach contains 4 main channel ELJs and two ELJs within a right bank side channel. The main channel ELJs are aggrading sediment, creating scour pools, and facilitating flow into a right bank side channel which is inundated at the Q1 flow level.

In the lower Larson's Phase 2 reach, the morphology shifts to a combination of a single-threaded pool-riffle and a multi-threaded braided planform (Figure 24 and Appendices B-H: Larson's). The river is single threaded for the first 1,500 ft of river channel directly downstream of the bridge. At that point, the river shifts to a braided planform with multiple channels flowing around islands that were established by ELJs (Figure 25 and Figure 29). The braided planform continues downstream throughout the reach and is fed by Plumbago Creek near RM 20. Downstream of this, there is a three-way flow split that is mediated by an ELJ occurring near RM 19.75, where flow is directed into secondary channels on both banks. Both of these channels were inundated during our June 2018 field visit (450 cfs USGS Saxon Bridge Gage), but not during September 2019 low-flow habitat surveys (85 cfs). Throughout the reach, the log structures are facilitating sediment deposition and sorting, both up and downstream of the bridge.

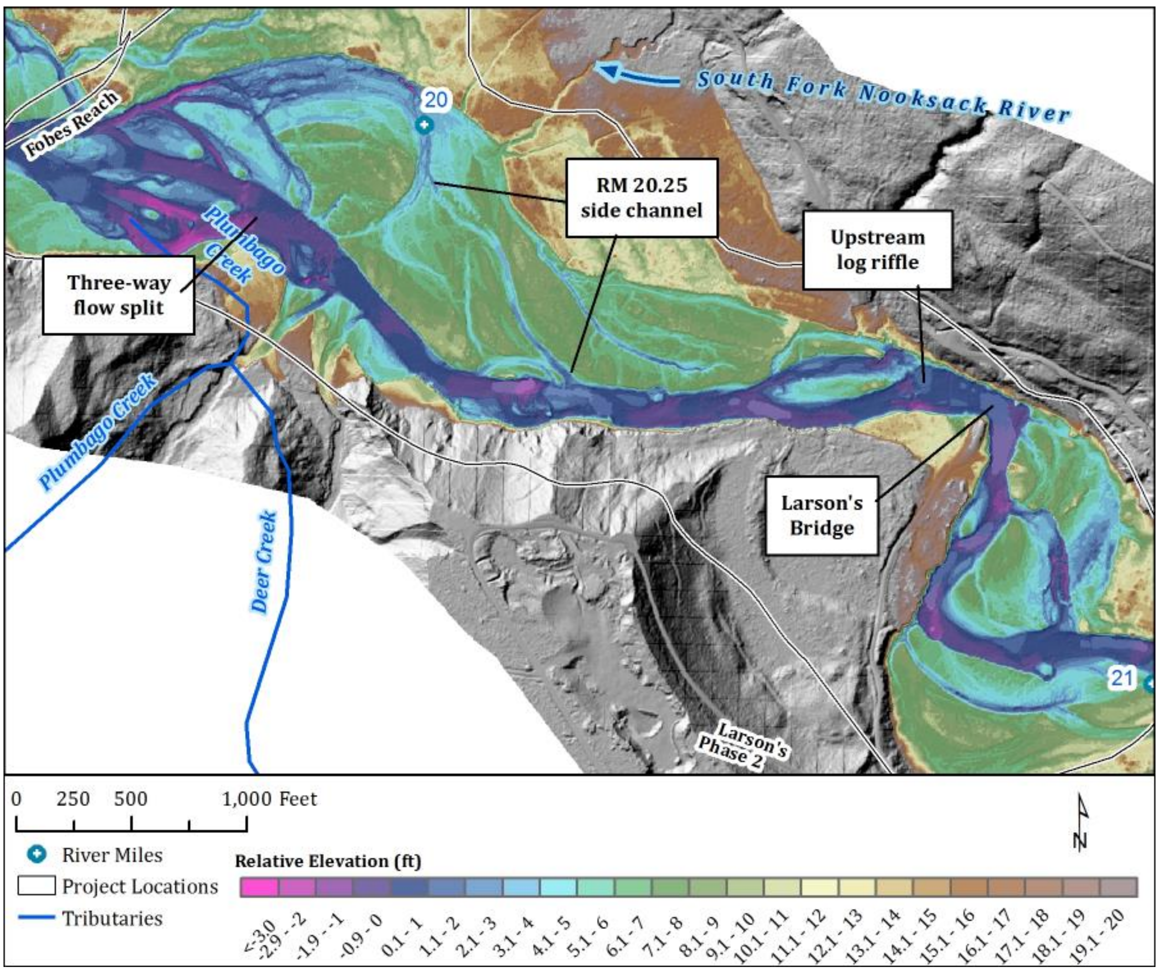


Figure 24. Relative elevation model (REM) for the Larson's Phase 1 and Phase 2 reach on the Upper South Fork Nooksack River below Larson's bridge. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

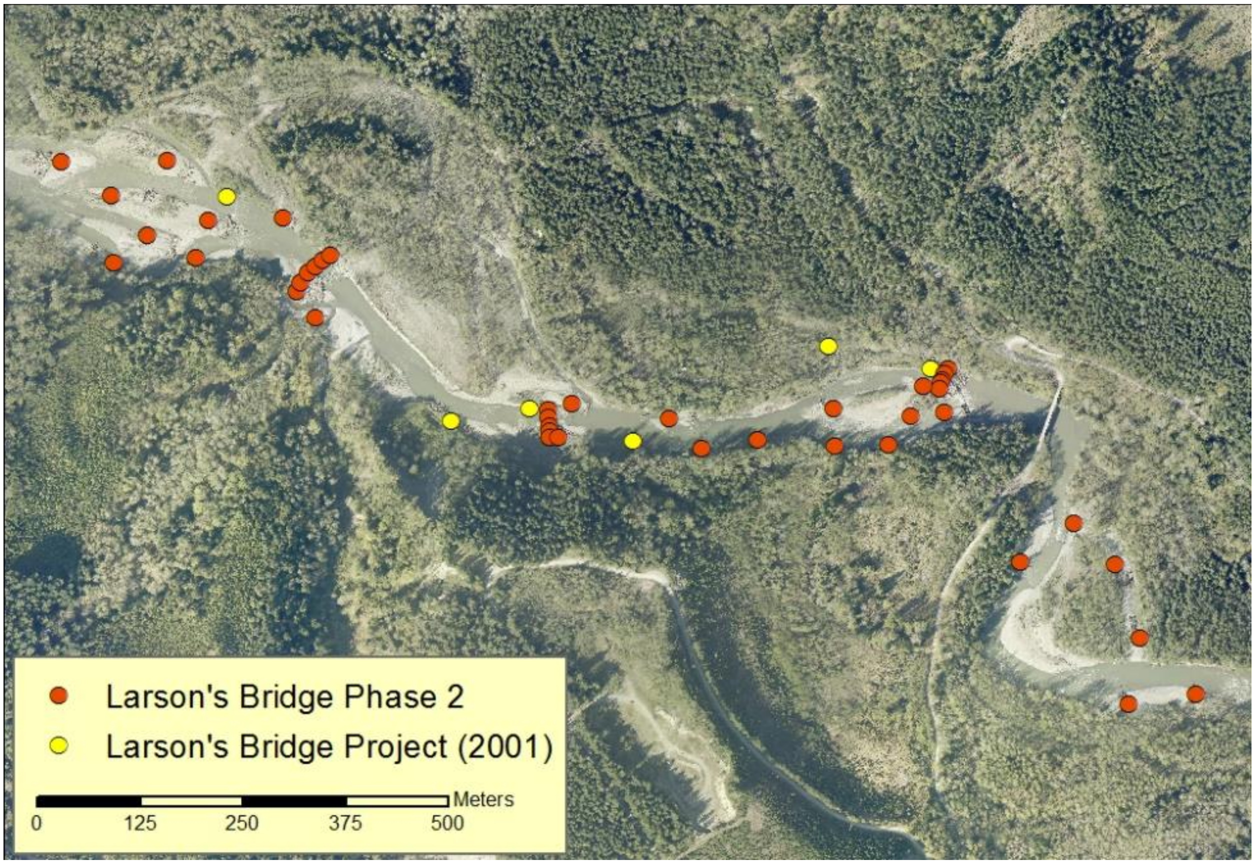


Figure 25. ELJ's placed in Larson's Phase 1 (Larson's Bridge) and Phase 2 projects (Source: NT and LT 2019)

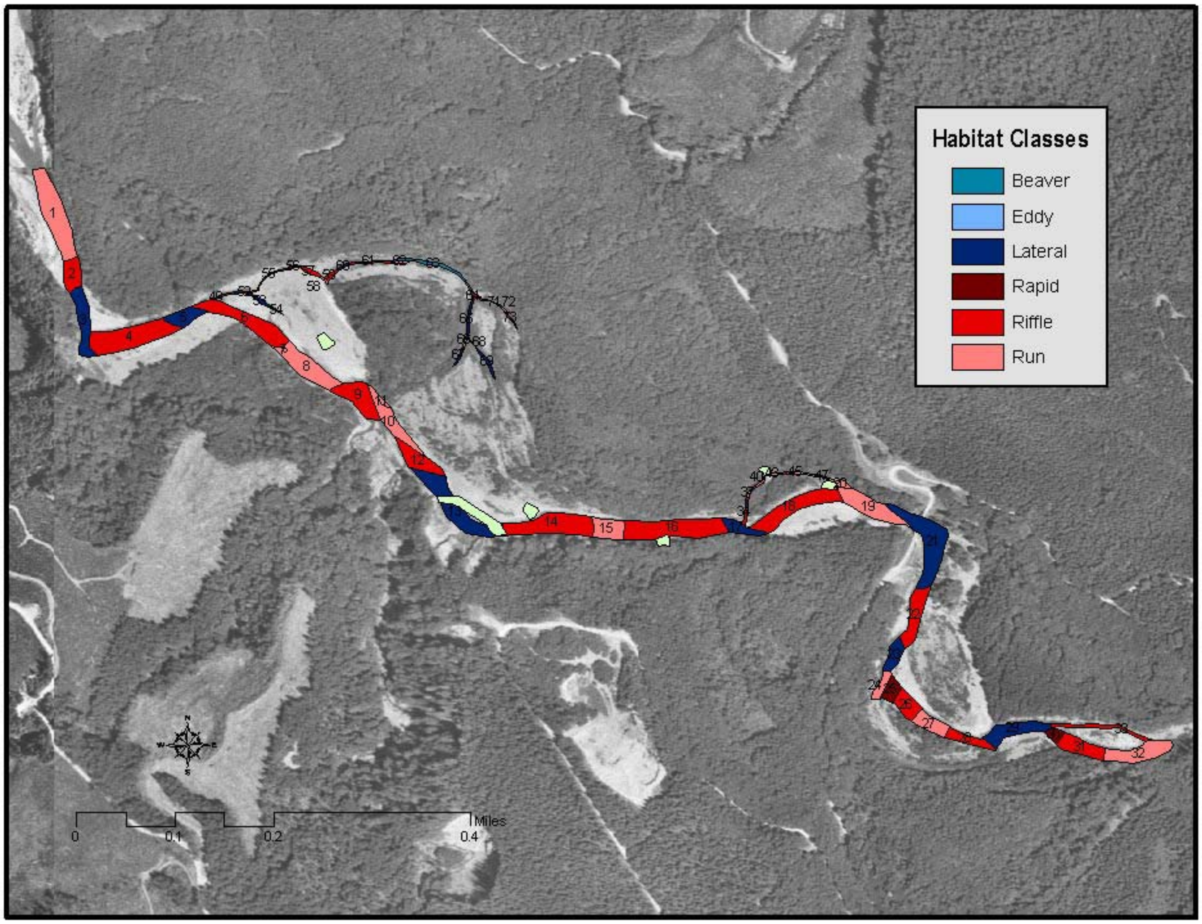


Figure 26. 2000 habitat mapping in the Larson's Bridge Reach (pre-project for Phase 1) (Source: Maudlin 2001).

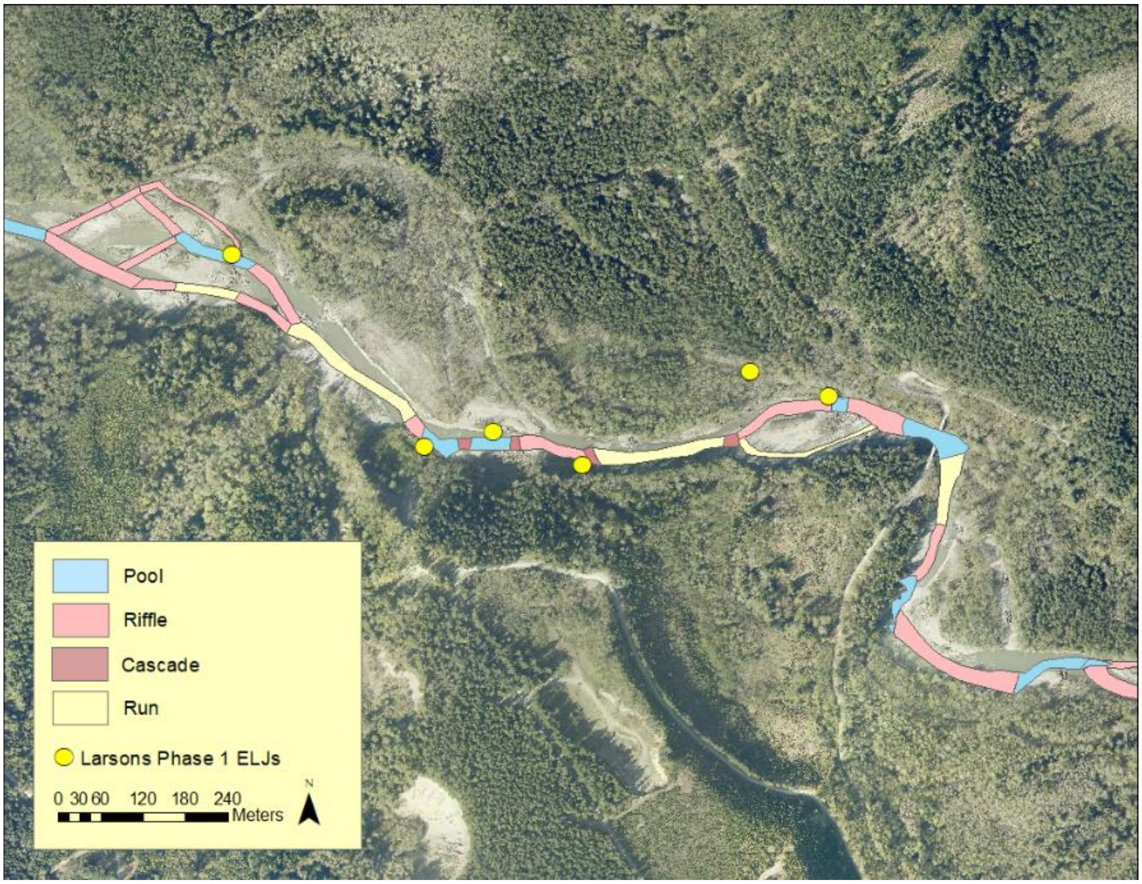


Figure 27. 2005 habitat mapping in the Larson's Phase 1 and 2 Project areas (LNR 2005 data, photo from 2016, Source: NNR and LNR 2019).

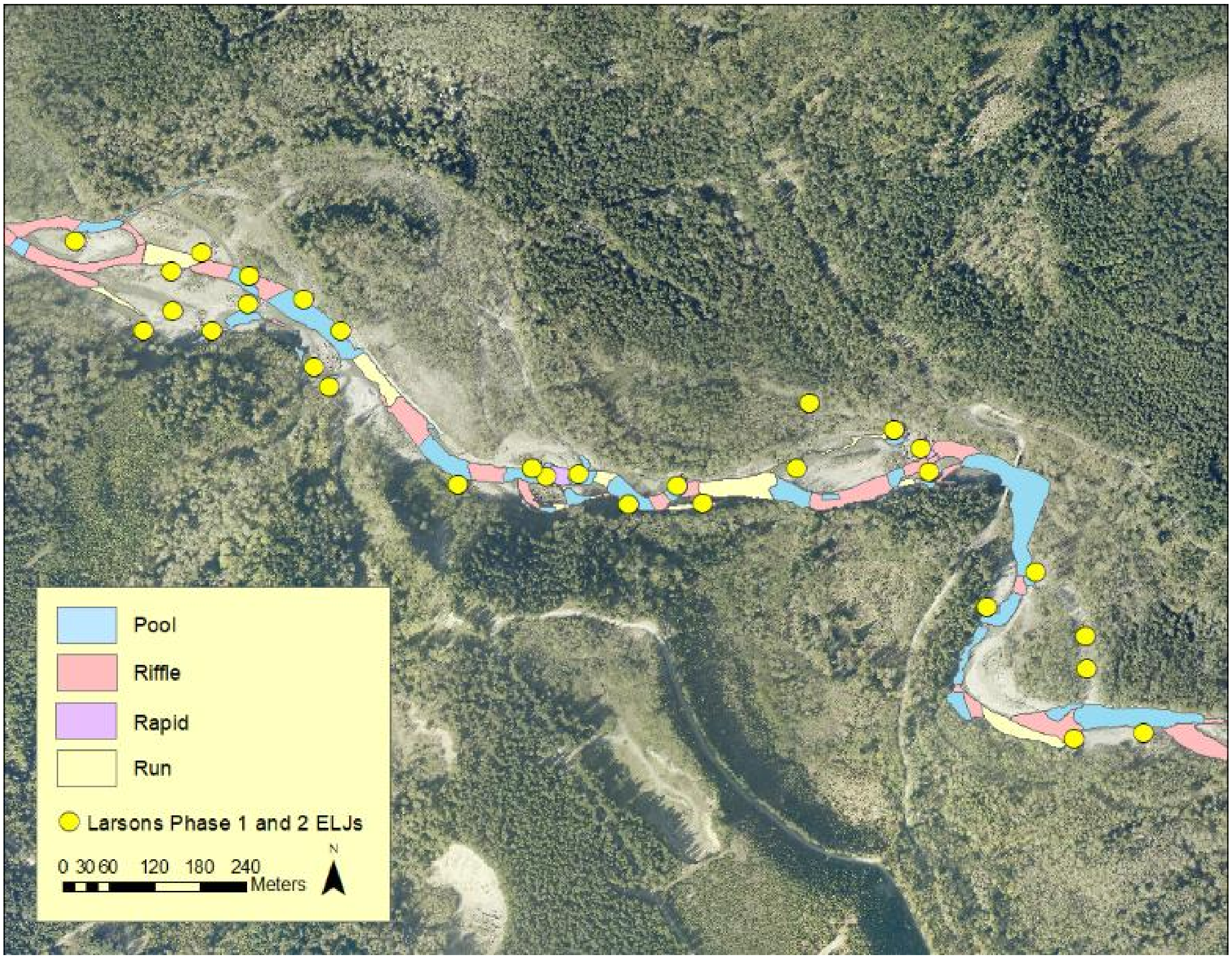


Figure 28. 2019 habitat mapping in the Larson's Phase 1 and 2 Project area (LNR 2019 data, photo from 2016).

Figure 29. Downstream view near RM 20.5. Log structures are facilitating multi-threaded channel planform. Flow is left to right. Photo was taken on 6/26/18.

There are three main side channels that are inundated at the Q1 flow level within the lower Larson's Phase 2 reach (Appendices F-G: Larson's). These channels are distinguished from the multi-threaded secondary channels described above in that they contain small portions of the overall flow and generally flow through floodplain areas. There is a right bank side channel directly behind the most upstream engineered log riffle that is not connected during low flows, but is inundated at Q1. These flows, however, may not be very deep and could be over-represented by the hydraulic model[1] as there was reed canary grass present in the channel during the site visit which indicates infrequent flows capable of scouring vegetation. There is another right bank side channel near RM 20.25 that flows northward into the right floodplain area. This side channel is ~3,300 ft long and has an open inlet. Field observations indicate that 2-3' of scour has occurred along the banks which demonstrate that the channel is frequently inundated. Field observations of the inlet, which is mediated by an ELJ, indicate that the channel is inundated around 800 cfs (Figure 30). The hydraulic model confirms that there is 2-3 ft of depth during the Q1 flow. This channel flows into a secondary channel downstream from the three-way flow split. Overbank flow from this channel is predicted at the Q2 flow level which spreads out across

[1] The bare-earth topobathymetric LiDAR DEM filters out most of the large logjams present at the mouth of this channel. Because of this, a large portion of the obstruction is not present in the hydraulic model and thus, flows may be over-represented in this area. The logjam is visible in the logjam LiDAR analysis.

the broader floodplain surface. The third side channel occurs along the right bank near RM 19.6 at the downstream portion of the reach and flows into the Fobes project reach downstream. This channel is also predicted to be inundated at the Q1 flow.

Figure 30. Inlet of the RM 20.25 right bank side channel in the Larson's phase 2 project reach. The photo is looking downstream into the side channel and was taken on 6/26/18. Note the ponded water and 2-3' of scour along the banks. Both indicate frequent inundation.

The Larson's Phase 2 reach has 17 jams/mile and the largest logjam area (89,561 ft^2) of all of the project reaches in the Upper South Fork. While the intensive restorative actions added a significant quantity of large wood into the system, including channel spanning log riffles and numerous ELJs, the structures have also been recruiting naturally occurring large wood and growing larger (sometimes significantly). As an example, the upstream log riffle has grown ~10-15' higher through racking in material that has floated from upstream (Figure 31).

Figure 31. ELJ at Larson's Phase 2 showing wood racking on jam.

Other downstream jams have also recruited natural wood which has increased their influence on geomorphic processes within the reach (Figure 29). As described above, this wood is helping to aggrade the channel bed, inundate side channels, form islands, and sort sediment – all of which addresses the limiting factors in the reach. This is exemplified by the channel unit distribution which shows a lower amount of fast water units than Camp 18 and a higher proportion of pools (Figure 32 and Figure 33 and Table 8). The relative pool area in the project reach has increased by ~136% compared to 2005 conditions (Figure 33).

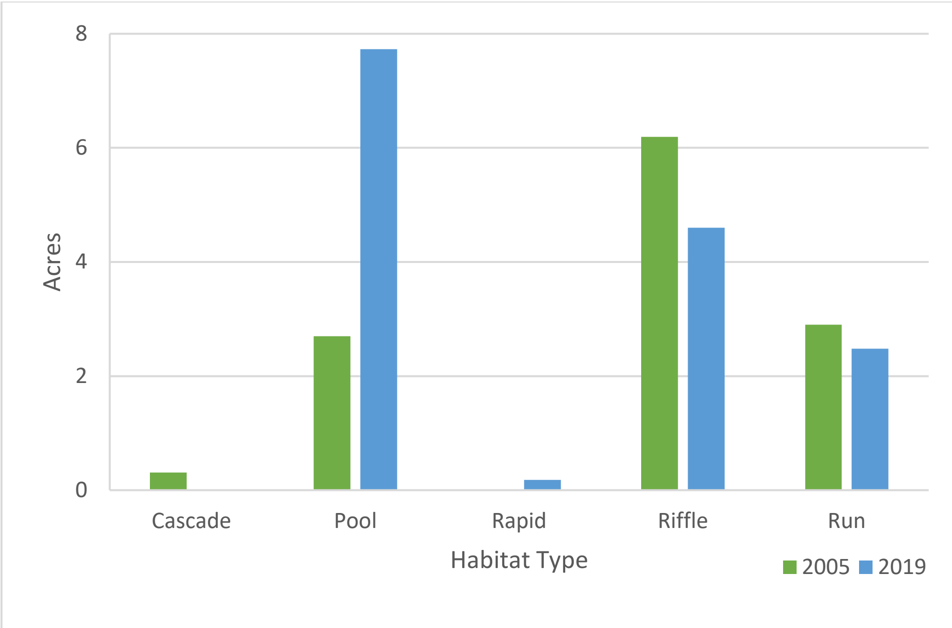


Figure 32. Channel unit area for the Larson's Phase 2 project reach from 2005 and 2019 habitat surveys.

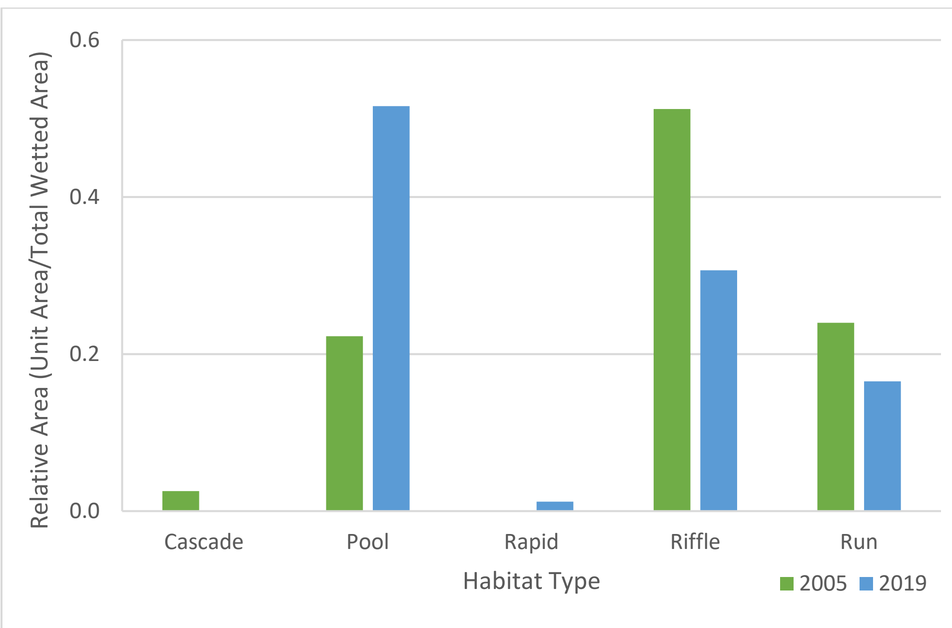


Figure 33. Channel unit distribution for the Larson's Phase 2 project reach. Channel units were estimated using field data from 2005 and 2019.

Table 8. Pre-restoration (2005) and post-restoration (2019) pool parameters for Larson's Phase 2 restoration project (construction completed in 2014-2015). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth $\geq$ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	9	37 (18)
Primary Pools (ELJ)	8	19 (9)
• Deep Pools (ELJ)	6	13 (8)
Secondary Pools (ELJ)	1	15 (8)
• Deep Pools (ELJ)	0	5 (5)
Isolated Pools (ELJ)	0	3(1)
• Deep Pools	0	1(0)

Fish observation results at Larson's Phase 2 are markedly different from other reaches in terms of the proportion of Chinook and coho observed in the project area (Figure 34). Of over 3,300 fish observed at the site, 8.9% (300 fish) were juvenile Chinook and 15% (505 fish) were juvenile coho. The reach also supports large numbers of *O. mykiss* (2,482 fish), with minimal numbers of sucker or Mountain Whitefish. The increased mid channel cover, increased edge habitat, and slower velocity habitats with cover may influence these observations and the higher numbers of fish using this project area. This area is also a core spawning area for Chinook, increasing the likelihood of juvenile use. During the snorkel survey, nearly 75% of Chinook observed were associated with wood, in both side channel and main channel habitat, and wood had the highest level of structure use in Larson's (Figure 35). Larson's Phase 2 had the highest wood area of all the projects. Larson's had nearly 50% of all of the Chinook observed during the juvenile survey, and had the highest density of Chinook across all projects, which could be related to high quality habitat and a high level of use by spawners (Figure 36). Spawning use also appears to have increased following restoration. In the three years before restoration (2011-2013), 110 redds were found in the reach, whereas in the three years after restoration (2016-2018), 231 redds were found. This increase can be attributed to both the early success of the South Fork Nooksack Chinook Rescue Program resulting in more Chinook spawners in the South Fork in recent years and habitat uplift in the project area. LNR Fisheries Biologist, Donald Kruse, has reported increased bed aggradation, increased spawning area and increased number of redds upstream of the channel spanning logjams since restoration (*personal communication, 2018*).

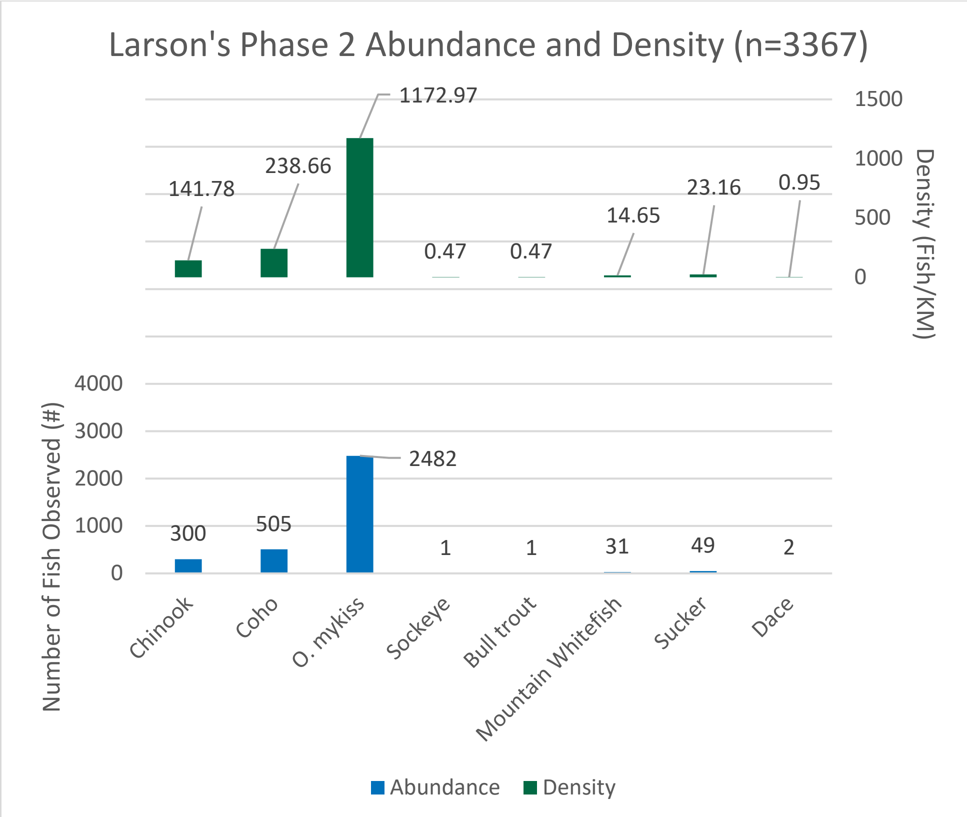


Figure 34. Snorkel survey data from the Larson's project area (August 7, 2018).

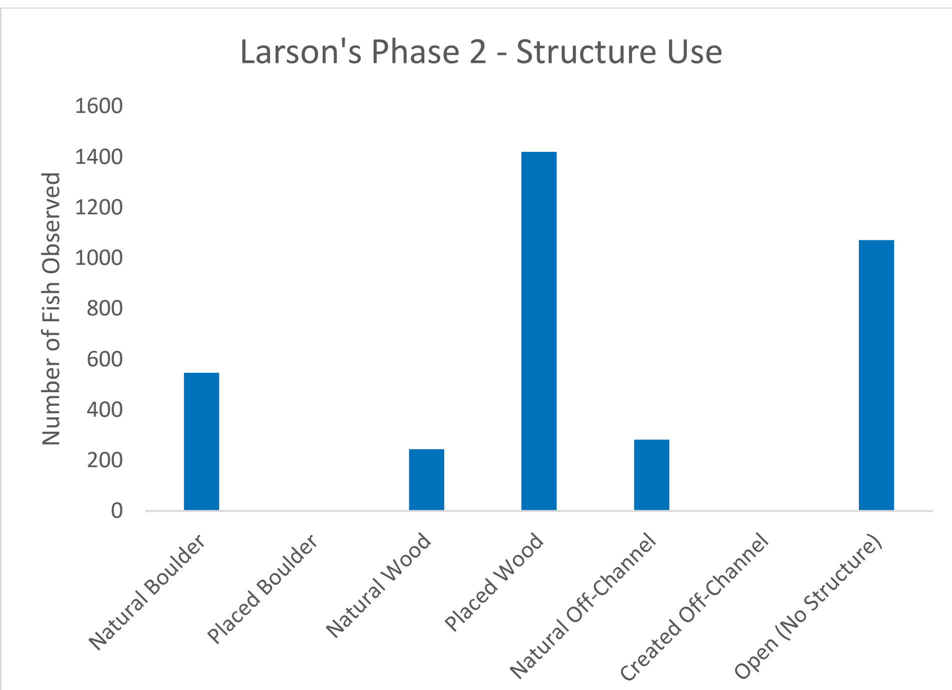


Figure 35. Observed structure use from the Larson's project area (August 7, 2018).

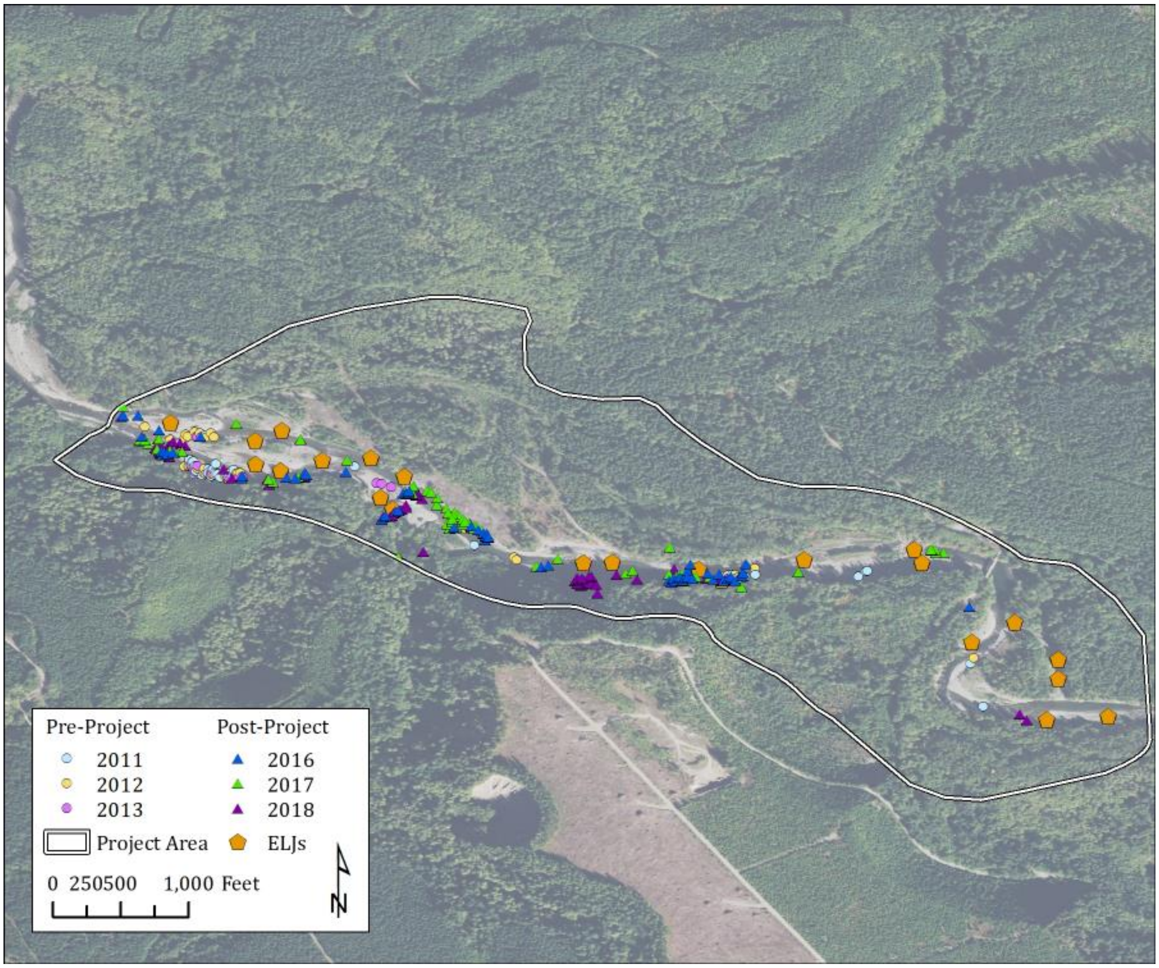


Figure 36. Chinook redds at Larson's Phase 2 before and after restoration. Years during construction (2014-2015) not shown. Aerial imagery from 2017 USDA NAIP.

Monitoring Metrics

Larson's Phase 1

Larson's Phase 1 was completed in 2001. Pre-project descriptions and data are found in Maudlin (2001) although data collection methods and summaries may differ from later collection efforts.

Objective 1- Relocate the thalweg away from the landslide

This objective has been met. The landslide was estimated to have delivered about 210,000 cubic yards of sediment to the South Fork Nooksack between 1995 and 1998 (Abbe 1999). As of 2005, the river thalweg was isolated from the landslide and sediment from the landslide was being contained behind the revetment (Figure 37).

Figure 37. Sediment storage behind revetment in Larson's Phase 1 (Source: Maudlin 2005).

Objective 2- Increase pool frequency, residual depth and cover

This objective has been partially met by the project implementation. The habitat mapping from 2000 (Maudlin 2001), 2002 (Maudlin 2005) and 2005 doesn't show an increase in the number of pools over that time frame. There were seven pools mapped in the reach at all three time periods. However, Maudlin (2005) noted that new pools were created in the vicinity of Logjams 1, 3, and 4 where there had previously been no pools, and that primary pools were formed at four of six placed logjams (Maudlin and Coe 2011). Scour near Logjams 5 and 6 has extended the pool area and added cover (Maudlin 2005). Prior to project construction in 2001, the average residual depth in the reach was 6.0 feet in 2000 (Maudlin 2005). Post-construction, the residual depth was 5.5 feet in 2002, 3.87 ft in 2005, and increased to 7.6 ft in 2011 (Maudlin 2005; Maudlin and Coe 2011).

Objective 3 – Increase channel roughness

Modest increases in woody cover were noted in the Maudlin (2005) report for Larson's Phase 1. In 2000, it was noted that the pool cover was provided by bedrock for the 7 pools in the reach. By 2002, there was one pool that included large wood as cover and a second with cobbles as cover. Each of the logjams were interacting with the low-flow channel in the 2002 survey (Maudlin 2005). In 2011, five of the 6 ELJ-formed pools had a total logjam cover area of 7,050 square feet interacting with the wetted channel.

Roughness was evaluated using bedform variation measures (i.e. the number and size of pools and riffles through the reach) and the amount of wood interacting with the channel. The sum of residuals was identified in Maudlin (2005) as the measure for the bedform variation and this measure increased from 1998 (1.44) to 2002 (1.67) to 2004 (1.93). It was also noted that the amount of wood interacting with the low flow channel increased from a single piece to six log jams that were created by the project.

Objective 4 – Increase secondary channel length

This objective was partially met. Changes in side channel and main channel length were measured using a plan view map of the channels, discharge measurements at multiple channels, cross-sections and a longitudinal profile of the main channel. Mainstem channel length was measured at 8,780 ft in 2000 and 8,600 ft in 2002, showing a slight reduction in channel length. This change was attributed to the construction of Logjam 5, which cut off the meander bend adjacent to the landslide. Further, floodplain habitat and side channels were mapped in 2000 and 2002 and no increase in wetted habitat was found at 300 cfs (Maudlin 2005). At higher flows (up to 430 cfs), the floodplain channel behind Logjam 2 connected 1,750 ft of rearing habitat to the intermittent off-channel areas further downstream, but as of 2002 sediment was building at the mouth of the channel, which may have limited the availability of this habitat. Braided channel length was noted as increasing by 1,650 feet downstream of Logjams 5 and 6 (Maudlin 2005, NNR and LNR 2019) (Appendix C: Larson's).

Objective 5- Reduce fine sediment originating in the reach

Minimal data are available regarding sediment changes as a result of the project. Maudlin (2005) did not note reductions of fine sediment passing through the reach as measured by pebble counts and embeddedness, however there is evidence that the landslide input has been contained by the revetment. During 2011 field surveys, the landslide was revegetating with deciduous trees and based on aerial photo review in 2019, the lower slopes are revegetated, although the slide continues to fail (Maudlin and Coe 2011, NIT and LNR 2020).

Objective 6- Increase abundance of adult salmonids

Consistent use by spawners was noted in the reach post-construction and the percent of spawners using the project area as compared to the basin also consistent, averaging 24% across all years. Maudlin (2005) noted a composite count of 39 redds in the reach before construction (two data years) as compared to 79 redds after construction (two data years), although increases were noted throughout the South Fork Nooksack during those years. Spawner data from LNR showed 55 redds counted in 1999-2000, and 68 counted in 2002-2003. As a percent of the total composite redds across the South Fork Nooksack, the Larson's Phase 1 Reach included an average of 14% in 1986, 1999 and 2000 and an average of 11% in 2002-2018 (Appendix H). Although these results are not statistically significant, they do point towards at least relatively consistent use after project implementation. Spawner distribution maps show increased use at the gravel bars formed near Logjam 6 (Figure 38, Appendix C- Larsons). During 2011 field surveys, Maudlin and Coe (2011) documented development of a broad gravel tail-out at the pool formed by Logjam 3 that appeared suitable for spawning and over the past five years, this location has become a high use spawning area. In addition, juvenile snorkel surveys completed in 2018 found nearly 50% of all Chinook in the Upper South Fork observed were in the Larson's Reach.

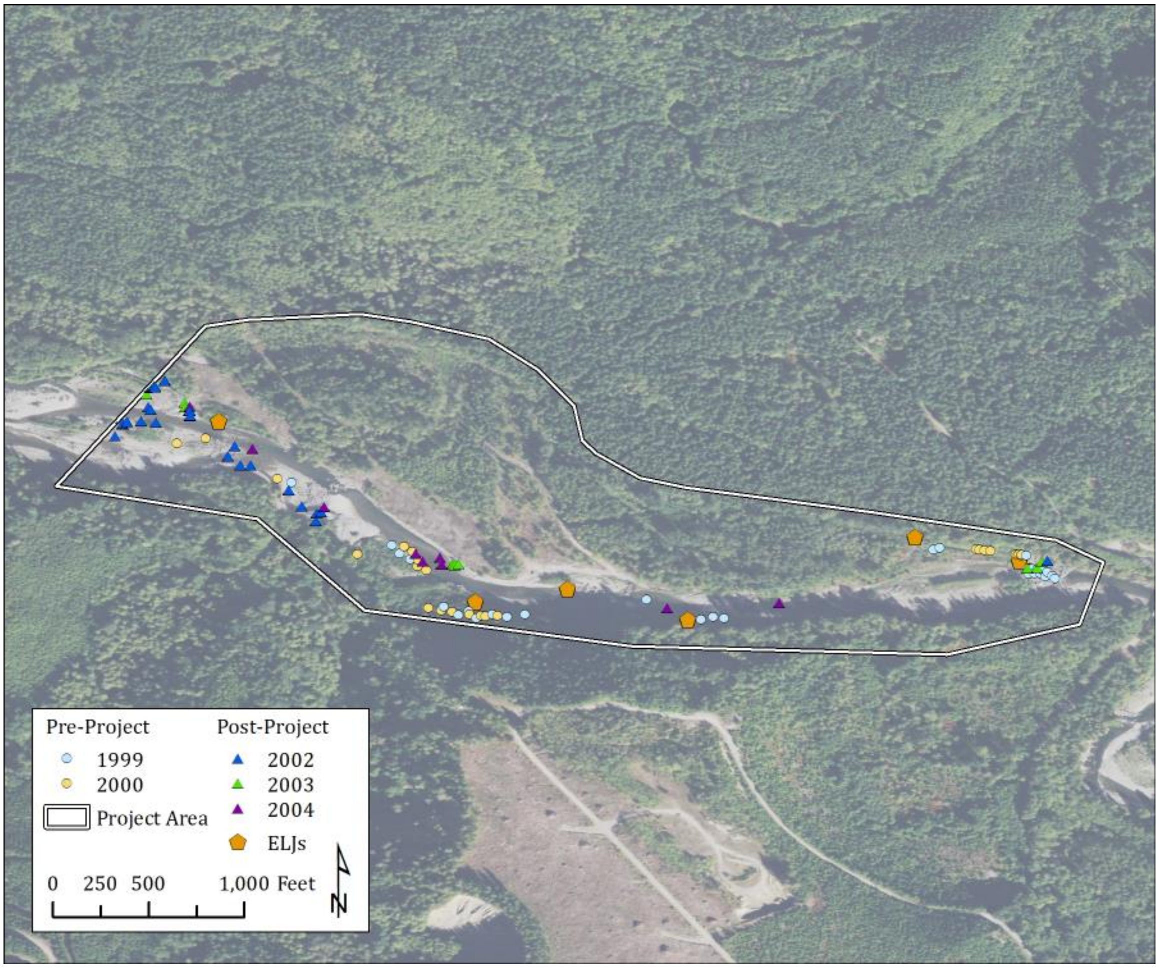


Figure 38. Chinook redds before and after restoration at Laron's Phase 1. Year during construction not shown (2001). Aerial imagery from 2017 USDA NAIP. Data prior to 1999 not available. Log jams are numbered sequentially from east to west, so log jam 6 is the western most jam.

Table 9. Larson's Bridge Phase 1 objectives and success (Adapted from: NNR and LNR 2019).

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	LIMITING HABITAT FACTORS
Increase main channel and secondary channel length	Habitat unit diversity; secondary channel length; main channel length	**Not met**- the project led to an immediate short-term increase in secondary channel length, but this has been lost. There was no indication that the length would be reconnected. Habitat diversity does not appear to have increased substantially.
Relocate the thalweg away from the landslide	Sediment source reduction	**Met**- the landslide continues to be isolated from the channel.
Reduce fine sediment originating in the reach	Sediment source reduction	**Uncertain**- monitoring of sediment showed no change, although local sources have been limited.
Increase pool frequency, residual depth and cover	Pool formation	**Partially met**- the number of pools did not increase as of 2005, although primary pools were created and pool area increased. Average residual

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	LIMITING HABITAT FACTORS
		depth increased between 2000 and 2011 and woody cover increased.
Increase channel roughness	Floodplain reconnection	**Met**- increase in bed-form diversity and wood.
Increase abundance of adult salmonids	Increase salmon population	**Uncertain**- adult and redd monitoring show consistent use. Not enough data for statistical analysis.

Larson's Phase 2

Larson's Phase 2 was completed in 2015. Pre-project data were collected from habitat surveys in 2005 and the basis of design report for the construction design (Natural Systems Design, 2013). Project metrics for the Larson's Phase 2 project were evaluated by comparing pre-project and post-project data in the context of the objectives.

Objective 1 – Create 3 thermal refuge areas for migrating salmonids by 2016 by co-locating 3 wood structures (and resultant pools) with known cool-water inputs

Available data are inadequate to completely assess this objective. Thermal refuge areas were not able to be completely evaluated due to limited pre- and post-project temperature data located in the project reach. Three wood structures with pools were located in the areas thought to have cool water, however, without thermal monitoring in those areas and a control point for temperature monitoring, these pools could not be evaluated for temperature differences. For future testing, we recommend simultaneous collection of data at the target site and from an adjacent control unit, i.e. a riffle.

Even though it was limited by a lack of control sites, ***thermal monitoring of the Phase 1 project found no difference in temperature with depth in the main channel pools associated with the logjams (LNR 2002). In summer 2019, continuous temperature data showed no thermal refuge at the primary pool at the downstream channel-spanning logjam (LNR 2019 data).*** Although, ELJ-formed pools were located in areas thought to have cool water, recent monitoring and research in the South Fork Nooksack River has found that thermal refuge creation is often most successful when separated from the mainstem channel (J. Helfield, pers. comm, 2019). Thermal refuge can be influenced by the depth of solar radiation penetration, isolation of water from flows that would cause mixing, and the difference between air temperature and water temperature (Ozaki 1994, Tate et al. 2006). Increasing depth in pools and providing pool habitat in areas separated from the mainstem flow could help increase the potential for thermal refuges to develop. Additionally, to detect any thermal refuges, a more complete assessment of pre and post temperatures is needed.

Objective 2 – Enhance 1.33 miles of side channels at the Q1 flow level by 2020

This project objective has been met under the Phase 2 project and was also included as an objective in the Phase 1 project. There are 1.44 miles of side channels that are engaged during the Q1 flow level under post-project conditions. This represents an increase of 0.98 miles of connected side channel length compared to pre-project conditions (0.46 miles during Q1 flow). About a half mile of this additional channel length comes from the connection of a right bank channel (that is being influenced by a large channel-spanning log-riffle structure near RM 20.0) which was not connected under pre-project conditions. This objective has been completed 3 years ahead of schedule, but monitoring should continue over the long-term to assess the longevity of side channel habitat.

Objective 3 – Enhance activation of 13.8 acres of floodplain at the Q1 flow level by 2020

This objective has not been met yet. There are 8.8 acres of connected floodplain habitat during the Q1 flow level under post-project conditions as measured in 2017. This represents an increase of 7.6 acres compared to pre-project conditions (1.2 acres of connected floodplain during Q1). The increase in floodplain connectivity is primarily due to the additional side-channel length, as there is not widespread diffuse flow over floodplain surfaces during the Q1 flow (1356 cfs). The lack of diffuse floodplain flow is expected under the Q1 flow scenario as the Q1 flow represents an estimate of bankfull conditions for the project reach.

Bed aggradation will need to continue on the current trajectory in order for this objective to be met. LNR documented 1 to 6 feet of channel bed aggradation upstream of three channel spanning logjams within two years of construction. Channel bed aggradation was greatest upstream of the lower two channel spanning jams, with an overall bed aggradation of approximately 3 feet between river mile 20.0 and 20.5. However, because the channel network will adjust to flow conditions (i.e. capacity will increase with more flow), widespread diffuse inundation of floodplain surfaces is unlikely under the Q1 flow which represents a proxy for the bankfull flow conditions in the South Fork (Castro and Jackson, 2001). The 2-year flow is a more relevant target discharge for this objective as flow should overspill the banks and inundate the floodplain. Objectives for future projects should be scaled to lower acreage of floodplain engagement based on the performance of Larson's Phase 2.

Objective 4 – Create 13 primary pool habitats by 2016

This objective has been met. As of the 2019 data, there were 37 pools within the Larson's Phase 2 reach of which 19 were primary pools. Field data from 2005 show 9 total pools and 8 primary pools (Table 8). The number of total pools and primary pools have both increased substantially since project construction, and the goal of creating 13 primary pools has been met. Additionally, 18 pools were formed by ELJs, eight of which qualify as both primary and deep (average residual depth > 3.28 ft (1 m)) pools.

Objective 5 – Reestablish an anabranching channel planform by 2020 by improving the stability of up to five mid-channel islands

This objective has been partially met as of the 2019 field survey. The river is currently establishing a multi-thread channel planform under post-project conditions with 7 mid-channel islands and associated perennial secondary channels forming. Braided channels do not have forested islands between them and are considered much more temporary than anabranching channels, which are separated by islands with more permanent vegetation (Springer, 2020). Definitions of anabranching vs. braiding differ by source. The islands between the channels in Larson's Phase 2 are not currently more than three times the active channel width, but they do have permanent vegetation, so we refer to the network as a multi-threaded channel. These data do show an increase in island formation from pre-project conditions, where the channel was primarily single-threaded and there were only two forested islands. The morphological shift towards an anabranching system is likely to continue as the log structures accumulate more wood, the bed continues to aggrade, vegetation colonizes the lee of the jams, and the channel network continues to develop and stabilize. Additional monitoring is recommended to determine the extent of island formation over the long-term.

Table 10. Larson's Phase 2 Project objectives and success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Create 3 thermal refuge areas for migrating salmonids by 2016 by co-locating 3 wood structures (and resultant pools) with known cool-water inputs.	Thermal refuge creation	**Uncertain**- available monitoring data did not show thermal refuge areas, but no scanning of pools for seeps and springs occurred.
Enhance activation of 1.33 miles of side channel at the 1-year flow and above by 2020 through placement of wood structures in the mainstem that promote bed aggradation and local water surface rise.	Secondary channel length	**Met**- the Phase 2 project met this objective based on modeling.
Enhance activation of 13.8 acres of floodplain at the 1-year flow and above by 2020 through placement of wood structures that promote bed aggradation and local water surface rise.	Floodplain reconnection	**Not met**- modeling showed an increase in floodplain area due to side channel connectivity, but further bed aggradation will be required to meet this objective.
Create 13 primary pool habitat units by 2016 through placement of wood structures.	Pool formation	**Met**- Field mapping found 19 primary pool units in 2019.
Reestablish an anabranching channel planform by 2020 by improving the stability of up to 5 existing mid-channel islands using wood structures.	Secondary channel length	**Partially met**- the project has developed a multi-thread channel with 7 mid-channel islands/bars; longer-term monitoring of bar stability and vegetation growth is needed to determine island formation.

Conclusions/Recommendations

The Larson's Phase 1 Project achieved the objectives for thalweg movement away from the landslide and increasing channel roughness and cover. Primary pools were also created as part of the project, although a change in the number of pools was not noted. Early increases in side channel length were later lost, but the level of use by spawning salmon remained consistent over time. Overall, the project did address the acute issue of the landslide, allowing spawner use to remain constant within the reach.

The Larson's Phase 2 project is well on its way to achieving most of the project objectives. The ELJs were constructed mid-channel and blocked over 50% of the main flow in several areas to store sediment. The project has created geomorphically significant changes in the river morphology – effectively switching the reach from a single-threaded plane bed to a complex multi-threaded morphology. The engineered wood structures have stored substantial sediment and forced flow up onto the floodplains at higher flows. At one riffle structure in the upstream section of the reach, storage of sediment happened very quickly – after the first high flow following construction. Much of the wood is interacting directly with the low flow channel which is creating slow water habitats and providing significant cover. The 2019 field data show that 80% of the pools in the reach are being formed by wood, with 50% formed by ELJs, showing the substantial influence of placed ELJs on the morphology. At flood flows, the wood is effectively inundating and creating side channels throughout the reach.

The success of this project can be attributed to the treatment types, locations, and frequencies of ELJ placement, which were constructed in the main flow of the channel, blocked 50 to 60 percent of the flow, and were dense enough to create a significant geomorphic response. The channel spanning log riffles have been effective at recruiting additional wood and aggrading sediment, which has allowed for flow to spread out over a broader extent of the valley. At least two of the structures have seen channel development around the flank of the structure, and this issue should be monitored over the long-term to measure changes in bed elevation. Nevertheless, a multi-thread channel network has developed within the jam placement area. Forested islands are forming in the sediment deposited between these structures, which should hopefully help sustain this morphology into the future. The elevated water surface levels from the channel spanning structures have also increased inundation of several side channels.

In the area directly downstream of Larson's bridge, where the log riffles and ELJ configuration were constrained to the channel margins, the treatment has been less effective. The log riffle was not constructed across the entirety of the channel in this location to meet budget constraints, leaving a pathway for the main channel flow rather than forcing it to spread out into several channels. Once the riffle recruited a large quantity of wood, the main channel simply occupied this middle pathway and cut off the right bank side channel. Continuing a log riffle treatment across the current channel at this location is recommended to connect the right-bank channel as designed.

Creation of thermal refuge in the Larson's reach has not been achieved (or at least not detected), although primary pools have been created and side channel and floodplain habitats have been reconnected. The creation of thermal refuge in the mainstem channel will likely be difficult as mixing of any cool water source with the mainstem flow is likely to dilute the effects of the cool water input. Research by Dr. James Helfield (J. Helfield, pers. comm.) has shown that separation from the main channel flow (either in off-channel or side channel habitat, or in a residual pool that is deep enough to stratify completely) is a key element in the creation of thermal refuge. Even if not providing a thermal refuge, large pools can provide thermal benefits by other means, such as storing cooler water from overnight cooling for a longer period than other habitats and encouraging groundwater/surface water interaction that may not lead to a measurable thermocline. Additional monitoring of floodplain and side channel habitats reconnected by the project would help to detect any cooler areas that may exist now or help plan for further adaptive management if additional sources are found that are not currently accessible to fish.

Fobes Reach

The Fobes project reach is located directly downstream from the Larson's project reach and extends from RM 19.5 to 18.3 along the Upper South Fork Nooksack River. The project was completed in 2010 and was intended to address the limiting factors of *Low Habitat Diversity* and *High Water Temperatures* through the placement of ELJs on gravel bars adjacent to the channel, with a primary focus on improving holding habitat (deep pools with cover) for spawning Chinook salmon. The project also targeted creation of scour pools and thermal refugia in the vicinity of Fobes Creek. A total of 9 large and 5 small ELJs were constructed during this project. The main objectives of the project were:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Fobes Reach	1. Create complex cover: Increase habitat diversity (i.e., increase the quantity of complex wood cover in the channel) by placing ELJs throughout the project reach.	low habitat diversity
	2. Increase key habitat quantity by increasing the number and depth of pools for holding and rearing, and increasing the number of pool tailouts for spawning.	lack of key habitat

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
	3. Create scour pools: Increase the availability of summer temperature refugia by encouraging formation of deep, thermally stratified pools in areas of cool water influence (tributaries, groundwater recharge areas).	high water temperature
	4. Create channel complexity and activate off-channel habitats: Structure placement in the channel should impede flows and provide better potential connectivity with the surrounding floodplain areas.	low habitat diversity

To meet these objectives, 14 ELJs were constructed within the extents of the unvegetated channel limits within the Ordinary High Water Mark of the river (Herrera Environmental 2010b). The structures were generally aligned parallel to the direction of the flow, and were intended to deflect river flows along either side of the structure when engaged and create sediment and hydraulic complexity and scour deep pools to create cool-water holding habitat. There were originally 21 ELJs designed for the project, but due to permitting restrictions intended to minimize impacts to Chinook spawning grounds, most ELJs designed for the wetted channel were removed from the final design. Thirteen of the 14 ELJs were constructed on dry cobble bars out of the low flow channel. Nine large ELJs were constructed on existing lateral bars throughout the project reach and were designed to engage with river flows to create scour pools and potentially create new side channels throughout the existing unvegetated channel and floodplain areas. Five small ELJs were constructed at locations where the addition of large woody debris would provide habitat complexity with cover that was lacking throughout the project reach. One small ELJ was constructed immediately downstream of the confluence of Fobes Creek in a left bank side channel within the wetted channel and was designed to create a scour pool and create a cool water refuge area. The structures were built out of large wood pieces placed around piles and tied together with manila rope.

Reach Description

The Fobes reach contains a single-threaded plane-bed morphology and an average slope of 0.0047 ft/ft (Figure 39 and Appendices B-H: Fobes). The river meanders at a small amplitude within a narrow 200-300’ wide unvegetated corridor from RM 19.5-18.7 where large riffles are separated by high velocity runs. Between RM 19.5-19.0, the channel is actively migrating eastward into the riparian forested floodplain and away from ELJs built during the first phase on the left bank gravel bar (Figure 40). The adjacent floodplain surface is ~8-10 feet above the low flow water surface, a depth which may indicate that the channel is incised. The active corridor widens at RM 18.7 where a forested island confines the main channel to the right side of the inset floodplain. The development of an inset floodplain is another potential indicator of incision in this reach. The left side contains a relict main channel pathway that is currently unvegetated and serves as a high flow overflow channel. The elevation of this former main-channel pathway above the current main channel elevation indicates that the river is downcutting into the channel through time. The island between the channels contains three ELJs that are not engaged with the low flow channel. At RM 18.5, near the Fobes Creek confluence, there is another flow split where the channel is actively migrating into the left flow path. The left flow path is straight and is actively recruiting small diameter (6-12’) trees as it migrates northward into the floodplain. The left channel has laterally migrated nearly 100 feet over the past decade. The right flow path contains 2 ELJs and 3 natural stable wood accumulations with key piece diameters of ~36-48” which have likely been recruited from the adjacent right bank riparian forest. The valley narrows below the confluence of this channel at RM 18.2, as the river is a confined canyon and rapid section.

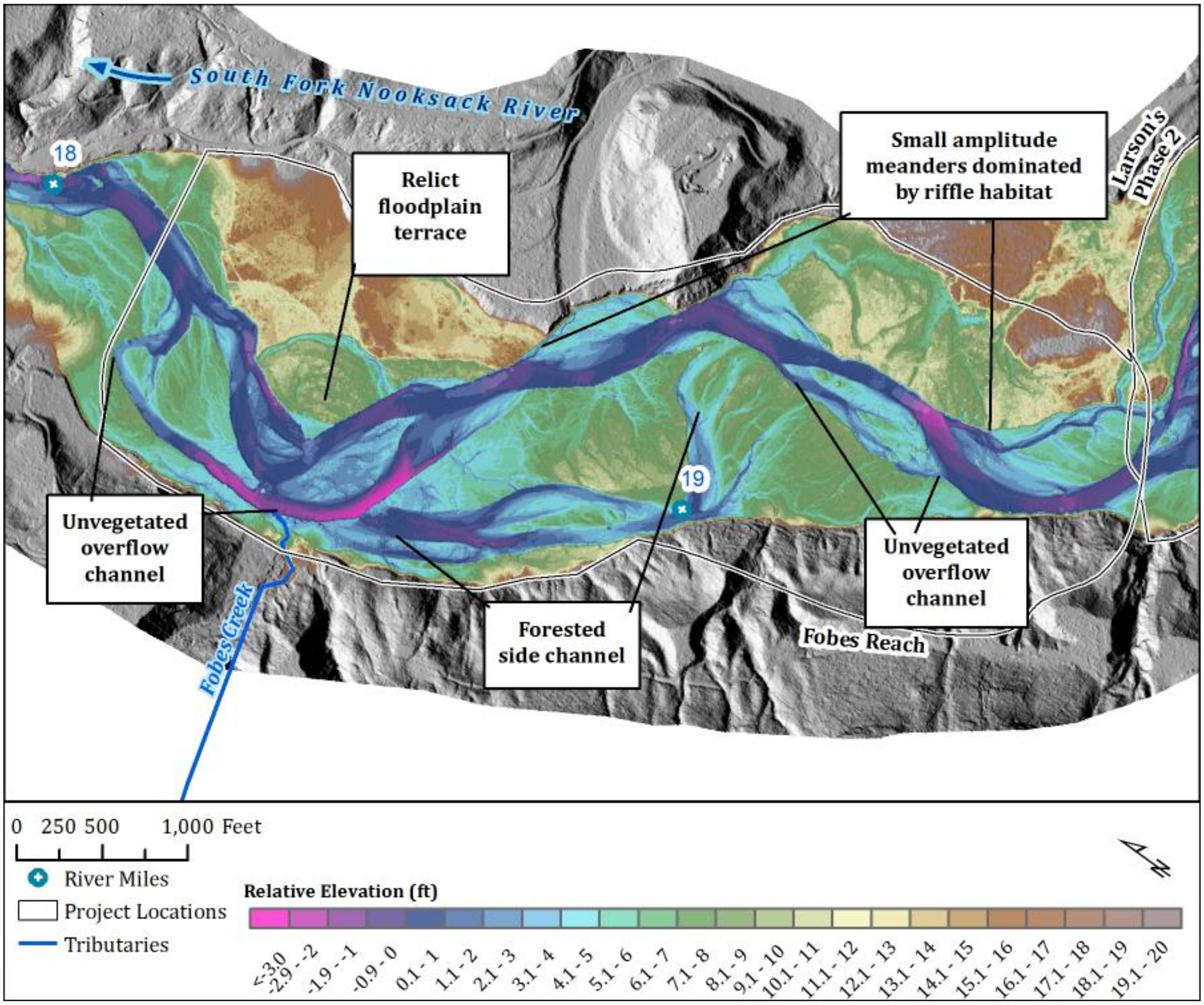


Figure 39. Relative elevation model (REM) for the Fobes reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

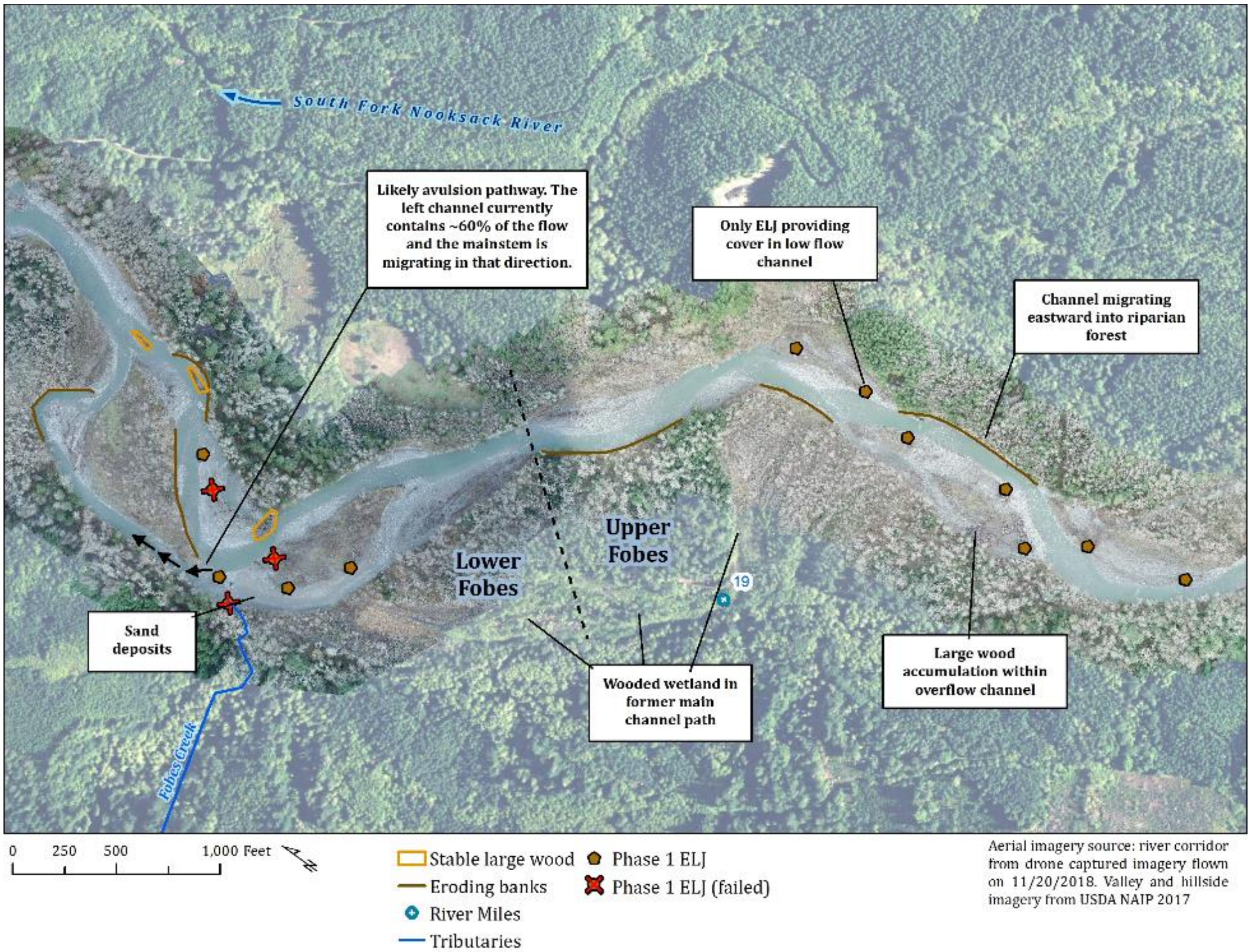


Figure 40. Geomorphic conditions of the Fobes project area (shown here as Upper Fobes and Lower Fobes) (NSD 2019).

There are three side channels within the Fobes reach – two unvegetated overflow channels and a high flow side channel (Figure 39). The most upstream overflow channel is located near RM 19.4 along the left bank and is ~1,200 ft long. The inlet of the channel is maintained by an ELJ on the apex of a gravel bar. This channel is unvegetated and was dry at the time of the field surveys, so habitat units were not identified. This channel is inundated at the Q1 flow level. The second overflow channel is located near RM 18.6 and is ~3,200 ft long. The inlet of this channel is also maintained by an ELJ. This channel is also unvegetated, included run habitat during the 2019 survey, and is inundated at the Q1 flow level. The forested side channel is located near RM 19 along the left bank and is ~3,200 ft long. This channel flows through a floodplain forest and likely provides well shaded rearing habitat. However, the channel is only inundated with ~0.5-1 ft of depth at the Q2 flow level (Appendix G-Fobes-Depth). There is an inset floodplain formed behind two ELJs near RM 19.2, which is backwatered during the Q1 flow and establishes a flow-through connection at the Q2 flow (Appendices F-G, Fobes-Depth).

The Fobes reach contains 11 engineered log jams and 3 stable natural log jams (10/mile). Of the 14 engineered log jams installed in 2010, 11 remain. Three of the ELJs in the lower project area have broken up and the logs mobilized downstream. The project was not modeled to assess the response of each structure to high flows. Much of the existing wood is located on the apex of bars or within the main channel near RM 18.3. This accumulation is providing in-channel cover and adding habitat complexity which is demonstrated by the increase in the number of channel units in the reach (Figure 41 and Figure 42). However, only one ELJ at RM 19.2 is providing cover in the low flow channel. The habitat distribution by channel unit type is relatively constant, with close to 50% riffle habitat and over 80% fast water habitat overall (fast water habitat includes riffle habitat). The total area of habitat increased between 2005 and 2019 (Figure 43 and Figure 44). There were 17 pools mapped in 2019 (12.1 pools/mile) as compared to 6 in 2005 (Table 11). The number of primary pools increased from 6 to 7, however the number of deep pools (residual pool depth ≥ 3.28 ft or 1 m) remained unchanged at 4.

Figure 41. 2005 habitat mapping in the Fobes project area (LNR 2005 data, photo from 2017).

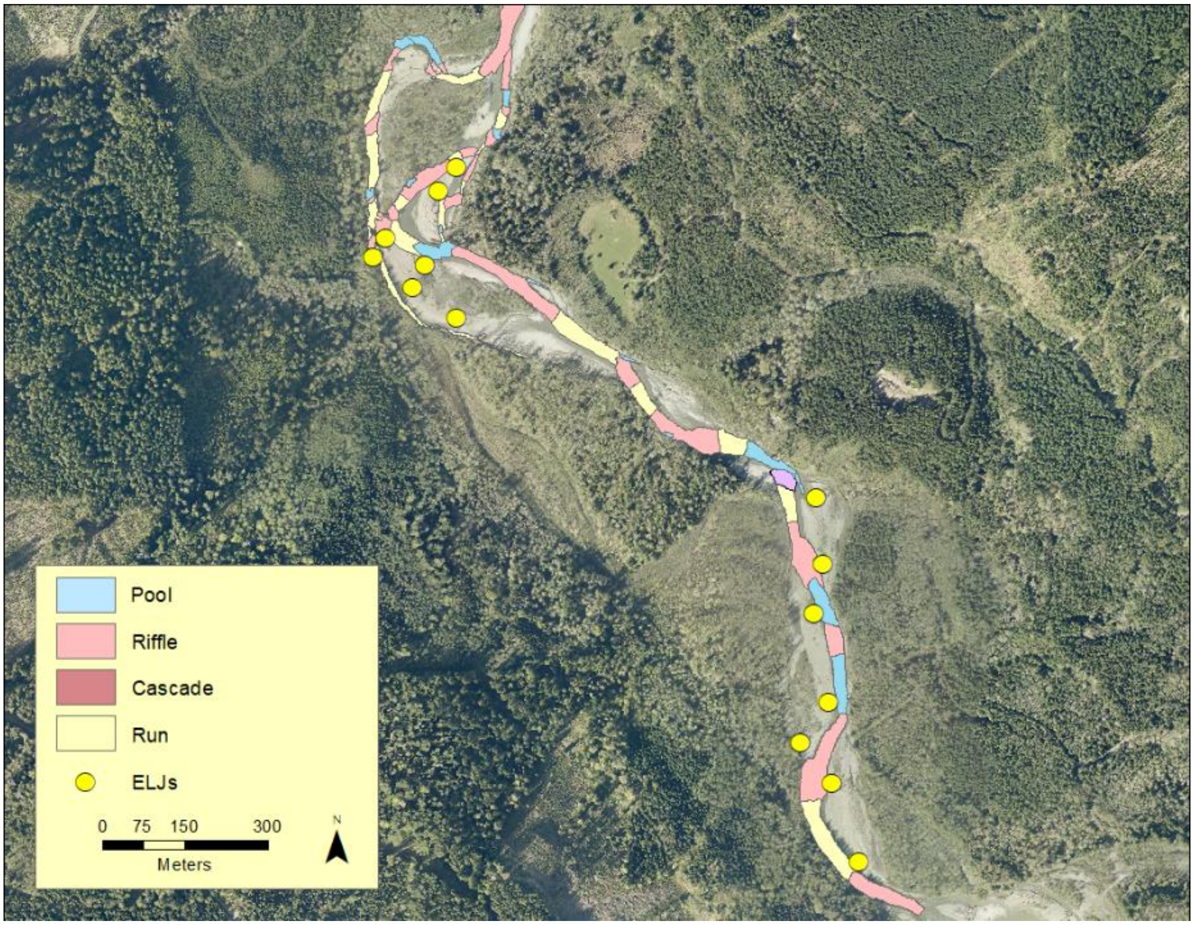


Figure 42. 2019 habitat mapping in the Fobes project area (LNR 2019 data, photo from 2016).

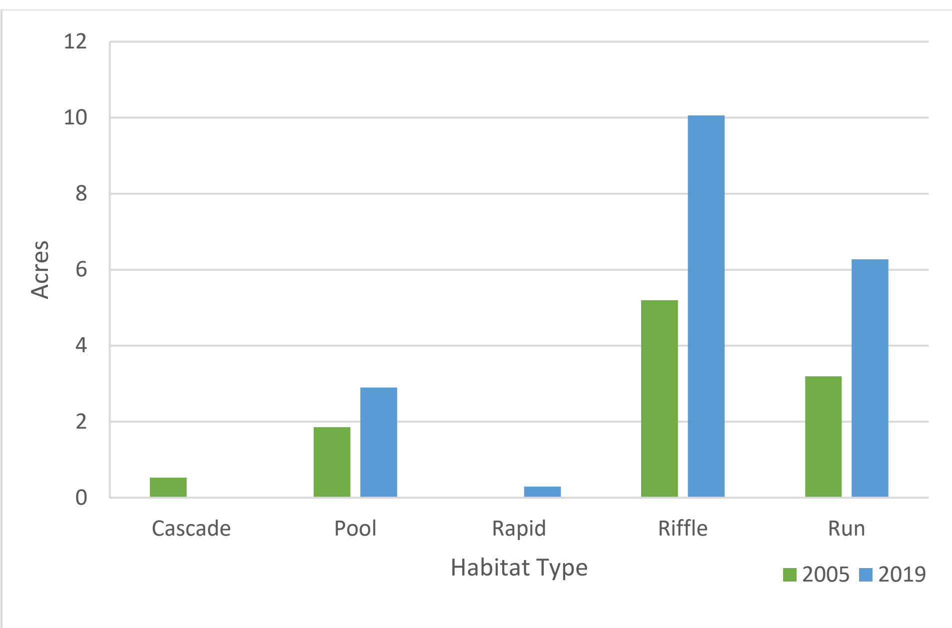


Figure 43. Channel unit distribution by area for the Fobes project reach. Channel units were measured during the 2005 and 2018-2019 field surveys.

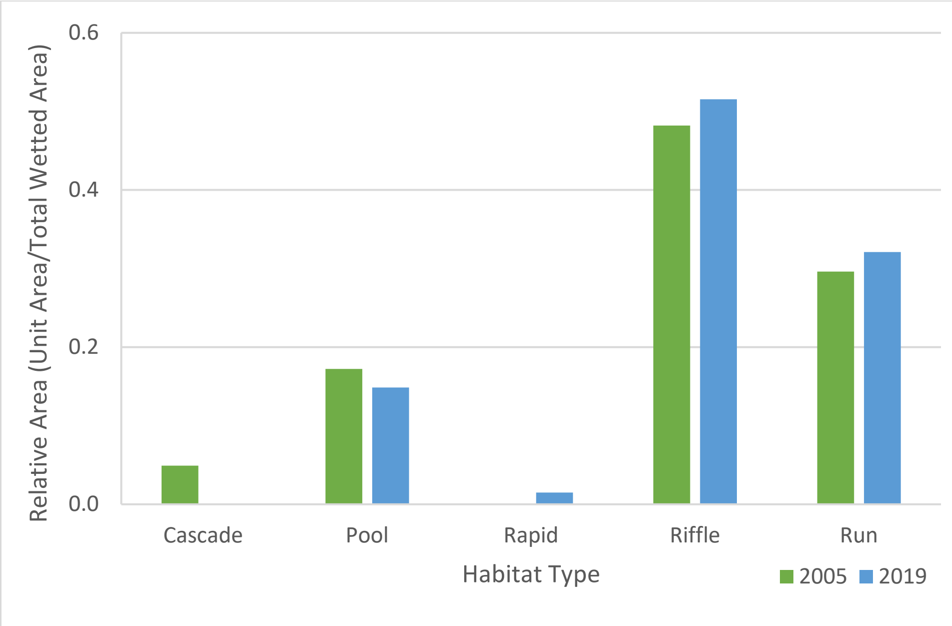


Figure 44. Relative area of channel unit types for the Fobes project reach. Channel units were measured during the 2005 and 2018-2019 field surveys.

Table 11. Pre-restoration (2005) and post-restoration (2019) pool parameters for the Fobes restoration project (construction completed in 2010). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth $\geq$ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	6	17 (2)
Primary Pools (ELJ)	6	7 (0)
• Deep Pools (ELJ)	4	4 (0)
Secondary Pools	0	10 (2)
• Deep Pools (ELJ)	0	0 (0)

There were relatively high numbers of fish observed in the Fobes reach and it is one of the larger project areas included in this study. The Fobes reach is a core spawning area for Spring Chinook (WRIA 1 SRP, 2005) and on average 25% of Chinook redds have been found in the reach across all spawner survey years (range from 9% to 51% from 1999 to 2018). The mean number of Chinook redds per year has decreased from 53 pre-project (years 1896, 1999 - 2009) to 38 post-project (years 2011 – 2018), despite the overall numbers of redds in the South Fork increasing since 2016 as a result of the early success of the South Fork Chinook Rescue Program. Juvenile fish observations from August 2018 at the project site were fairly evenly split between coho and *O. mykiss* with lower abundance of juvenile Chinook (Figure 45). Densities of fish mirror the abundances within the reach. Structure use observations indicate that many juvenile fish are using natural off-channel habitat with a lower level of use of natural wood and boulders. Less than 1% of fish were observed using placed wood (ELJs), likely due to the lack of structure engagement with the low flow channel during the time of surveys. There were also a relatively high number of fish observed not using any habitat structure (Figure 46). These were mostly *O. mykiss* with a few coho and Mountain Whitefish.

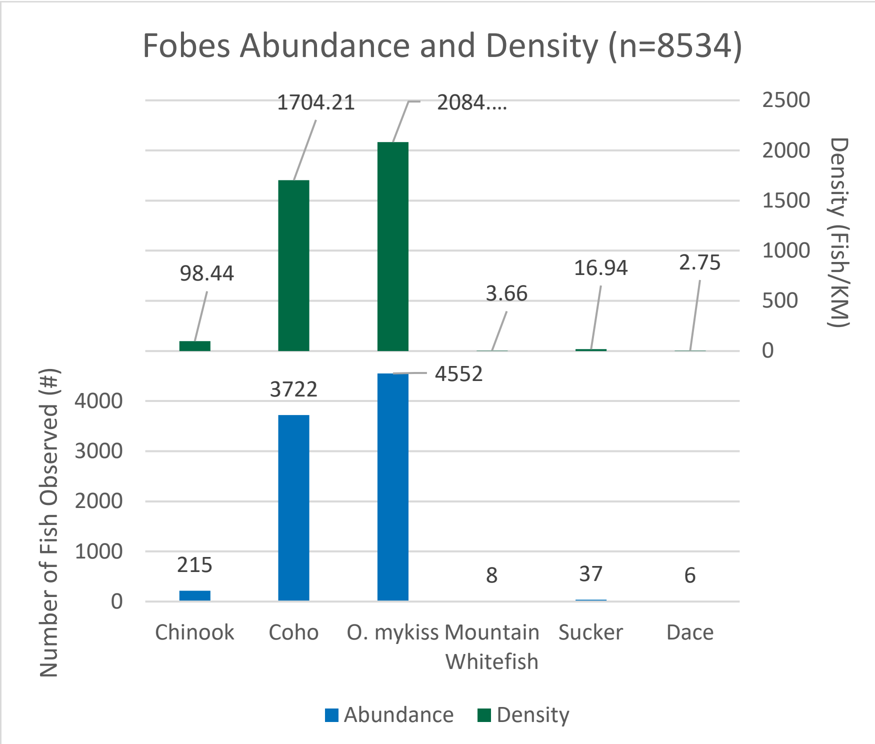


Figure 45. Fobes abundance and density from snorkel surveys (August 2018).

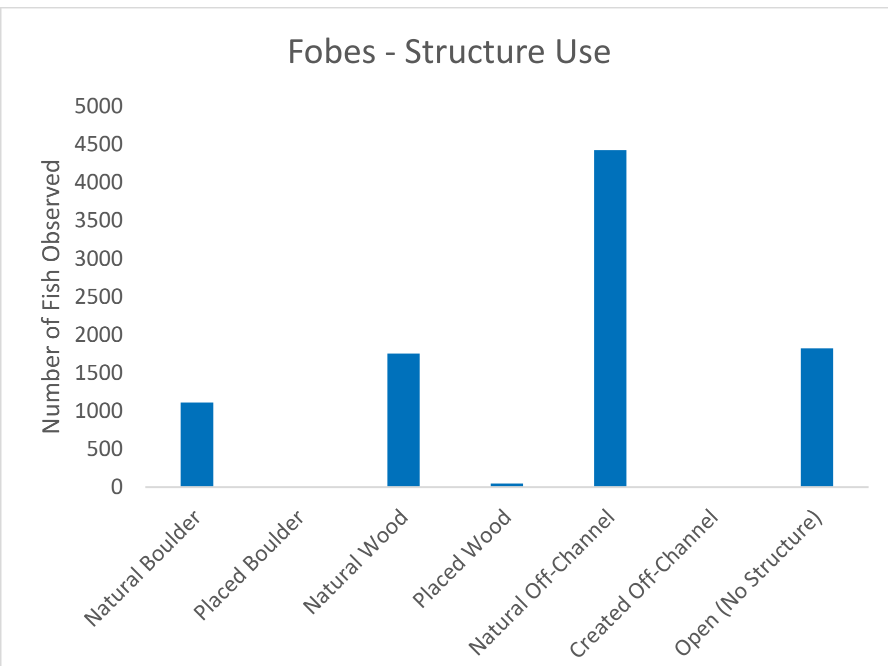


Figure 46. Fobes fish use by structure type from snorkel surveys (August 2018).

Monitoring Metrics

The Fobes project was completed in 2010 and available pre and post project data were used to evaluate the effectiveness of the project (Herrera Environmental, 2010). Project metrics for the Fobes project reach were evaluated by comparing pre-project and post-project data in the context of the objectives.

Objective 1 – Create complex cover and increase habitat diversity

This objective was met with increases in the number of log jams and wood area between 2005 and 2019. The total jam count was 19 in 2005 and 33 in 2019, with total wood area increasing from 50,943 ft^2 to 63,620 ft^2 (Table12). However, approximately two thirds of the wood was not engaged with the low flow channel at the time of the survey, reducing the habitat benefit to holding adult Chinook during summer low flows. In addition, the channel is actively migrating away from ELJs in the upper portion of the project and into the riparian forest along the right bank near RM 19.25. This is reducing any potential cover and pool formation from the ELJs and disrupting riparian processes by recruiting trees to the river before they are large enough to remain stable.

Habitat diversity in terms of the number of channel units increased from 19 channel units in 2005 to 34 in 2019 (Figure 41 and Figure 42), although the number of channel unit types remained constant at four. The area of habitat increased from 2005 to 2019 (riffle habitat area nearly doubled) but the proportions in terms of distribution and diversity remained similar (Figure 43 and Figure 44). The interaction of ELJs during the low flow was limited due to the placement of structures along the margins of the channel, however, the creation of channel units is influenced by interactions at the bankfull, or channel forming flow. Even though the wood cover provided at low flows is reduced, the effects of the ELJs at the channel forming flows (Q1) (Appendix C- Fobes, Appendix F- Fobes) may still have influenced the formation of a higher number of channel units.

Objective 2 – Increase key habitat quantity by increasing the number and depth of pools and pool tailouts

This objective was technically met by the project with the number of pools increasing from 6 to 17 between 2005 and 2019, although the majority are shallow, secondary pools. Eight of the 16 pools were formed by wood, however only two of these pools were formed by ELJs (Table 11), suggesting that the pool creation was not due to direct project effects. Primary pools in the reach increased from 6 in 2005 to 7 in 2019, but the number of deep pools (residual pool depth ≥ 3.28 ft (1 m)) remained unchanged at 4 over the same time period. The average maximum residual depth increased from 1.7 feet to over 5 feet and the average pool tailout depth increased from 0.43 ft to 1.31 ft. Pool habitat area increased from 1.86 acres in 2005 to 2.75 acres in 2019 (Figure 43), although the overall proportion of pool habitat within the reach decreased by ~12% (Figure 44). Since the absolute number and depth of pools increased, the objective was met, but those changes may or may not have been influenced by the project actions.

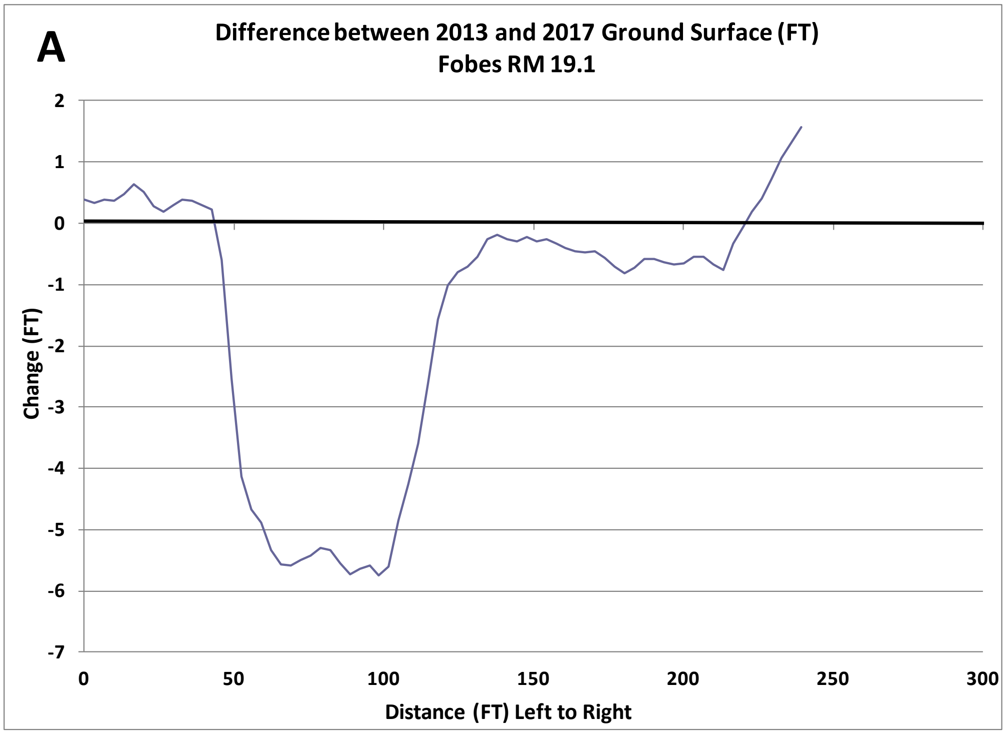
Objective 3 – Create scour pools to increase the availability of summer temperature refugia

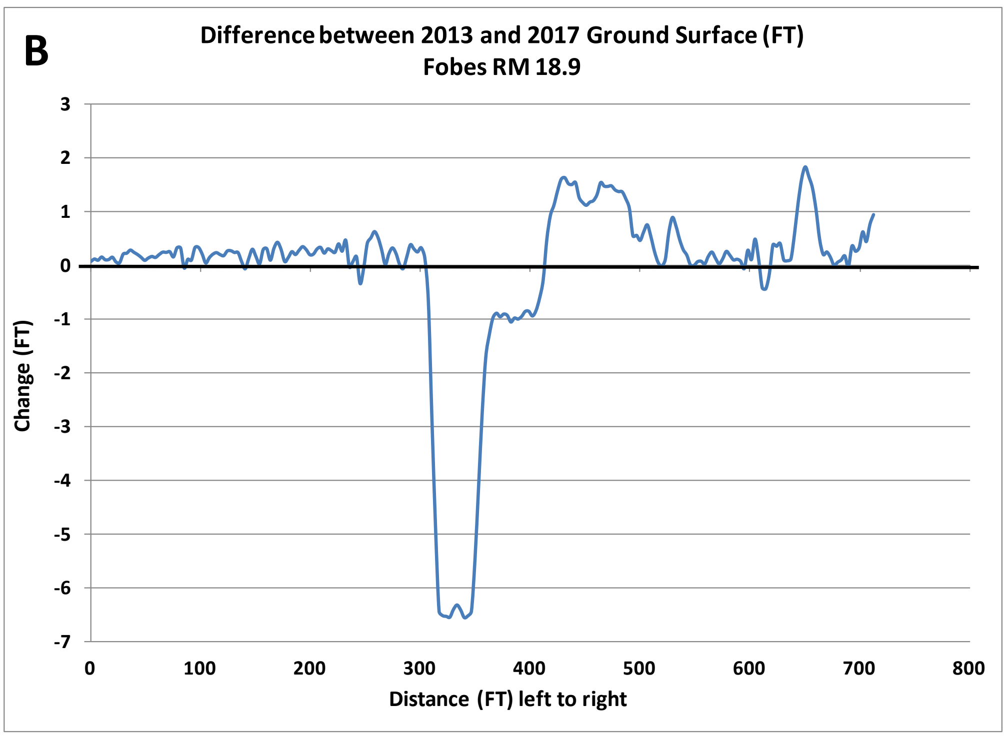
This project objective was partially met. The Fobes project has increased the number of pools within the reach from 6 to 17 and increased the average residual depth. Pools were formed by a variety of features including beaver dams, debris piles, resistant banks, single logs, bank roots, and engineered log jams. Scour is noted in the field notes for four of the pools, so, in that sense, scour pool creation was completed. The small ELJ installed to create a thermal refuge pool downstream of the confluence of Fobes Creek failed and was not present during 2019 surveys. Discrete temperature data in August 2019 indicated no thermal refuge about 100 meters downstream of the Fobes Creek confluence. No pool stratification was observed in the reach, although scanning the reach thoroughly for seeps and springs has not been completed. Known cold water inputs based on FLIR and/or temperature monitoring data include Fobes Creek, the left bank wetland outlet upstream of Fobes Creek, and a right bank tributary at RM 19.1. Additional research on the components associated with thermal refuge is on-going (J. Helfield, pers. comm) and may lead to further improvements for future project actions.

Objective 4 – Create channel complexity and activate off-channel habitats

Pre-project field survey data showed that 0.82 acres were identified as side channel habitat, and there was no off-channel habitat identified. Post-project field survey data identified 2.34 acres of side-channel and 0.51 acres of slough habitat, indicating an increase in activated off-channel habitats, even at the low flow. The left channel at the RM 18.7 flow split is currently disconnected and actively silting in. This has reduced side channel length and decreased habitat quality in the area. The thalweg of the right channel at RM 18.7 has cut down 4 feet in elevation between 2013 and 2017 (Figure 47). This is another indicator of incision that has occurred within the project area following restoration. Floodplain inundation and activation of floodplain side channels is limited in all reaches during frequent high-flow events (approximately less than 5-yr events), especially in the Upper Fobes sub-reach (RM 19.0–19.5) (NSD, 2019). There is also a risk of the mainstem channel avulsing entirely into the left channel at the RM 18.5 flow split, which would disconnect high quality spawning habitat in the right channel and mute the cold water thermal signature of Fobes Creek during the summer. There is one "off-channel" habitat area that is inundated during the Q1 flow level which is a left bank channel that is bare gravel and located near RM 18.5. An additional left bank channel is connected during the Q2 flow level near RM 19.25. This channel flows through a forested floodplain and is heavily shaded, however, the channel is only inundated with ~0.5-1 ft of depth at the Q2 flow level (Appendix G-Fobes-Depth). These connections show that further areas of off-channel and side channel habitat are available at higher flows, on top of the areas identified during the field surveys.

In terms of channel complexity, there was also an increase in the number of wood structures between 2005 and 2019, which contribute to channel complexity, although at low flows, many of the wood structures are not wetted. The number of channel units increased from 19 to 34 and the area of wood cover increased by 26%. The reach contains a moderate percentage (15%) of slow water habitats and is dominated by riffles (over 50%) at low flow conditions.


A
Difference between 2013 and 2017 Ground Surface (FT)
Fobes RM 19.1
2
1
0
-1
-2
-3
-4
-5
-6
-7
Change (FT)
0
50
100
150
200
250
300
Distance (FT) Left to Right


B
Difference between 2013 and 2017 Ground Surface (FT)
Fobes RM 18.9
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
Change (FT)
0
100
200
300
400
500
600
700
800
Distance (FT) left to right

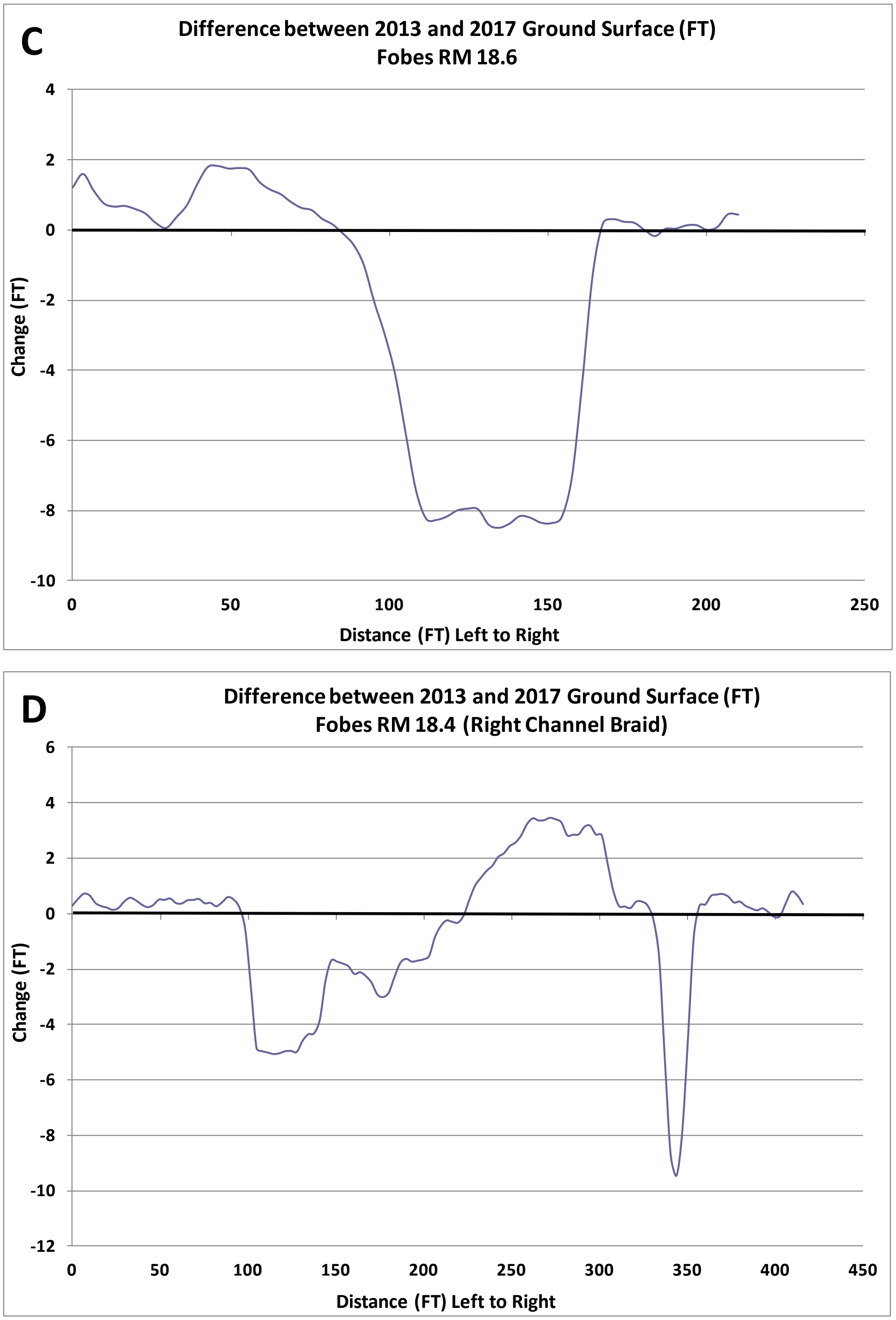


Figure 47. Change in water surface elevation (WSE) (feet) between 2013 and 2017 LiDAR at locations within the Fobes project area (A. RM 19.1, B. RM 18.9 above, C. RM 18.6, and D. RM 18.4 below) showing recent and rapid channel incision. Elevations were compared using 1-meter resolution LiDAR. In order to be comparable to the 2013 LiDAR, the 2017 WSE was derived from green LiDAR (which measures below the water surface). Elevations are from river right (x-axis 0) to river left. At these locations, the channel bed incised 5 – 8 feet over five years.

Table 12. Fobes Project objectives and success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVES SUCCESS
Create complex cover: Increase habitat diversity (i.e., increase the quantity of complex wood cover in the channel) by placing ELJs throughout the project reach.	Habitat unit diversity	**Met**- the project increased the number of logjams and wood volume in the reach, although many of the logjams are not interacting with the low flow channel. The amount of wood cover is over 64,000 square feet under the OHW. The amount in contact with the low flow channel is only about 23,000 square feet. Habitat diversity increased from 19 to 34 main channel units since baseline conditions and were likely influenced by channel forming flows (Q1).
Increase key habitat quantity by increasing the number and depth of pools for holding and rearing, and increasing the number of pool tail-outs for spawning.	Pool formation	**Met**- the project has increased the number of pools and pool tail-outs in the reach and increased the average residual depth of pools. However, the majority of these are shallow, secondary pools. Only one new primary pool has been formed, but the overall number of deep, primary pools has not increased. Only two secondary pools have been formed by ELJs. Changes may not be due to project actions.
Create scour pools: Increase the availability of summer temperature refugia by encouraging formation of deep, thermally stratified pools in areas of cool water influence (tributaries, groundwater recharge areas).	Thermal refuge creation	**Uncertain**- pool count increased, but no pool stratification or thermal refuge was observed, and an ELJ-formed pool was not created at the cool water Fobes Creek confluence as designed. Scanning for seeps and springs was not conducted in the project reach to identify potential refuge areas.
Create channel complexity and activate off-channel habitats: Structure placement in the channel should impede flows and provide better potential connectivity with the surrounding floodplain areas.	Floodplain reconnection	**Partially met**- the project increased the amount of off-channel habitat and the number of channel units. There was also an increase in the number of wood structures and area of cover. The diversity of channel units remained the same and surface model interpretation indicate continued local floodplain incision.

Recommendations

The Fobes project met many of the objectives identified at the project outset (Table 12) but further engagement of the wood structures with the main flow could enhance these outcomes further. The area of wood and the number of structures in the reach increased from 2005 to 2019, as did the number of channel units. Most of the ELJs have yet to engage with the low flow channel and in the upstream segment; the river has simply meandered around the ELJs because they were spaced too far apart.

Sediment storage (as illustrated by a reduction in D_{50}) was noted in wide planar channels to occur at wood densities of 4 pieces per 100 m^2 (Montgomery et al. 2003). Further, Montgomery et al. (2003) also note that pools occurred every bankfull width along the channel length, at a spacing of 0.5 pieces/m or 500 pieces/ km. Using similar wood densities in future efforts may help prevent flanking of flow around structures. Providing a higher density of ELJs (enough to block 50 to 60 percent of the flow in the main channel) would reduce the ability of the river to meander around the structures. In the downstream portion of the reach, near the Fobes Creek confluence, the ELJs were built on a point bar on the inside of a meander bend. This encouraged channel migration *away* from the structures – which further disconnected them from the river. This meander bend has since avulsed and cut off engagement with the ELJs. The number and area of pools increased, but the proportion of pool habitat decreased and the reach continues to be dominated by fast water habitat. It is uncertain whether or not the availability of summer temperature refugia was increased, as available monitoring data have not detected any significant differences in temperature, although a more robust monitoring structure is needed. Side channel and slough habitat showed an increase in area, and additional side channels were noted as connected in the 2019 habitat data. However, additional floodplain inundation and activation of floodplain side channels could be achieved with more dense structure placement (500 pieces/km) and enough structures to block 50 to 60 percent of the flow.

There is the potential to substantially increase habitat benefits of the Fobes project through adaptive management. Increasing the interaction of the ELJs with the low flow could enhance the habitat benefits in this reach in terms of increasing the proportion of pool habitat and provide more complex wood cover for holding adult Chinook. Any future project conducted in this reach should focus on building logjams that are engaged with the active channel at low flows and at a high enough density (e.g. 500 pieces per km) to influence flow and sediment transport conditions. Because many of the ELJs are still present, they can be used as a starting point for any future design work.

Additional benefits from side channel habitat could be gained by increasing the amount of vegetation along the reconnected channels. Further investigation into seeps or springs in the reach would also increase the potential to detect or create additional coldwater refuge habitat.

Cavanaugh Island

The Cavanaugh Island project is located downstream from the Fobes project and extends from RM 17.1 to 16.5 along the Upper South Fork Nooksack River. The project was completed in 2012 and was intended to address the limiting factors of *Low Habitat Diversity* and *High Water Temperatures* through the placement of six ELJs along gravel bars and banks of the mainstem channel and nine small habitat structures within the Cavanaugh Island side channel. The design was altered and not fully implemented during the permitting process to reduce short-term construction impacts on fish habitat (E. Stover, project manager, pers. comm. 2019). The main objectives of the project were:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Cavanaugh Island	1. Increase available key habitat quantity: Improving available key habitat quantity will stem from holding and rearing pools derived from ELJs. We expect each ELJ to have at least one scour pool.	lack of key habitat

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
	2. Improve habitat conditions for spawning salmon: seek to increase flow in the side channel. This channel, while dry during low flows, receives water during high discharge events to maintain a 30-foot wide unvegetated, gravel dominated bed.	low habitat diversity
	3. Increase thermal refugia availability/ wood structures in known cool water areas. This also includes the plumes of two cooler water tributaries and a groundwater seep that enters the channel from the terrace bordering the western side of the channel.	high water temperature
	4. Improve riparian function. Build 3 ELJs near the head of the island and tie in with existing large wood to protect Cavanaugh Island and its vegetation from scour during high flows. After construction, ORV roads will be decommissioned and planted to regenerate antecedent riparian conditions.	high water temperature

Reach Description

The Cavanaugh Island reach contains a single-threaded pool-riffle morphology (Appendices B-H: Cavanaugh Island). The river meanders to the west around Cavanaugh Island, which is formed by the mainstem channel along the right side of the valley and a 30 ft wide side channel (the Cavanaugh side channel) along the left side of the valley (Figure 48 and Figure 49). The 11-acre Cavanaugh Island is ~2-6 ft above the low flow water surface and provides the primary floodplain surface within the reach as the rest is constrained by the valley walls. There is another forested floodplain terrace along the right side of the valley near RM 17 that is ~1000 ft wide and ~6-8 ft above the low flow water surface. The upstream and downstream ends of the reach are characterized by locations where the mainstem of the channel abuts bedrock outcroppings along the left hillslope. There is another bedrock outcropping along the right bank in the middle of the reach near RM 16.75. Cavanaugh Creek joins the reach near the downstream portion of the reach around RM 16.6 (Figure 48).

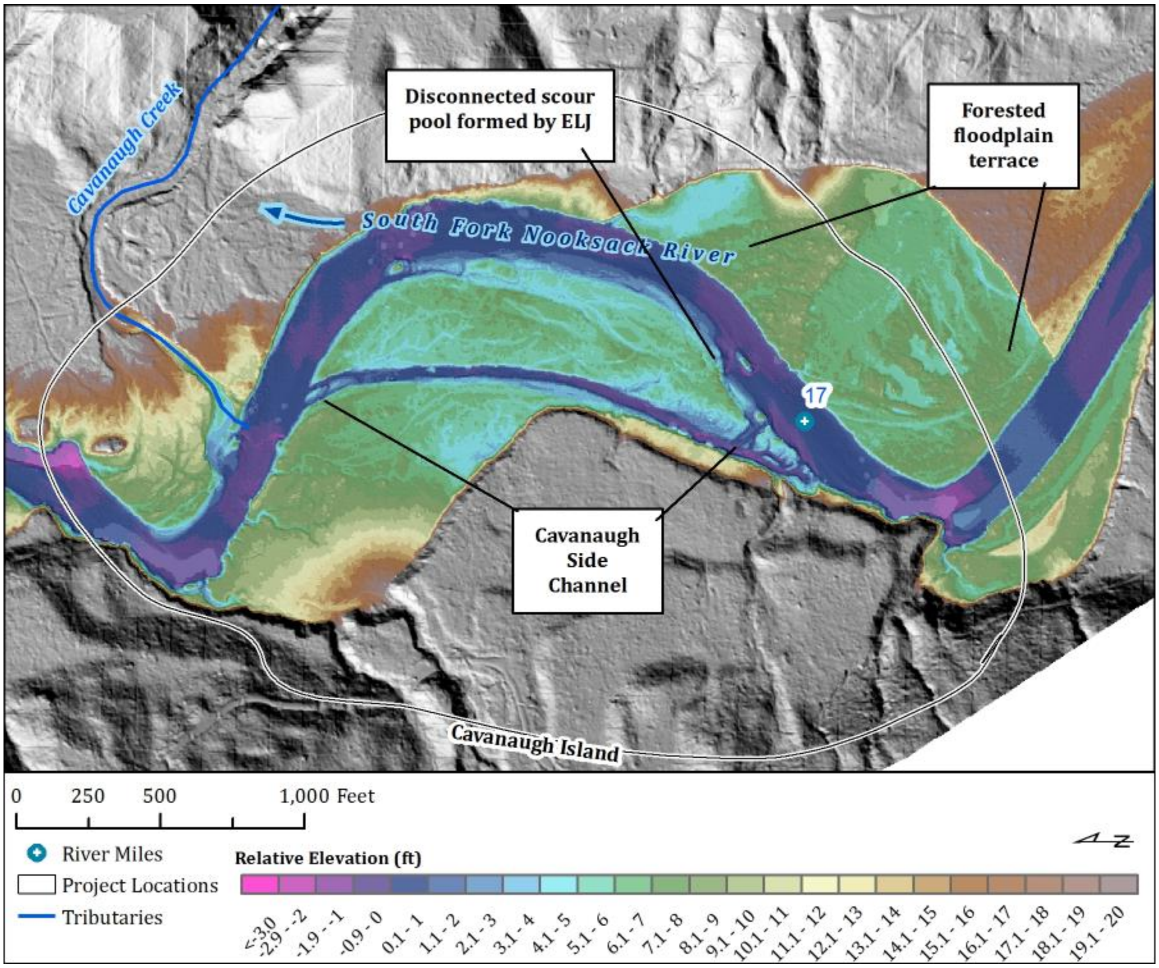


Figure 48. Relative elevation model (REM) for the Cavanaugh Island reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM.

Figure 49. Upstream view of Cavanaugh Island side channel outlet near RM 16.6. Flow is from left to right and photo was taken on 6/26/18.

The Cavanaugh Island side channel is the sole side channel within the project reach. The inlet to the channel is located along the left bank near RM 17 towards the inside of a meander bend. The channel is ~1,850 ft long, ~30 ft wide, and contains an unvegetated gravel bed. The channel contains two primary inlets that are ~250 ft apart. The upstream inlet was open during the field reconnaissance however, it was receiving minimal flow (<0.5' of depth) from the mainstem river. The downstream inlet is adjacent to an ELJ and was blocked by wood and sediment to surface flow during the field visit. Subsurface flow was observed to be occurring through this inlet. The flow through the inlet remained primarily sub-surface through the upstream portion of the side channel with some surface expressions occurring at pool locations. Flow was observed through the outlet of the side-channel which indicates that the channel gains sub-surface and tributary flow throughout its length (Figure 49). The channel is predicted to be inundated by at least the Q1 flow level with field observations predicting a surface connection near 1000 cfs.

Cavanaugh Island contains 26 log jams (32.5 jams/mile). All of the jams built on the Cavanaugh Island point bar along the left bank of the mainstem channel are only partially engaged to the low flow channel. The jams contained small and shallow scour pools that were connected with shallow (<1' depth) slackwater features to the main channel (Figure 50). While the jams have recruited wood, they are not engaged with the mainstem low flow habitat but can offer backwater cover out of the main flow path. There are an additional 12 log jams within the Cavanaugh Island side channel which are acting to provide habitat within the side channel. The reach is dominated by fast-velocity habitats with 80% of the reach containing riffle or run channel units and 20% composed of slow-velocity pool habitat units (Figure 51 - 54).

Figure 50. ELJ disconnected from the mainstem channel within the Cavanaugh Island project area. While a scour pool is forming when the jam is engaged with higher flows, the feature is disconnected from the main-channel flow during low flow conditions. The ELJ is located along the left bank near RM 16.8 and is the middle ELJ near the side-channel inlet location. The photo was taken on 6/28/18 with flow to the left.

Figure 51. 2005 habitat mapping in the Cavanaugh Island project area (LNR 2005 data, photo from 2017). Habitats that were dry at the time of the survey (e.g. the Cavanaugh Side Channel) were not included in the habitat mapping.

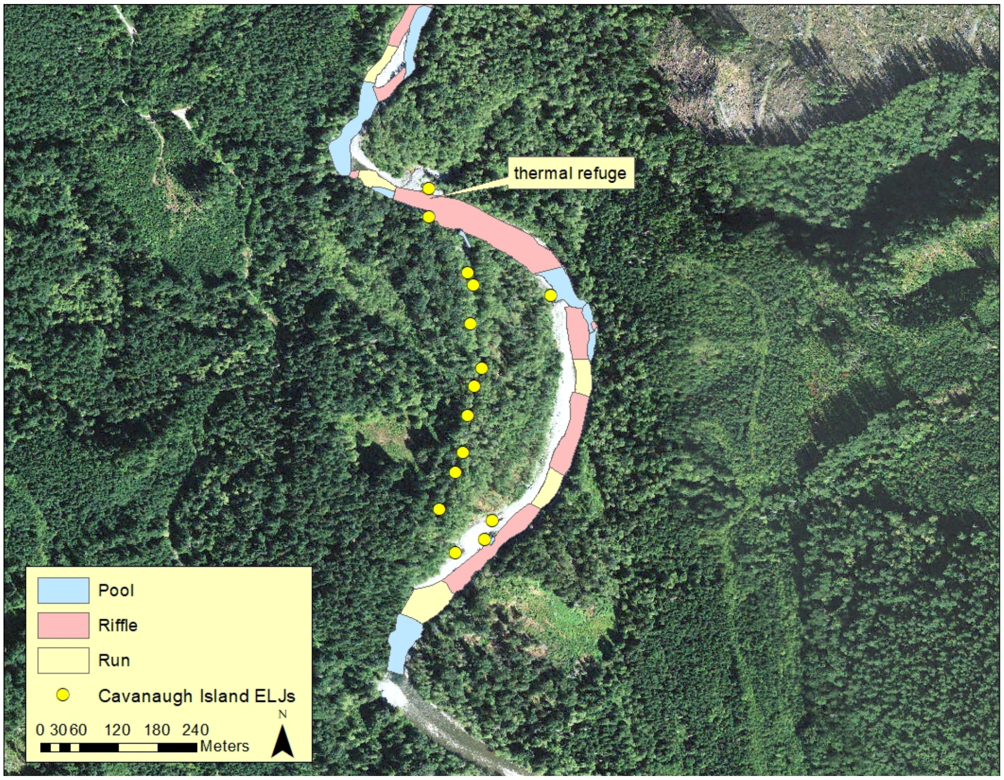


Figure 52. **2019 habitat mapping in the Cavanaugh Island project area (LNR 2019 data, photo from 2017). Habitats that were dry at the time of the survey (e.g. the Cavanaugh Side Channel) were not included in the habitat mapping.**

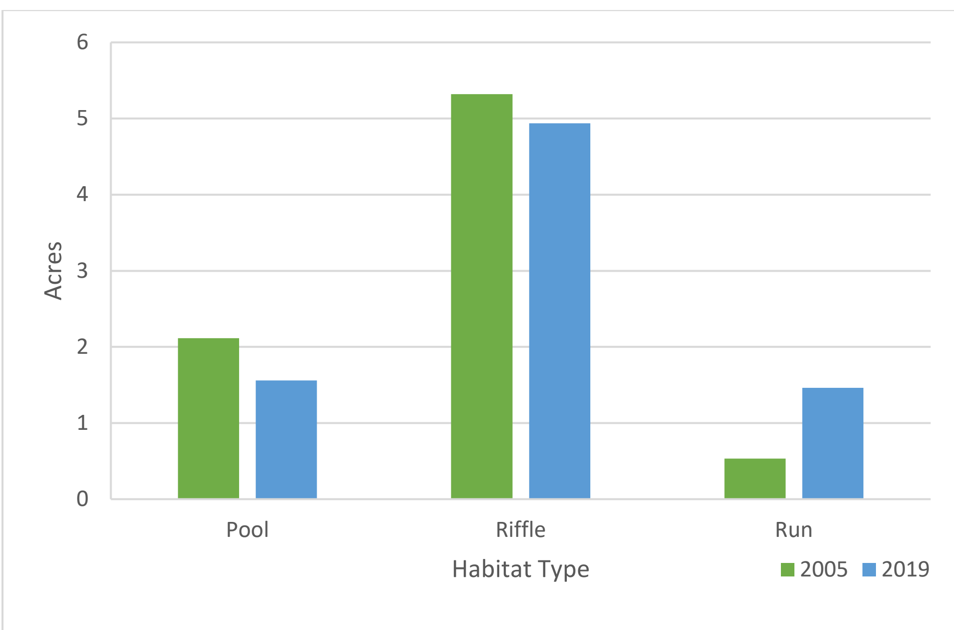


Figure 53. **Channel unit area for the Cavanaugh Island project reach. Channel units were mapped from 2005 and 2019 field data.**

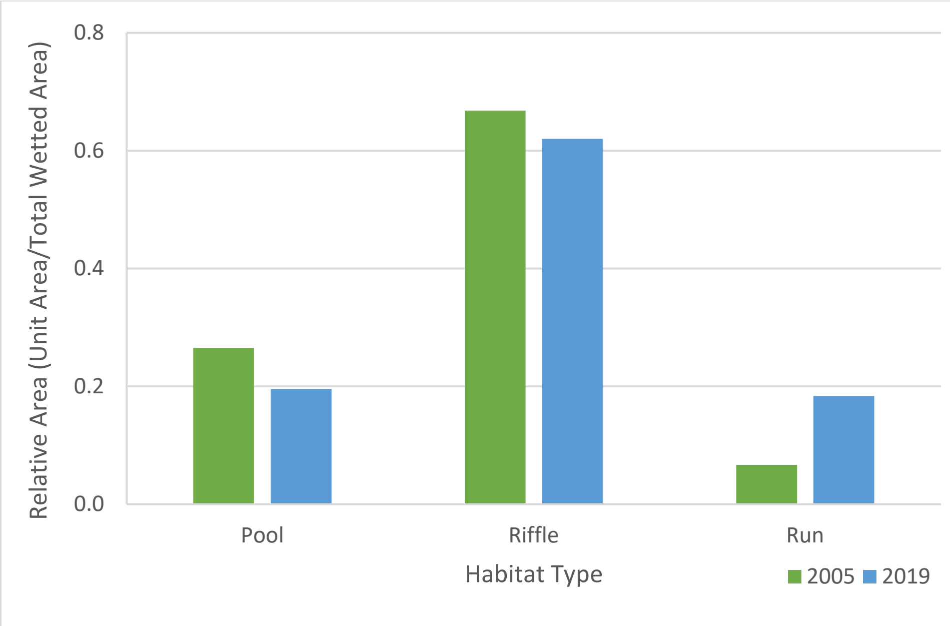


Figure 54. Channel unit distribution for the Cavanaugh Island project reach. Channel units were mapped from 2005 and 2019 field data.

Table 13. Pre-restoration (2005) and post-restoration (2019) pool parameters for the Cavanaugh Island restoration project (construction completed in 2012). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth ≥ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	5	7 (2)
Primary Pools (ELJ)	5	2 (0)
• Deep Pools (ELJ)	4	2 (0)
Secondary Pools	0	5 (2)
• Deep Pools (ELJ)	0	0 (0)

Fish use in the Cavanaugh Island project area was moderate with larger numbers and densities of coho and O. mykiss, and lower levels of use by Chinook (Figure 55). Presence of Mountain Whitefish, sucker and dace species were also noted. There were higher levels of structure use in the Cavanaugh Island project area with 80% of fish observed using structure (natural and placed) and 24% using structure placed by the project. The highest levels of structure use were noted at natural off-channel habitat, followed by natural wood and placed wood (Figure 56). The high level of use in natural off-channel habitat underscores the importance of reconnecting Cavanaugh Island side channels at low flow. On average, 10% of all South Fork Nooksack Chinook redds have been detected in this project reach across all spawner survey years (1986, 1999 to 2018). The mean number of Chinook redds per year has decreased slightly from 27 pre-project (years 1986, 1999 - 2011) to 22 post-project (years 2012 – 2018), despite the overall numbers of redds in the South Fork increasing since 2016 as a result of the early success of the South Fork Chinook Rescue Program.

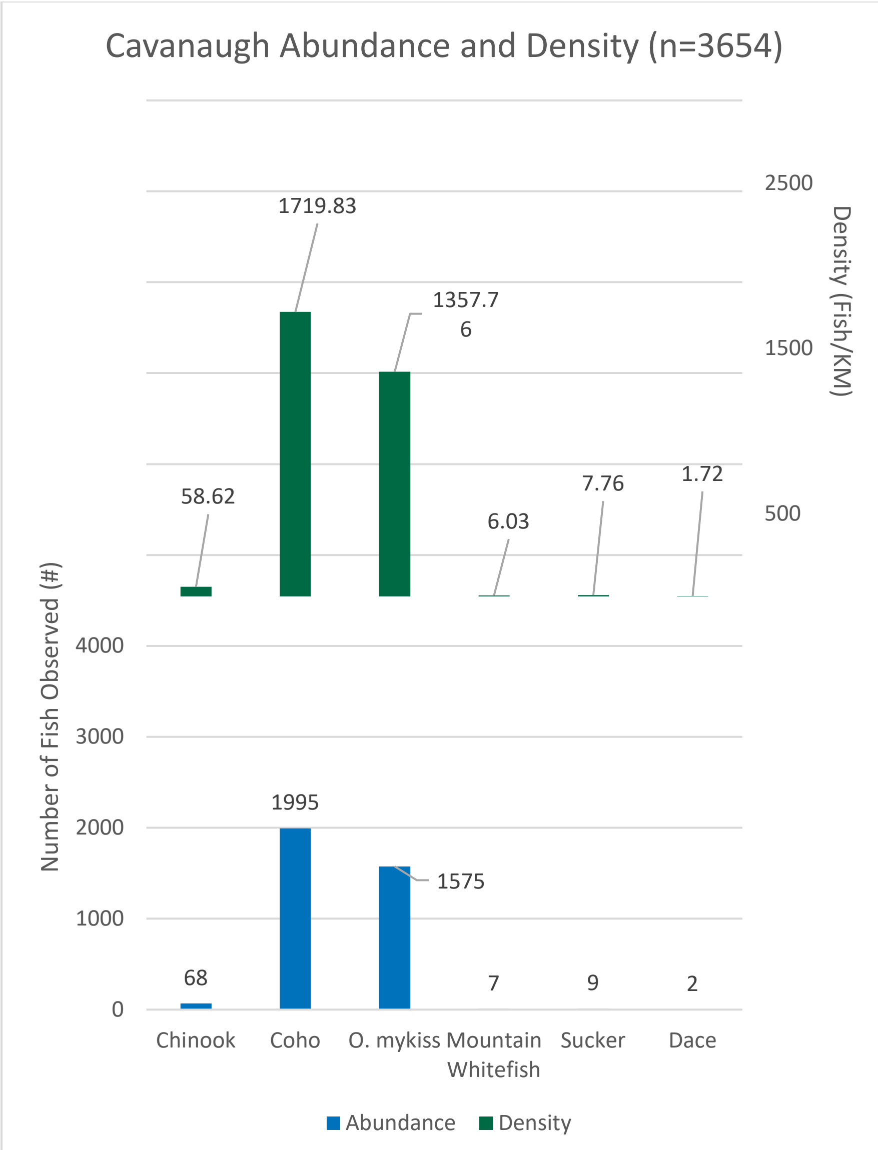


Figure 55. Cavanaugh Island abundance and density from snorkel surveys (August 2018).

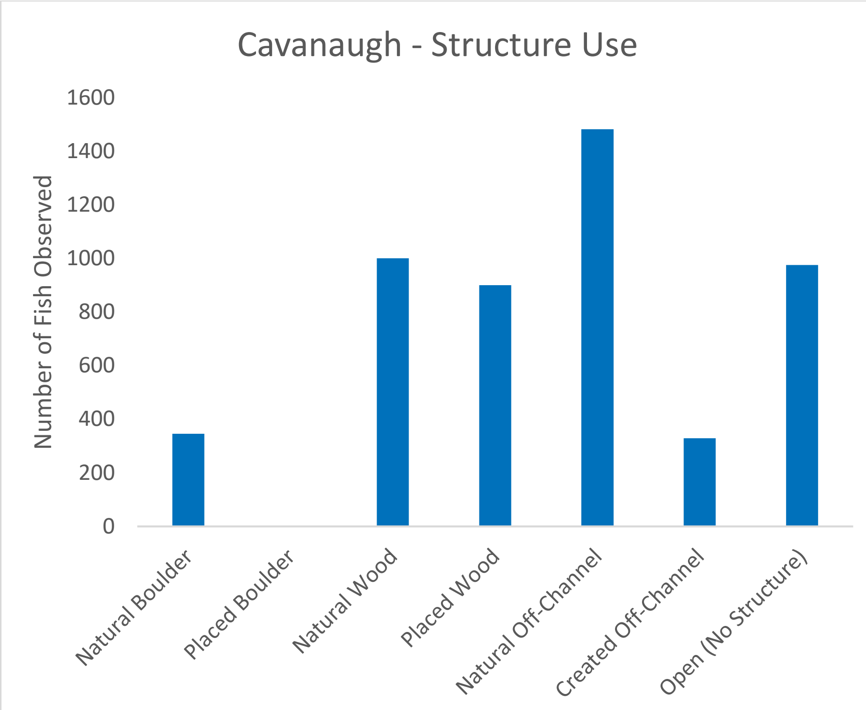


Figure 56. Cavanaugh Island fish use by structure type from snorkel surveys (August 2018).

Monitoring Metrics

The Cavanaugh Island Project was completed in 2012 and available pre-project data were used to identify baseline conditions (LNR field data 2005). Project metrics for the Cavanaugh Island project reach were evaluated by comparing pre-project and post-project data in the context of the objectives.

Objective 1 – Increase available key habitat quantity by forming holding and rearing pools derived from ELJs

This objective has been partially achieved. Pool counts increased from 5 in 2005 to 7 in 2019 and two secondary pools in 2019 were formed by ELJs. Pre-project data showed 5 primary pools in the Cavanaugh Island reach, which are defined as key habitats (Table 13). As of 2019 field data, there are 2 primary pools within the reach, neither of which are formed by wood or ELJs. The majority of ELJs are located in the Cavanaugh side channel, which was not mapped as wetted habitat during the 2019 habitat survey, and thus, are not providing fish habitat during those conditions, but may provide rearing habitat at the Q1 and Q2 flow levels (Appendix F and Appendix G).

Objective 2 – Improve habitat conditions for spawning salmon by seeking to increase flow in the Cavanaugh Island side channel

This objective was not achieved. The Cavanaugh Island side channel becomes engaged with surface flow at ~1000 cfs based on field observations. Below this flow level, there is hyporheic connectivity which provides flow through the channel and back into the mainstem at the outlet. This does not provide enough upstream connectivity during low flow periods for spawning salmonids in order for the objective to be achieved. There was not an increase in spawning use within this channel from pre- to post-project conditions, as there were no redds observed in the side channel during either time period (Figure 57).

The lack of spawning use and low flow connectivity, which limits access for spawners, demonstrates that this objective was not achieved.

Objective 3 – Increase thermal refugia availability by building wood structures in known cool water areas

This objective has been partially achieved. There were two ELJs constructed in the vicinity of the known cool water areas (ELJs 12-01 and 12-02) and one of them appears to be providing thermal refuge, based on limited, preliminary data, The ELJ built along the right bank near the Cavanaugh Creek outlet (ELJ 12-01) has formed a small, secondary, 2 ft maximum depth (1 ft residual depth) scour pool per the 2019 habitat data. A 1.2°C decrease in temperature with depth was noted at that location during the June field visit. This area was located at the confluence with Cavanaugh Creek which may be contributing the cooler water at this location; the other structure located at a seep (ELJ 12-02) did not show a cool water influence. Discrete temperature measurements on July 9, 2019, indicated a thermal refuge (>2°C difference) in the small ELJ scour pool (13.6°C) at the mouth of Cavanaugh Creek near ELJ 12-01 compared to ambient temperature upstream (15.6°C) of the Cavanaugh Creek confluence also showing the potential influence of Cavanaugh Creek (LNR 2019 data) (Figure 52). At low flows, the small pool is mostly isolated from the South Fork and provides limited habitat value. This objective has been partially met, but additional cold water refuges would provide additional benefit.

Objective 4 – Improve riparian function by building 3 ELJs near the head of the Cavanaugh Island to protect the island and its vegetation from scour at high flows; decommission and plant ORV roads

This objective has been achieved although it will take time to fully assess riparian function. The size of Cavanaugh Island has remained essentially unchanged between pre (2011) and post (2017) conditions (11.7 acres in 2011 vs 11.8 acres in 2017). Thus, the ELJs are helping to protect the island from bank erosion. The island was planted after construction with grand firs, spruce, and cedar, but the success of these plantings was not monitored for this report. The existing riparian vegetation primarily consists of immature alder and maples, few cottonwoods, and very few conifers. One conifer was visible on the head of the island with most trees having a diameter at breast height of 8 inches, showing relatively recent vegetation colonization. Vegetation re-establishment is critical to the sustainability of placed wood structures in the river. Monitoring of the existing conifer plantings and additional plantings on Cavanaugh Island may be warranted in order to achieve this objective. ORV roads have been decommissioned.

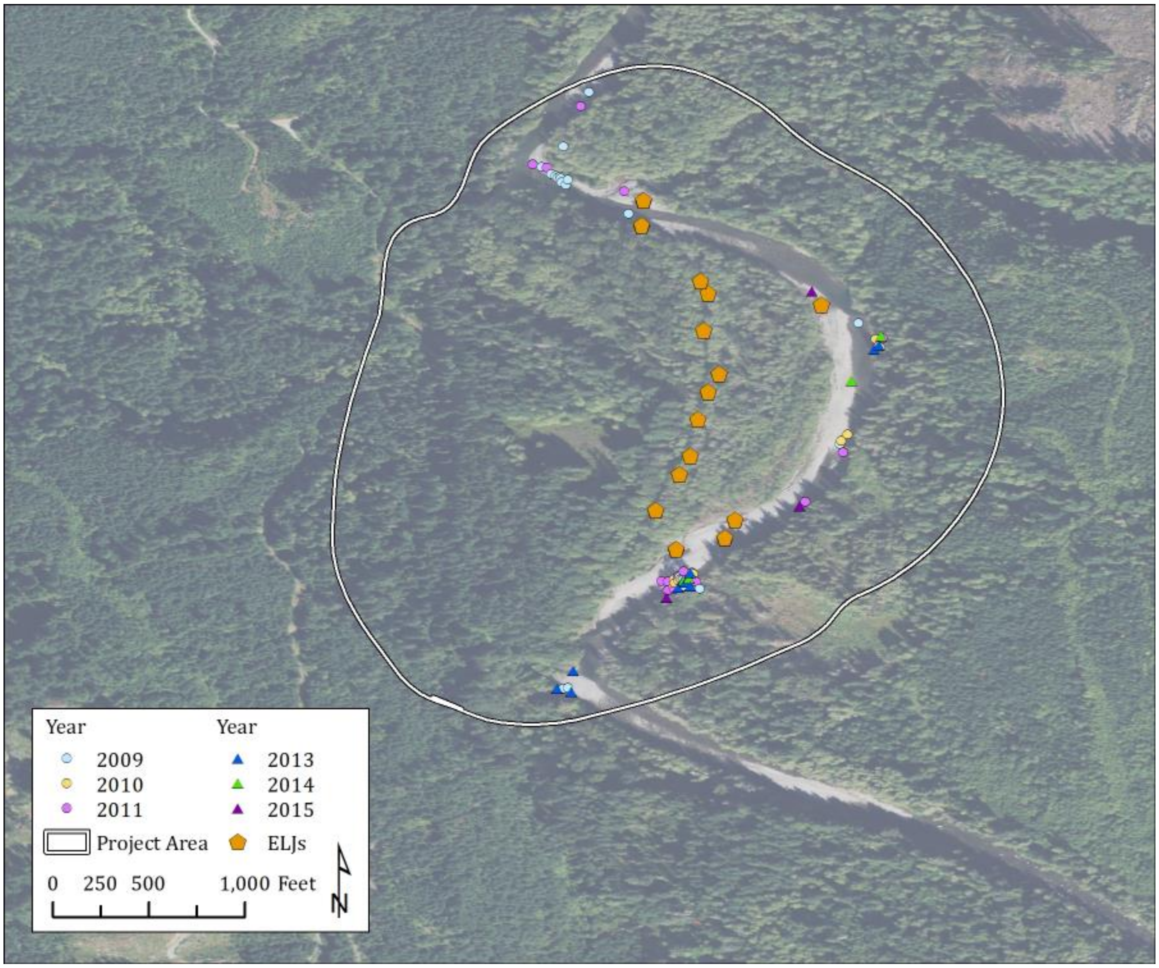


Figure 57. Chinook redds before and after restoration at Cavanaugh Island project. Year during construction (2012) not shown. Aerial imagery from 2017 USDA NAIP.

Table 14. Cavanaugh Island Project objectives and evaluation of success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Increase available key habitat quantity: Improving available key habitat quantity will stem from holding and rearing pools derived from ELJs. We expect each ELJ to have at least one scour pool.	Pool formation	**Partially met**- Engineered logjams have increased the number of pools in the reach, but the number of primary pools has decreased, and have not met the target of each logjam forming a pool.
Improve habitat conditions for spawning salmon: seek to increase flow in the side channel. This channel, while dry during low flows, receives water during high discharge events to maintain a 30-foot wide unvegetated, gravel dominated bed.	Secondary channel length	**Not Met**- The target side channel becomes connected at ~1000 cfs, but does not maintain enough flow during spawning season to meet the objective.
Increase thermal refugia availability/ wood structures in known cool water areas. This also includes the plumes of two cooler water tributaries and a groundwater seep that enters the	Thermal refuge creation	**Partially Met**- The logjam located at the confluence with Cavanaugh Creek showed a decrease in temperature with depth, which could be related to inflows from the creek. At low flows,

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
channel from the terrace bordering the western side of the channel.		the same area was 2°C cooler than upstream river temperatures.
Improve riparian function. Build 3 ELJs near the head of the island and tie in with existing large wood to protect Cavanaugh Island and its vegetation from scour during high flows. After construction, ORV roads will be decommissioned and planted to regenerate antecedent riparian conditions.	Floodplain forest protection	**Met**- Logjams have been constructed and the island size has been maintained. The ORV trail has been decommissioned. Initial planting occurred and monitoring and additional riparian planting was suggested.

Recommendations:

The objectives of the Cavanaugh Island Project have been partially achieved. The island itself has been protected from erosion, some thermal refuge has been enhanced, and the ORV roads have been decommissioned. However, the number of primary pools has decreased, the side channel is not connected at spawning flows, and spawning has not increased in the project area. The island itself has maintained its size and been protected by the wood placements, although additional planting on the island is recommended to achieve riparian function.

The creation of a pool near the Cavanaugh Creek confluence with thermal benefit and the maintenance of an open inlet to the Cavanaugh side channel demonstrate that habitat restoration is possible within the geomorphic conditions of the reach. Structures built near the side channel inlet should maximize low flow obstruction in order to raise water surface elevations enough to inundate the side channel at low flow conditions. Current ELJs along the left bank at the upper end of the reach are separated from the low flow and are not providing cover or scouring pool habitat that is available at low flow, although they are maintaining the size of Cavanaugh Island. Engineered logjams should be placed strategically to interact with low flow channel to create deep scour pools for holding adult Chinook. Adequate permitting and construction time should be given to accommodate potential restrictions due to listed Marbled Murrelet use in this area.

Upper Cavanaugh-Fobes Phase 2

The Upper-Cavanaugh Fobes Phase 2 project is a continuation of the separate Fobes and Cavanaugh Island projects described above. The project is currently in design and aims to incorporate findings from this report in order to improve the effectiveness of the restorative actions that will be conducted. The project is in the preliminary design stage and seeks to address the limiting factors of *Low Habitat Diversity* and *High Water Temperature*. The descriptions provided above can act as “pre-project” conditions in any future effectiveness monitoring projects. Below are monitoring objectives for the project that can be used to establish specifications for future monitoring as well. The project reaches are considered separately.

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Upper Cavanaugh-Fobes Phase 2	1. Increase key habitat quality and diversity by creating up to 19 primary pool habitat units within five years through the placement of engineered logjam structures.	low habitat diversity and lack of key habitat
	2. Improve one-year (alluvial) floodplain channel connectivity for rearing by connecting up to 1.96 miles of off channel habitat through bed aggradation and increased water surface elevation from installation of four channel spanning log riffle ELJs. Their placements will factor in recreational safety and be established through design discussions between LNR and the WDNR.	low habitat diversity
	3. Provide for spawner occupancy of the Cavanaugh Island side channel by raising bed elevations downstream from its inlet.	low habitat diversity and high water temperature
	4. Increase thermal refugia for salmonid species by creating up to two primary pool habitat units within five years in areas of cool water refuge through the placement of ELJs.	high water temperature
	5. Increase holding and rearing habitat by creating and enhancing up to 16 acres of wetland and 66 acres of floodplain habitat within five years.	high water temperature

Table 15. Pre-restoration (2019) pool parameters for the Cavanaugh-Fobes Phase 2 restoration project. Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth $\geq$ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2019
Total Pool Count (ELJ)	31 (4)
Primary Pools (ELJ)	13 (0)
• Deep Pools (ELJ)	9 (0)
Secondary Pools	18 (4)
• Deep Pools (ELJ)	0 (0)

Fish observations in the Cavanaugh and Fobes project areas were fairly consistent with a split between coho and *O. mykiss* dominating the observations and a small percentage of juvenile chinook (Figure 58 and Figure 59). With over half of the reach area in fast water habitats, and ELJ's that are not fully engaged during low flows, the capacity for Chinook juvenile use at the site could be improved. These two sites, however, account for a large percentage of the coho and *O. mykiss* observed during the snorkel survey. This is a high use Chinook spawning area, approximately 35% on average, of all South Fork Nooksack Chinook redds have been detected in this project reach across all spawner survey years (1986, 1999 to 2018) (Table 23).

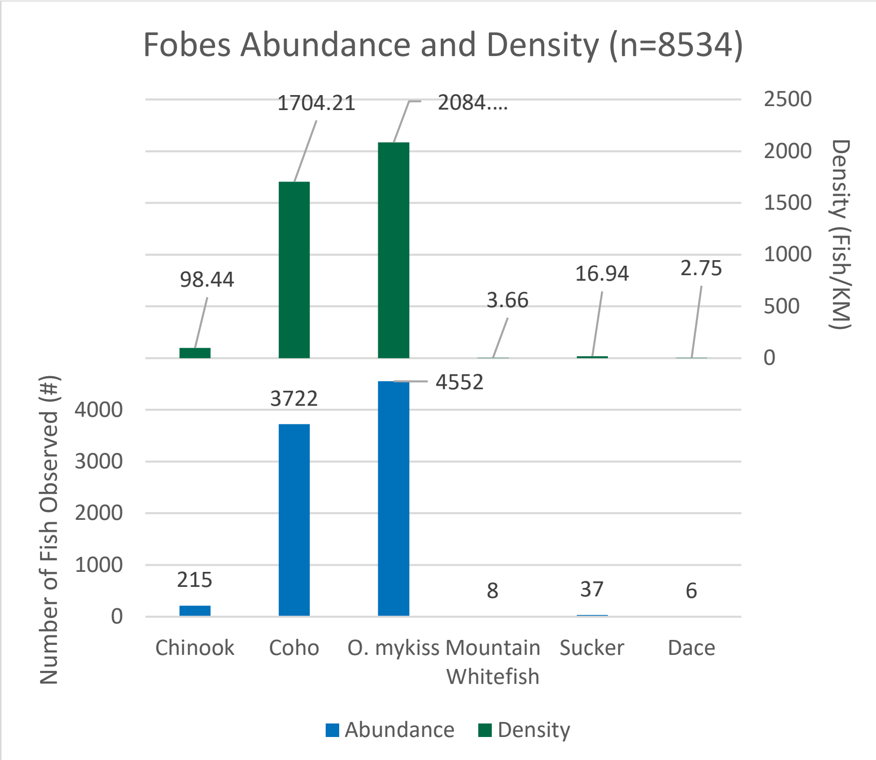


Figure 58. Snorkel survey results for Fobes project reach (August 2018).

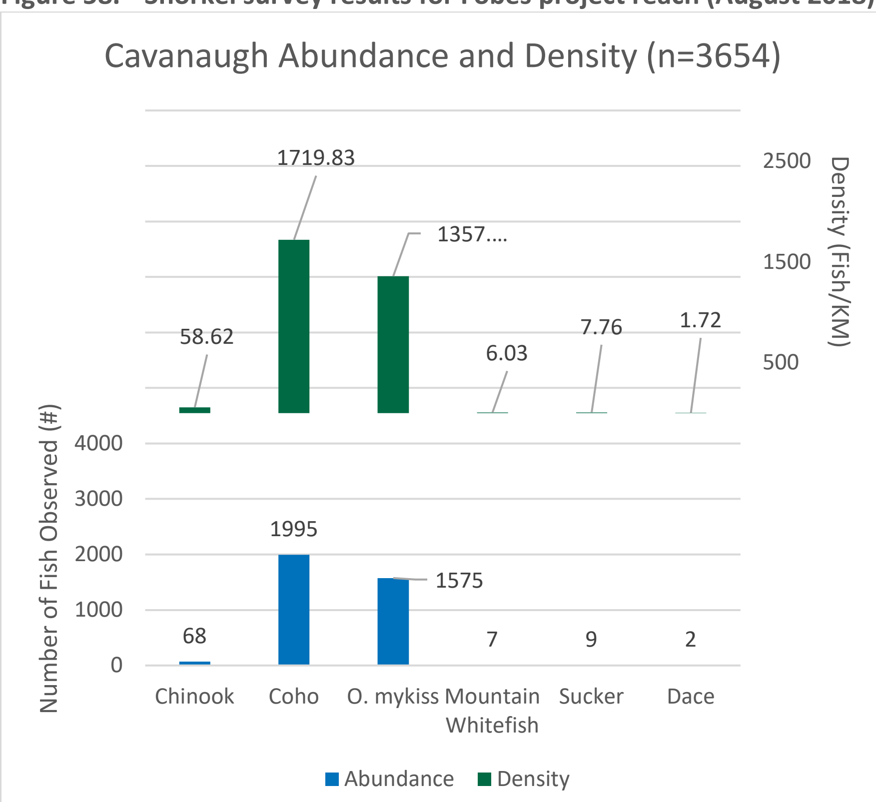


Figure 59. Snorkel survey results for Cavanaugh project reach (August 2018).

Monitoring Metrics

The Upper Cavanaugh Fobes Phase 2 project is in preliminary design and the goal is to improve upon the function of the previous Cavanaugh and Fobes projects. The objectives and current base line information are summarized below.

Objective 1 – Increase key habitat quality and diversity by creating up to 19 primary pool habitat units within five years through the placement of ELJs

There are currently 13 primary pools in the Cavanaugh-Fobes Phase 2 Reach. Consideration of placement locations, hydraulics, and sediment transport will be critical to the formation of pools that can be tied to the placement of ELJs. Wood structures should have direct interaction with the low flow and be built at a frequency (spacing) that prevents migration away from the structures and directs flow energy into scouring deep holding pools to benefit adult Chinook returning to spawn in the South Fork.

Objective 2 – Improve floodplain channel connectivity during the Q1 flow level by connecting up to 1.96 miles of off-channel habitat through bed aggradation and increased water surface elevation from installation of channel spanning log riffle ELJs

There is currently 4,400 ft (0.84 miles) of side channel habitat within the Fobes reach at the Q1 flow level, and 1,800 ft (0.34 miles) of side channel habitat within the Cavanaugh Island reach at the Q1 flow level (the Cavanaugh side channel) for a total of 1.18 miles toward meeting the objective. Additional floodplain areas besides Cavanaugh Island will need to be engaged in order to achieve this objective. We would recommend reviewing this objective with the design team to assess feasibility and identify specific locations and hydraulic outcomes for channel spanning ELJs that would promote bed aggradation. Channel spanning logjams, like those in Larson's Phase 2, have shown success in storing sediment and aggrading the channel to reconnect side channel habitat. That same approach to sediment storage and channel aggradation could be used in this reach as well. Lessons learned from Larson's Phase 2 about ELJ spacing would also benefit the design process for this reach. Designers should look carefully at structure spacing to prevent the river from flanking around behind the structures. In addition, the Q2 flow may be a more appropriate target discharge for this objective as the Q1 flow represents an estimate of bankfull conditions, whereas, the Q2 flow should overspill the banks and inundate the floodplain.

Objective 3 – Provide for spawner occupancy (low flow connectivity) of the Cavanaugh Island Side Channel

This objective is achievable if restorative actions are dense enough and block enough flow (e.g. 50-60%) to raise low flow water surface elevations in the vicinity of the side-channel inlet which could benefit spawners. Having a 50-60% blockage coefficient in the main channel would be an excellent starting point for diversion of substantial flow into the Cavanaugh Island Side Channel. Minimum blockage coefficients of >20% will be required to establish geomorphically based changes in flow patterns within the reach. Minimum depths and flow rates for Chinook spawners (e.g. > 0.35 ft and 0.65 ft/s) should be established for clarity of specifications and for measurable objectives during low flow (i.e. spawning season) (WDFW and WDOE 2016). From 2016-2018, no spawning has occurred in the side-channel (Figure 60).

Objective 4 – Increase thermal refugia for salmonid species by creating up to two primary pool habitat units in areas of cool water refuge

Primary pool goals could be separated from thermal refuge goals to increase potential for achievement. Primary pools, by definition, occupy more than half of the channel width, and cool water refugia are best maintained by keeping flow separated from the mainstem flow, so this combined objective may be very difficult to achieve. Additional pre-project data collection is recommended, including inventory of pool locations and depths, and water temperature analysis at each pool to identify and confirm locations of cool water refuge. Tributary streams have also been shown to have a strong influence on temperature and have the potential for the formation of thermal refuge- maybe even more so than via primary pools. The location and temperatures of tributary streams should also be noted as potential focus areas for thermal refuge creation. Additional research into criteria for creating cool water refuge is on-going, and separation of flow from the mainstem current, as well as targeting a maximum residual depth to separate the pool basin from the general flow of the river have both been noted as strategies for creation of cool water refuge (J. Helfield, pers. comm. 2019).

Objective 5 – Increase holding and rearing habitat by creating and enhancing up to 16 acres of wetland and 66 acres of floodplain habitat within 5 years

There are currently 2.8 acres of holding and rearing habitat (defined as side channels and sloughs) in the Fobes reach and 0.03 acres in the Cavanaugh reach as measured during the 2019 field survey. Within both the Fobes and Cavanaugh project reach, even at the Q2 flow level (which is above the flows for adult holding and most juvenile rearing), just 12.6 acres of floodplain are currently connected (excluding the Cavanaugh Island side channel), so this objective may not be achievable at 16 acres, depending on the flow target set for achievement. We would suggest verification of goal statement against hydraulic model output for proposed condition, and reviewing the goal statement with the design team to determine feasibility. Further, holding flows for adult Chinook are low flows in the summer, so the low flow model should be used for evaluation of wetland and floodplain acres. By definition, "floodplain" habitat is not likely to be connected at summer low flows, so this objective should likely be reworded. For Age-0 Chinook juveniles, outmigration in the spring may occur at higher flows, so velocity refuges are critical to create and maintain. However, wetland habitat may not be connected to the mainstem, so may not be the best target for rearing habitat. Floodplain habitat that is frequently connected to provide velocity refuge in the spring and summer during the outmigration would be the most needed for that life history type. Perennial off-channel habitat (again not wetland) would be a good target for Age-1 Chinook juveniles who are rearing for a full year before outmigration.

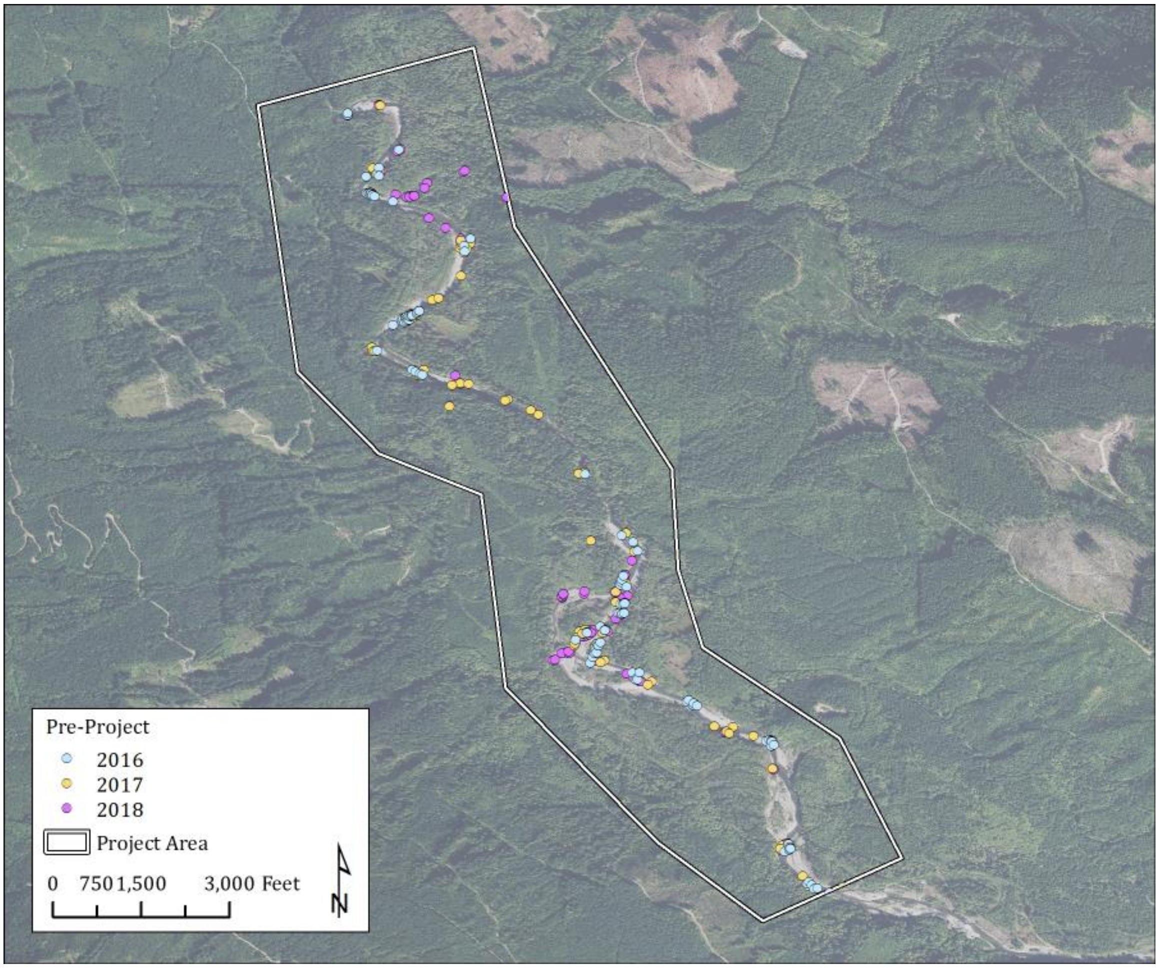


Figure 60. Chinook redds at Cavanaugh-Fobes Phase 2 project before restoration. Aerial imagery from 2017 USDA NAIP.

Recommendations:

The Upper Cavanaugh Fobes Phase 2 project has the potential to substantially increase the habitat benefit in these project reaches. As described above in the reach specific sections, some benefits have been gained from projects constructed in the reach so far, but further treatment should place structures densely enough (e.g. 500 pieces/km) to exert significant geomorphic influence on the channel to adequately influence channel processes and habitat conditions, and gain the maximum habitat benefit in the reach. This could include increasing the size and frequency of ELJs and installing channel-spanning log riffles to raise water surface elevation (WSE) enough to create and sustain deep pools and inundate off-channel areas. The design stage should also include a feasibility review of the objectives with the design team and adjustment of objectives, if necessary. Quantification of targets for side channel depths, spawning flows in the Cavanaugh Island side channel, and thermal refuge should be included as part of the objectives review. Using these quantified targets, subsequent monitoring efforts can help to verify that objectives are being met. Pre and post project monitoring of pools and temperature (with controls) is critical for evaluation of achievement of thermal refuge goals.

Skookum Edfro Phase 2 (Edfro Creek Reach)

The Skookum Edfro Phase 2 project is located downstream from the Cavanaugh Island project and extends from RM 15.4 to RM 14.9. The project was built during the summer of 2018 and was intended to address the limiting factors of *Low Habitat Diversity* and *High Water Temperatures* through the placement of fifteen ELJs along the banks of the mainstem channel and on gravel bars. The main objectives of the project are:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Skookum Edfro Phase 2	1. Increase habitat diversity and key habitats by forming 7 primary pools with ELJs within 5 yrs.	low habitat diversity
	2. Increase pool frequency by constructing 12-13 ELJs in areas that would provide holding adjacent to stable spawning habitat.	lack of key habitat
	3. Create one thermal refuge by co-locating the primary pool with cool-water input within 5 years.	high water temperature
	4. Increase floodplain activation at a broader range of flows to reduce hydraulic energy and provide velocity refugia for juveniles.	low habitat diversity
	5. Improve viable spawning areas by placing ELJs along the channel margin to increase deposition and storage of bedload sediments.	none
	6. Maintain flow split around Edfro Island by roughening the channel by placing 4 ELJs to encourage lateral channel migration and channel lengthening.	low habitat diversity

Reach Description

The Skookum Edfro Phase 2 reach contains a simple plane-bed channel morphology (Figure 61 and Appendices B-H- Skookum Edfro Phase 2). The reach begins near RM 15.5 after the channel leaves a confined bedrock canyon and flows into a straight plane bed reach. The river abuts bedrock near RM 15.3 and meanders hard to the left where it opens up into a ~650 ft wide alluvial valley. There is a 2-way flow split around Edfro island which is forested and ~2-6 ft above the low flow water surface. Edfro Creek joins the mainstem along the right bank of the right split channel near RM 15.2 The channels combine following the confluence into another plane-bed reach which extends to the end of the reach near RM 14.4. There is a narrow (~225 ft) forested floodplain surface directly downstream from the Edfro Creek confluence that is 2-6 ft above the low flow water surface. Coarse cobbles line the channel margins which indicate a lack of spawning gravels and a high sediment transport capacity through the reach (Figure 62).

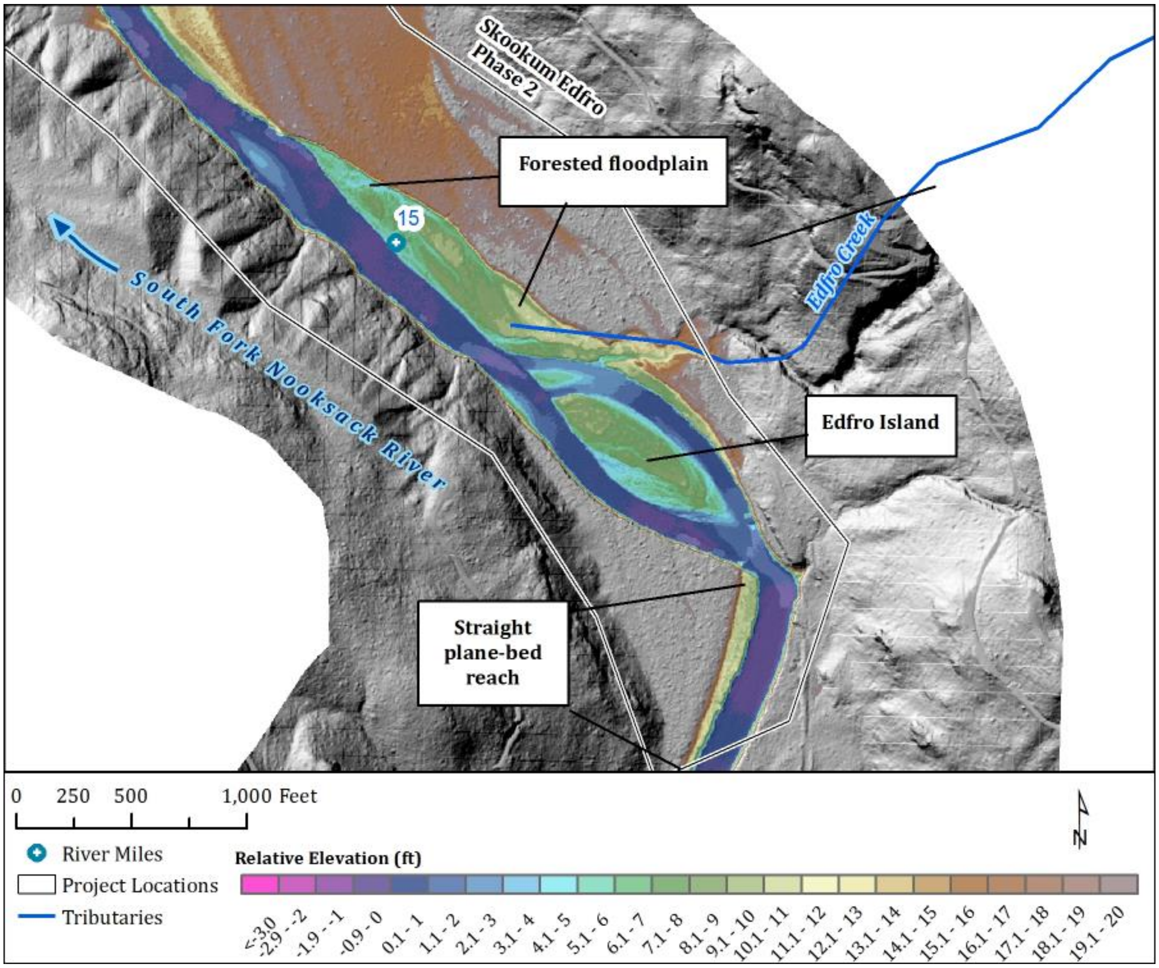


Figure 61. Relative elevation model (REM) for the Skookum Edfro Phase 2 reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

Figure 62. Coarse cobble along the channel margins within the Skookum Edfro Phase 2 Reach. Photo taken on 6/28/18.

The Skookum Edfro Phase 2 reach had low habitat diversity and a lack of stable large wood based on 2005 habitat surveys and 2017 reconnaissance, which underscored the need for the 2018 restoration activities. As of the 2005 survey, the reach contained 1 log jam (1.8 jams/mile), which increased to 16 jams with a wood area of 9,971 ft^2 in 2019. The surveyed jam is located after the valley widens beyond the straight plane bed reach. The 2005 dataset identified 3 pools, although all were within the straightened confined reach above RM 15.3 and were associated with boulders, bank wood, or the bedrock outcropping at RM 15.3 (Figure 63). The 2019 data show that 9 total pools were present including three primary pools (Table 16). The simplified habitat conditions in 2005 were further underscored by the channel unit distribution which was dominated by fast velocity units such as riffles and fast glides (Figure 65 and Figure 66). Slow water habitat units made up 9% of the reach area in 2005. The number of channel units in this reach increased from 13 in 2005 to 22 in 2019 indicating an increase in habitat diversity and additional pools formed in association with the log jams. The maps in Figure 63 and Figure 64 may not show all channel units identified above based on scale differences.

Juvenile snorkel surveys were not completed in this project reach. On average, 6% of all South Fork Nooksack Chinook redds have been detected in this project reach across all spawner survey years (1986, 1999 to 2018) (Table 23). Following project construction in 2018, 6 redds were detected in the lower portion of the right bank side channel around Edfro Island (Figure 68). Water diverted to the side channel during project construction provided spawning flows. In 2019, the side channel did not support spawning flows and no redds were detected. Future monitoring will determine availability of spawning habitat in the Edfro Island side channel.

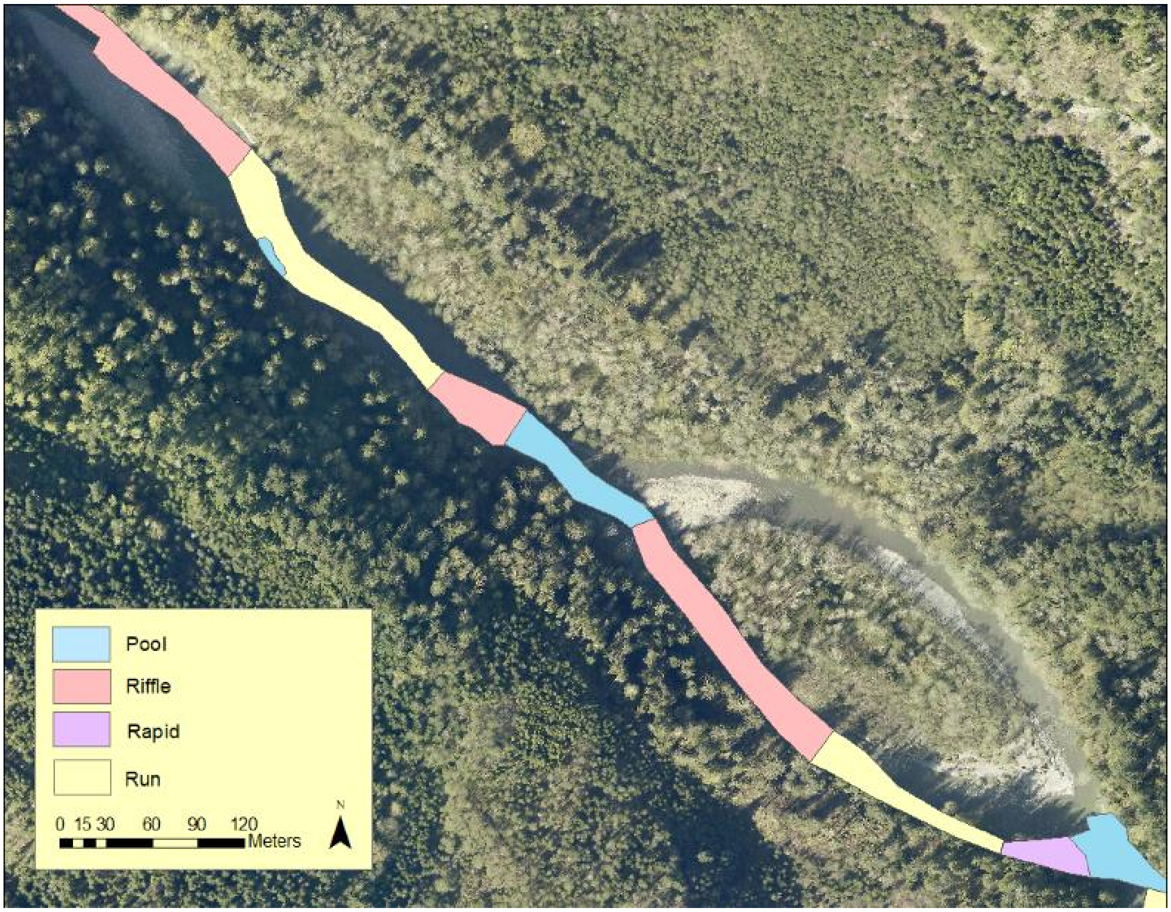


Figure 63. 2005 habitat mapping in the Skookum Edfro Phase 2 project area (LNR 2005 data, photo from 2016).

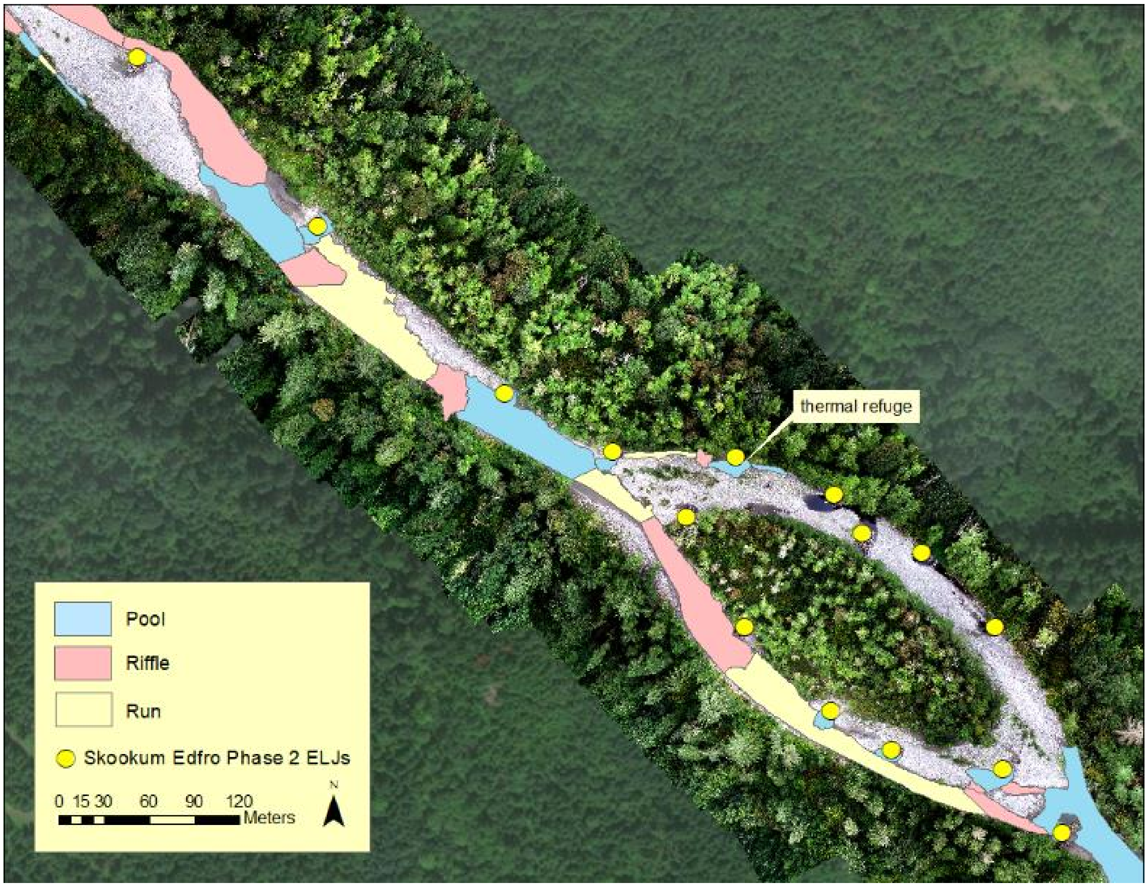


Figure 64. 2019 habitat mapping in the Skookum Edfro Phase 2 project area (LNR 2019 data, photo from 2019).

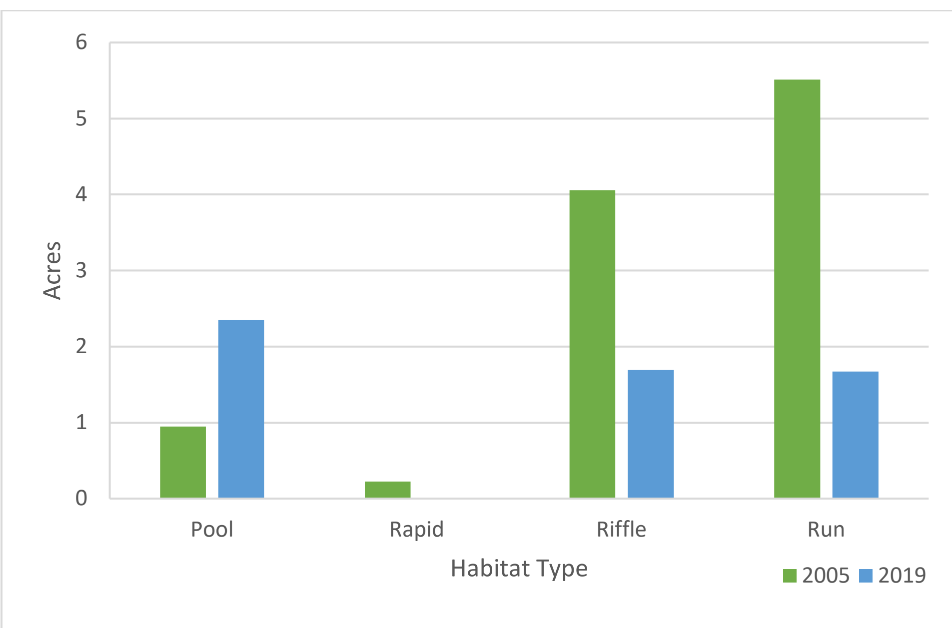


Figure 65. Area by channel unit type for the Skookum Edfro Phase 2 project reach from field surveys (2005 and 2019).

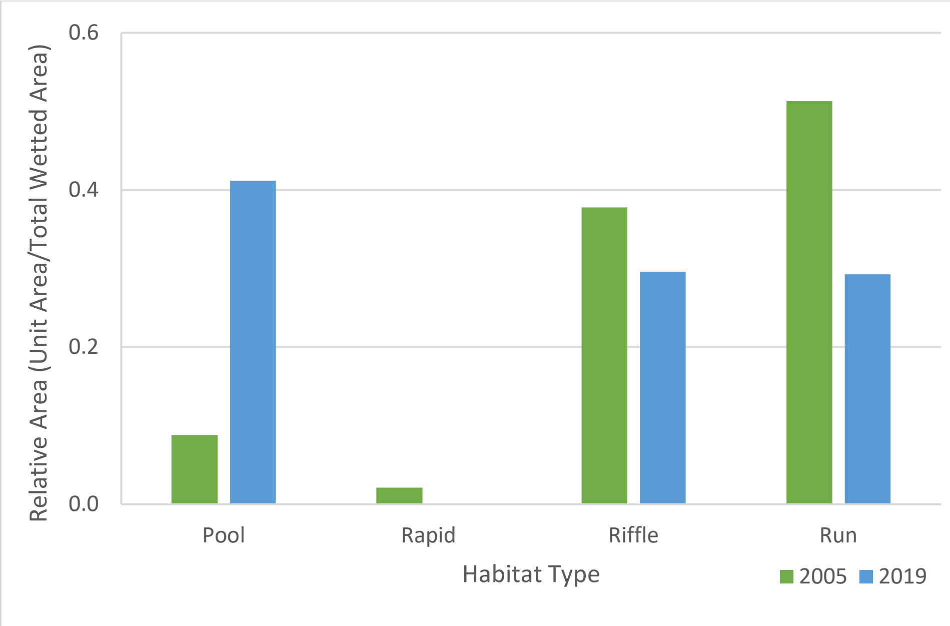


Figure 66. Distribution by channel unit type for the Skookum Edfro Phase 2 project reach from field surveys (2005 and 2019).

Table 16. Pre-restoration (2005) and post-restoration (2019) pool parameters for the Skookum Edfro Phase 2 restoration project (construction completed in 2018). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth ≥ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	3	10 (6)
Primary Pools (ELJ)	2	4 (1)
• Deep Pools (ELJ)	2	2 (0)
Secondary Pools	1	4 (4)
• Deep Pools (ELJ)	1	1 (1)
Isolated Pools (ELJ)	0	2(1)
• Deep Pools (ELJ)	0	0

Monitoring Metrics

Project metrics for the Skookum Edfro Phase 2 project reach were evaluated by reviewing pre-project and post-project data. The 2019 field surveys were conducted just one-year post-construction so the attainment of project objectives is not expected in such a short time frame.

Objective 1 – Increase habitat diversity and key habitats by forming 7 primary pools with ELJs within 5 years

This objective has not been met yet, although the project was just recently constructed. One primary pool formed by an ELJ has developed. In total, there were four primary pools in 2019, compared to 2 in 2005. Placed ELJ's formed four additional secondary pools, and one isolated pool observed during low flow 2019 surveys. The initial formation of a primary pool and pools formed by ELJs are positive indications of improving pool habitat. Subsequent monitoring could provide a definitive answer on whether the objective of forming 7 primary pools is made within 5 years.

Objective 2 – Increase pool frequency by constructing 12-13 ELJs in areas that would provide holding habitat adjacent to stable spawning habitat

This objective has been met. There are currently six pools within the project area that were formed by the fifteen ELJs based on low flow habitat surveys in 2019. Three of these pools have formed adjacent to existing spawning areas and potentially provide holding habitat (Figure 68). Chinook are currently spawning in the riffles at the upstream and downstream ends of the reach (at the head of Edfro island and below the right bank floodplain at RM 15) (Figure 68). In addition, there were three ELJ-formed secondary pools in the right channel around Edfro Island that were connected to the mainstem during 2018 spawning flows (Figure 68), but not 2019 flows. This project was just recently constructed and many of the log jams were constructed at the margins of the channel and are relatively small compared to the channel flow. Although holding pools have been formed near spawning areas, the relative effect of some of the structures on the channel morphology has been small, at least at the low flow. Larger jams that force more interaction with flow and sediment due to mid channel placement and a large blockage coefficient would likely have a greater hydraulic and thus geomorphic effect on the channel (Manners et al. 2006). Wood structures with blockage coefficients of 10% or less can be effective at creating and sustaining pools with complex cover. However, in alluvial valleys with actively migrating channels, arrays of engineered logjams must be constructed that are spaced no more than 80% of the unobstructed bankfull width, so that for any flow path, the river encounters at least a 20% blockage coefficient. However, the location of the Skookum Hatchery infrastructure and Saxon Road may limit the potential for larger scale work in this reach.

Objective 3 – Create one thermal refuge by co-locating the primary pool with cool-water input within 5 years

The ELJ installed at the mouth of Edfro Creek, the cool-water input in this reach, has formed a pool that spans the side channel, but it does not qualify as a primary pool. The pool does provide thermal refuge in the side channel on the right bank during summer low flows when temperatures are higher in the mainstem South Fork (Figure 67). Chinook redds were detected in the side channel during 2018 spawner surveys, indicating spawning adults had access to the pool, however, this was as a consequence of project construction which diverted flows into the side channel. In 2019, the pool was inaccessible to spawning adults during low flows. Many coho juveniles have been observed in this pool (A. Levell, pers. comm, 2019). This objective was partially met. The objectives of forming a primary pool and cool-water refugia should be decoupled as they may be difficult to achieve in the same location.

Objective 4 – Increase floodplain activation at a broader range of flows to reduce hydraulic energy and provide velocity refugia to juveniles

There was no floodplain inundation at the Q1 or Q2 flow levels within the project area in the pre-project conditions. Without post-project data from hydraulic modeling or field monitoring of high flow conditions, this objective cannot be assessed. During the habitat survey, no data were collected on recent debris within the floodplain to map out the extent of overbank flows, although a flood in November 2018 topped 13,000 cfs on the USGS gage at Saxon (USGS 2020). Even in the absence of indicators of high flow extents, there are only 11 acres of available floodplain within the project area that are less than 20 feet above the low flow water surface (Figure 59). Inundating these fairly confined areas may cause significant disturbance to existing vegetation, if hard points are not capable of protecting the floodplain areas until the trees can grow to a size large enough to resist the hydraulic forces.

Objective 5 – Improve viable spawning areas by placing ELJs along the channel margin to increase deposition and storage of bedload sediments

The channel margins currently consist of coarse cobbles and boulders. Reducing shear stress in these areas with ELJs should cause finer sediments (spawning gravel) to aggrade, but information on bed elevations before and after project implementation would be needed to assess storage of bedload sediments. Further, detailed sediment characterization (Wolman 1954) and mapping of spawning gravel areas before and after project implementation would be needed to assess changes in spawning areas. During the 2019 field surveys, detailed sediment information was not collected, and should be added to the protocol in order to assess these types of objectives. However, looking at photos in Google Earth, some areas of gravel deposition can be seen along the margins at the upstream end of the project and specifically, at the upstream end of the jam at the head of Edfro Island. Spawning data from pre-project conditions shows the vast majority of spawning occurs in two areas – in the left bank (main channel) channel directly downstream from the flow split around Edfro Island, and approximately 0.2 miles downstream from the channel split confluence. In both areas, the spawning is occurring in riffles directly downstream of a full channel spanning pool (Figure 64 and Figure 68). Future spawner surveys, and additional data collection regarding the deposition of sediments, bed elevation, and sediment sizes is needed to fully assess this objective.

Objective 6 – Maintain flow split around Edfro Island by roughening the channel by placing 4 ELJs to encourage lateral migration and channel lengthening

There was not a low flow split and side channel around Edfro Island during the 2019 habitat monitoring. In the lower section of the side channel, a groundwater-fed slough was present, and Edfro Creek was also contributing to this flow (Figure 64). LNR has documented flow split around Edfro Island during higher flows, and pool formation and wood deposition associated with engineered logjams on the north side of the island also indicate this connection. This flow split will need to be monitored to determine if this objective is met, and to what extent. Additional data is needed on channel length and position to determine if lateral migration and channel lengthening have occurred. This objective cannot be assessed with the available information.

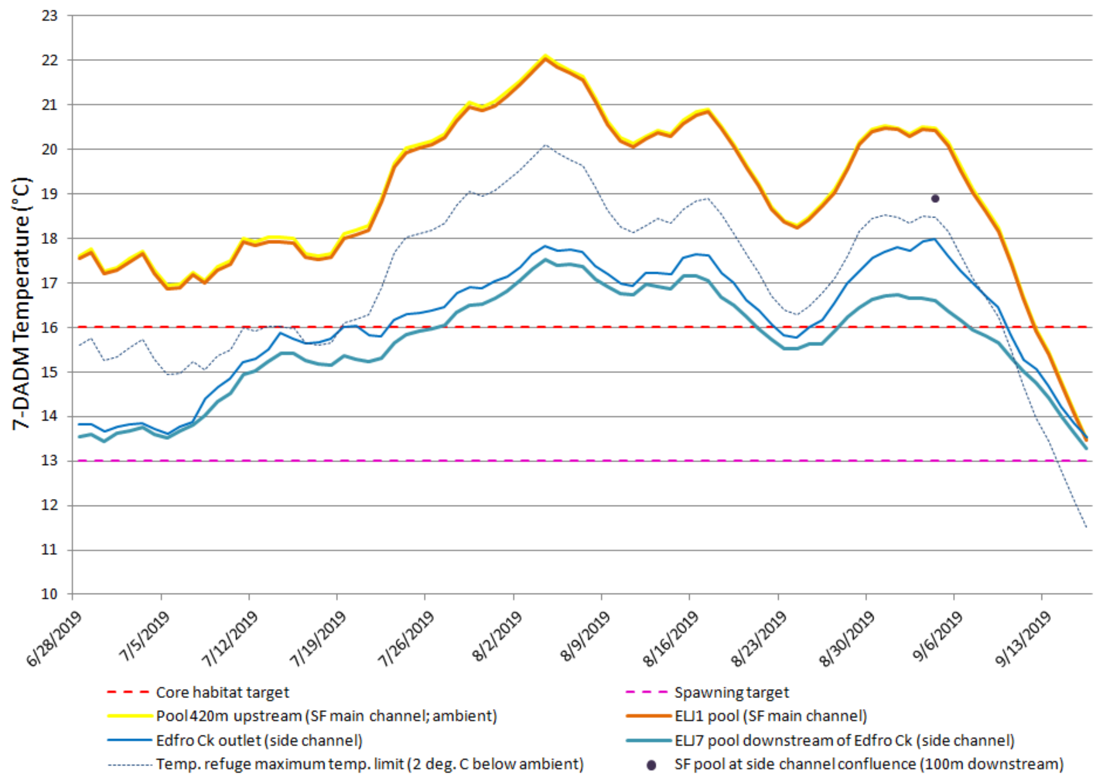


Figure 67. South Fork main channel and side channel temperature above and below the Edfro Creek confluence (paired probe controls) recorded in 2019 and presented as 7-day average maximum temperatures (LNR 2019).

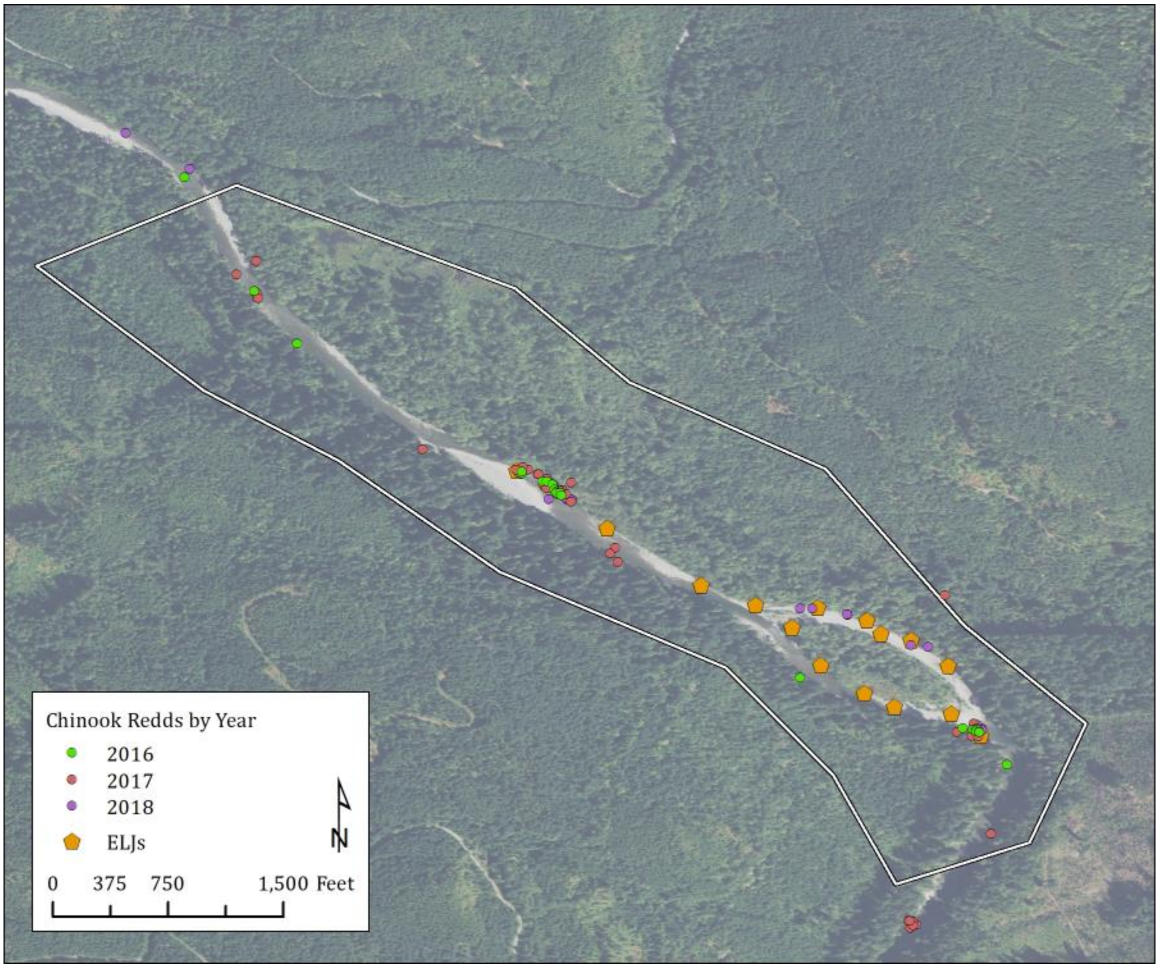


Figure 68. Chinook spawning map for Skookum-Edfro Phase 2. Aerial Imagery from 2017 USDA NAIP.

Table 17. Skookum-Edfro Phase 2 project objectives and success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Increase habitat diversity and key habitats by forming 7 primary pools with ELJs within 5 yrs.	Pool formation	**Partially Met**- Four primary pools, including one ELJ-formed pool were present in 2019, an increase from 2 in 2005. Five years post project will occur in 2023.
Increase pool frequency by constructing 12-13 ELJs in areas that would provide holding adjacent to stable spawning habitat.	Pool formation	**Met**- ELJs formed 1 new primary pool and 5 new secondary scour pools post-construction, three of which are adjacent to existing spawning areas.
Create one thermal refuge by co-locating the primary pool with cool-water input within 5 years.	Thermal refuge creation	**Partially Met** – Thermal refuge has been created / expanded in ELJ scour pool, but it is not a primary pool.
Increase floodplain activation at a broader range of flows to reduce hydraulic energy and provide velocity refugia for juveniles.	Floodplain connectivity	**Unknown** – The monitoring data to assess achievement of this objective are not available.
Improve viable spawning areas by placing ELJs along the channel margin to increase deposition and storage of bedload sediments.	Spawning gravel retention	**Unknown** – The monitoring data to assess achievement of this objective are not available.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Maintain flow split around Edfro Island by roughening the channel by placing 4 ELJs to encourage lateral channel migration and channel lengthening.	Secondary channel length	**Unknown** – There is evidence of spawning and high flow connectivity around Edfro Island, but the area was not connected during the low flow period in 2019.

Recommendations

Initial monitoring or the Skookum-Edfro Phase 2 project has shown increased pool frequency and initial formation of a thermal refuge in a side channel pool at the mouth of Edfro Creek. Current access to that refuge is limited at low flows, which may prevent use by spawners when temperatures in the South Fork are highest. This project was constructed very recently however, and additional time and monitoring are needed to adequately assess objective achievement. Assessment of three of the six objectives requires additional information in the form of hydraulic modeling to assess floodplain connection, sediment characterization (sediment sizes, distribution), bed elevation, areas of spawning gravels, and channel length in the area of the flow split around Edfro Island. These data should be collected before and after project implementation to adequately assess change. Since the project has recently been implemented, additional post-project data should be collected and compared to the design assessment information to try to capture changes from baseline condition. Future project efforts should review project objectives and ensure that adequate baseline monitoring data are available to assess objective achievement before project implementation takes place.

Skookum-Edfro Phase 1 and Skookum Reach project

The Skookum- Edfro Phase 1 and the Skookum Reach project areas are both co-located downstream from the Skookum-Edfro Phase 2 project reach and extend from RM 14.3 to 13.9. The project reach contains the Lummi Nation Skookum Creek hatchery on the right side of the valley directly downstream from Skookum Creek. The two projects were both built in this reach – Skookum Reach built in 2010 and Skookum-Edfro Phase 1 in 2016-2017. The Skookum Reach project included the setback of ~3,800 feet of a stream-adjacent road, the installation of 3 engineered logjams along a terrace of the South Fork Nooksack to create thermal refugia near the Skookum Creek confluence, and revegetation of the old road. This project had to consider flood risks to private property along the left bank and thus, could not dramatically influence flood hydraulics (no net rise in water surface). The 2016-2017 project was constructed following the purchase of that property by Whatcom Land Trust and was designed to engage more floodplain, as the no-rise requirement in the floodway was altered to a 0.2 ft average cross-section rise across the project. This project augmented the existing ELJs, so that they projected further into the channel, built four additional ELJs, installed four habitat log structures in the side channel, removed ~330 feet of rip-rap, removed a culvert over Christie Creek, and removed a cabin in the 100-year floodplain in order to address the limiting factors of *Low Habitat Diversity*, *High Water Temperature, and Elevated Fine Sediment*. Project structures were designed to scour deep pools with woody cover adjacent to the Skookum Creek and hatchery outfall cool water sources to provide thermal refuge for migrating and holding Chinook salmon and to provide cover near the hatchery outfall for returning salmon to reduce potential for poaching. This section will focus on evaluating the effectiveness of the 2016-2017 project, since it was built on restorative actions undertaken earlier, but will also evaluate the project response to the earlier project objectives where possible. The main objectives of both projects were:

PROJECT	OBJECTIVES	LIMITING FACTOR ADDRESSED
Skookum Edfro Phase 1	1. Increase habitat diversity and key habitats by forming four primary pool units with ELJ placement within five years.	low habitat diversity and lack of key habitat
	2. Create two thermal habitat refuge areas by co-locating new primary pool units with existing cool-water inputs within five years.	high water temperature
	3. Improve channel edge habitat by removing hydromodifications and adding four habitat log structures along the low-flow island channel within five years.	low habitat diversity and elevated fine sediment
Skookum Reach	1. Increase key habitat quantity in 3,400 ft of South Fork channel	lack of key habitat
	2. Relocate 3,800’ of stream-adjacent road, well away from the river (replace with 3,000 ft of road).	elevated fine sediment
	3. Increase habitat diversity in 1,100 ft of South Fork channel	low habitat diversity
	4. Provide refugia from elevated water temperatures in three holding pools	high water temperature

Reach Description

The Skookum Edfro Phase 1 reach contains a simple plane-bed channel morphology (Figure 69) and Appendices B-H: Skookum Edfro Phase 1). The reach begins at the confluence of Skookum Creek, a major tributary and cold water source, which joins the Upper South Fork Nooksack River on the right bank near RM 14.3. The right side of the valley contains the Skookum Creek hatchery, which is disconnected from the river by a road. There is a 200-500 ft terrace on the river side of the road, which is 8-10 ft above the low flow water surface. The same terrace extends to the left side of the valley, where it is 100-600 ft wide until RM 14.0. Downstream of RM 14.0, the river abuts the left hillslope. There is a vegetated mid-channel island in the middle of the reach near RM 14.1 with the main channel running along the left side of the island and a small side channel along the right. The side channel had ~0.5-1 ft of depth during the field survey (Figure 69).

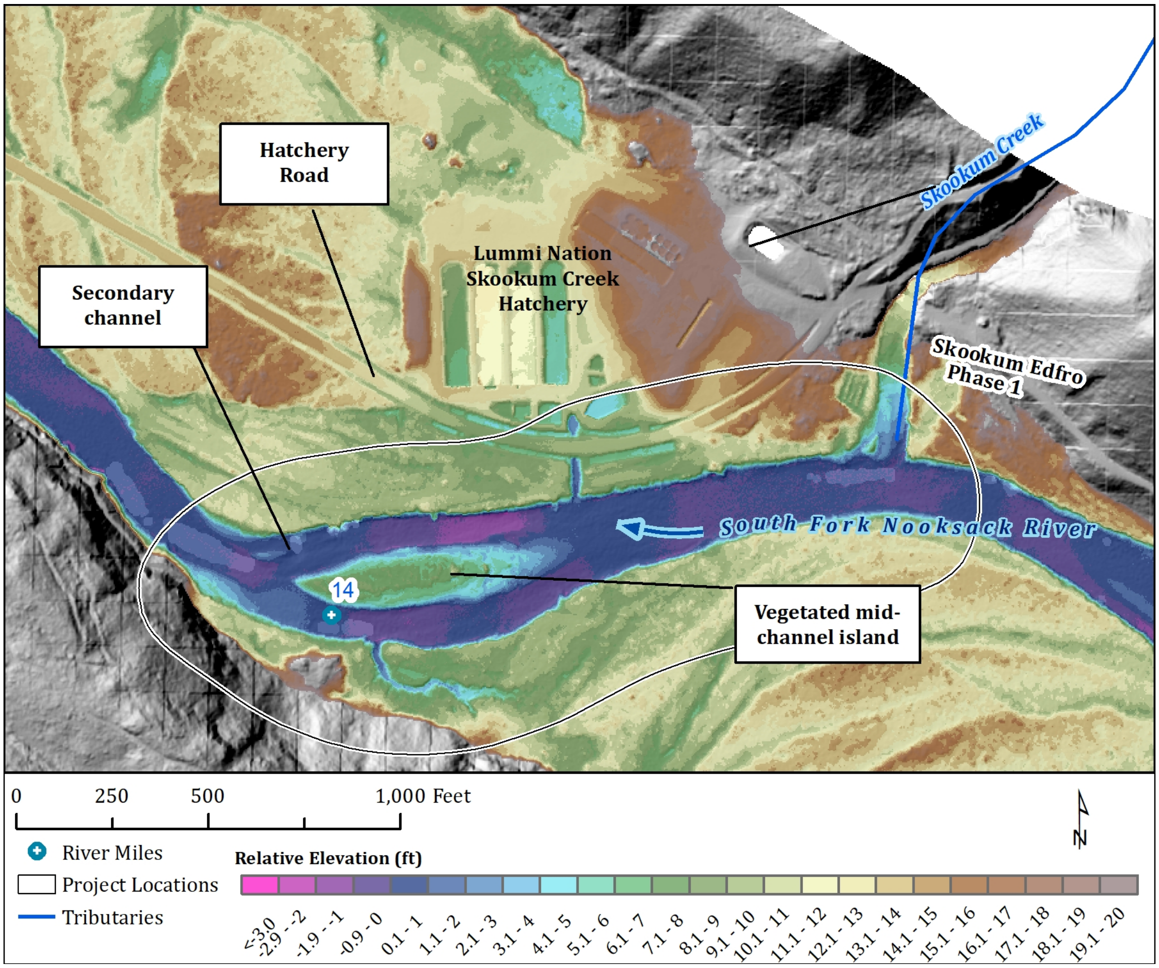


Figure 69. Relative elevation model (REM) for the Skookum Edfro Phase 1 reach on the Upper South Fork Nooksack River. The REM was developed using the 2017 topobathymetric LiDAR DEM. Flow is to the left.

The reach is dominated by fast-velocity habitat units which comprise roughly 91% of the total area, with pools comprising the remaining 9% of the reach (Figure 73). Pre-project data from 2005 identify one pool in the project area (Table 16, Figure 70). During monitoring in 2011, two small secondary pools were noted at two of the three structures built as part of Skookum 2010 (Maudlin and Coe 2011). Field surveys in 2019 identified six secondary pools at ELJs and one primary confluence pool (Figure 71 and Figure 74).

Juvenile snorkel surveys were not completed in this project reach. On average, 4% of all South Fork Nooksack Chinook redds have been detected in the Skookum Reach and Skookum Edfro Phase 1 project reach across all spawner survey years (1986, 1999 to 2018) (Table 23).

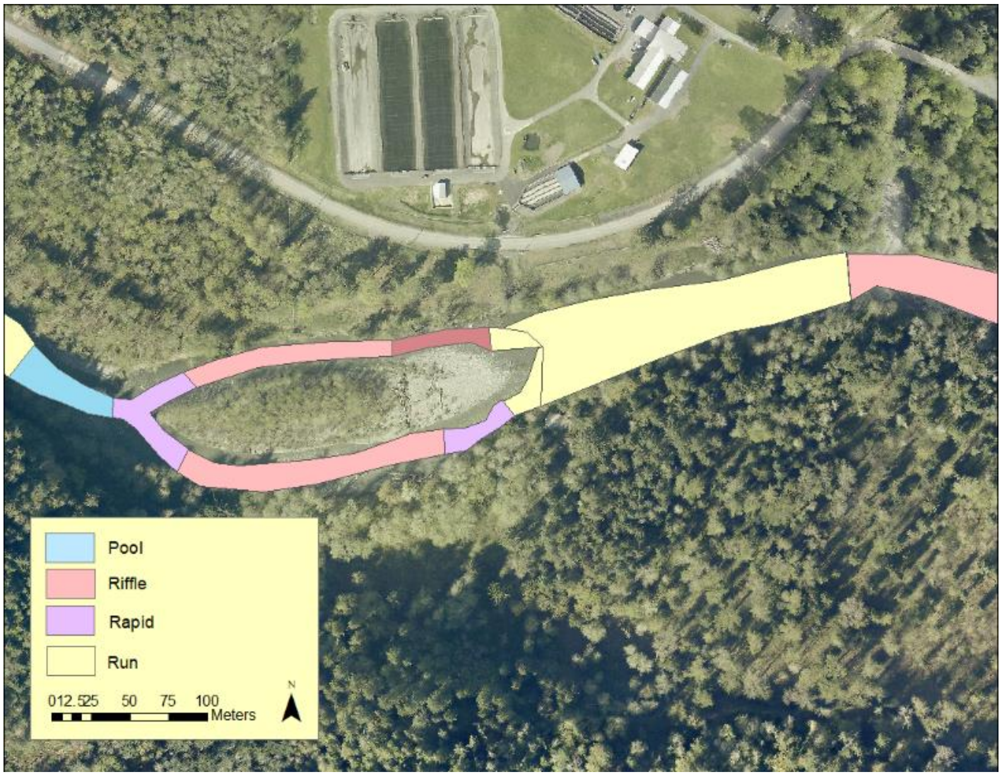


Figure 70. 2005 habitat mapping in the Skookum and Skookum Edfro Phase 1 project area (LNR 2005 data, photo from 2016). Mapping may not show the entire project area, so numbers of pools may differ from Table 16.

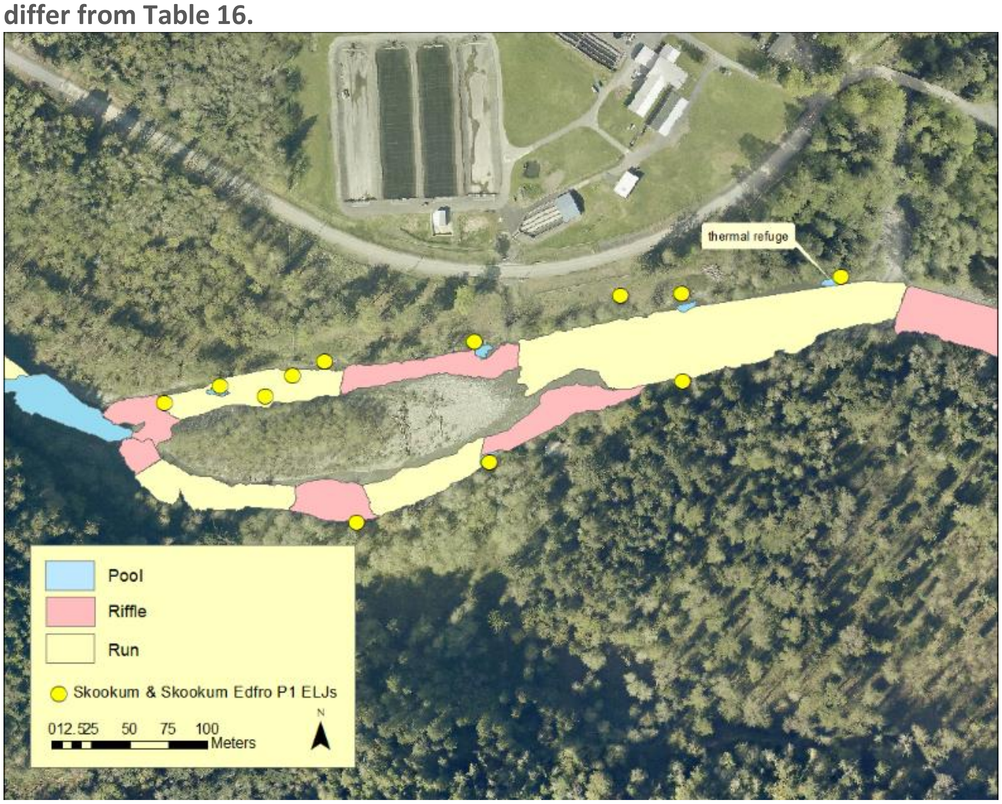


Figure 71. 2019 habitat mapping in the Skookum and Skookum Edfro Phase 1 project area (LNR 2019 data, photo from 2016).

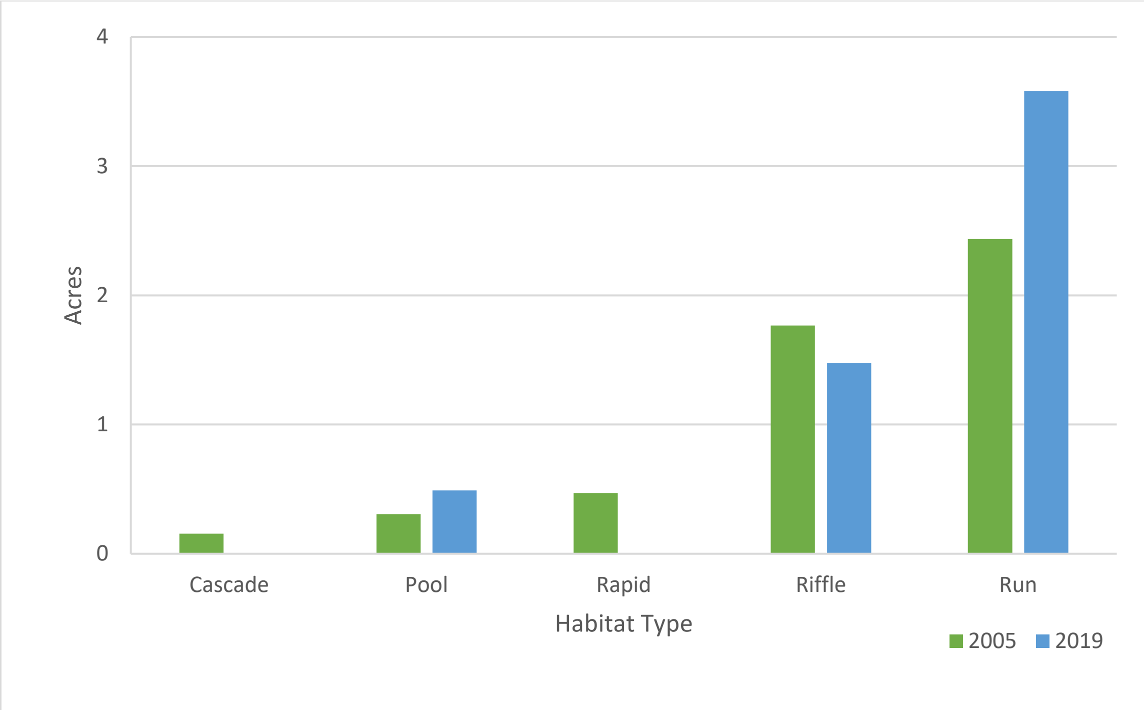


Figure 72. Channel unit area for the Skookum Edfro Phase 1 project reach.

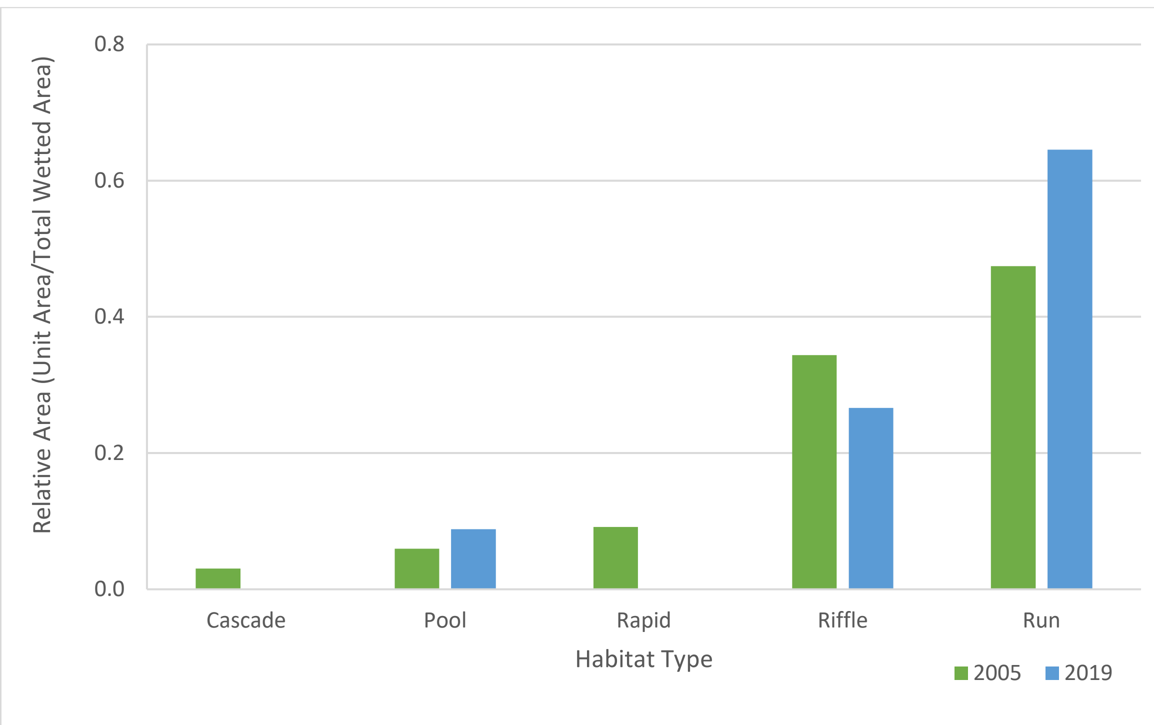


Figure 73. Channel unit distribution for the Skookum Edfro Phase 1 project reach.

Table 18. Pre-restoration (2005) and post-restoration (2019) pool parameters for the Skookum Edfro Phase 1 restoration project (construction completed in 2016-2017). Pool parameters include the total number of pools, number of primary and secondary pools, and number of deep pools (residual depth ≥ 3.28 ft (1m)). Those pools formed by an ELJ are shown in parentheses.

POOL PARAMETER	2005	2019
Total Pool Count (ELJ)	1	7 (6)
Primary Pools (ELJ)	1	1 (0)
• Deep Pools (ELJ)	1	1 (0)
Secondary Pools	0	6 (6)
• Deep Pools (ELJ)	0	1 (1)

Figure 74. Scour pool associated with an ELJ within the Skookum Edfro Phase 1 reach. The jam is located directly downstream from the Skookum Creek confluence and the pool is 4.2 ft deep (max depth). The photo was taken on 6/28/18 with flow going to the right.

Monitoring Metrics

The Skookum Edfro Phase 1 project was completed in 2017 in the same area as the original Skookum Reach project, as adaptive management for that project. Since both projects are in the same area, post-project data primarily reflect the more recent restoration actions, but some evaluation of the original objectives is possible. Pre- and post-project monitoring results are discussed below by objective.

Skookum-Edfro Phase 1

Objective 1 – Increase habitat diversity and key habitats by forming 4 primary pools with ELJs within 5 years

This objective has not been met yet, although only two years have passed since construction, so the five-year time frame has not passed. The field survey in 2019 identified 6 secondary pools associated with ELJs which is an increase over two that were noted in 2011 using the same field methods. One deep, confluence-formed primary pool was detected at the downstream end of the project, the same primary pool detected in 2005. No ELJ-formed primary pools were identified, likely due to the placement of the ELJs along the margins of the channel in the project area. The habitat diversity has decreased from 5 channel types found in 2005 to 3 mapped in 2019 (Figure 73) but again, this is only two years after construction. Additionally, the proportion of run habitat has increased and the two habitat types not present in 2019 that were found in 2005 are cascades and rapids, so the loss of the steep fast water units is not really a net degradation.

Objective 2 – Create two thermal refuge areas by co-locating new primary pool units with existing cool-water inputs within five years

This objective has not been met, although two thermal refuges co-located with ELJ-formed secondary pools have been created. Three ELJs were installed and augmented adjacent to the cool water area downstream of Skookum Creek and the hatchery outfall. The secondary pools associated with two of these structures did contain cooler water than the main flow, but do not qualify as primary pools because they do not span at least 50% of the wetted channel (Hawkins et al 1993). Skookum-Edfro Phase 1 was built in 2016-2017, so additional time and high flows may result in larger pool formation.

Field data collection in 2018 and 2019 highlighted the role of Skookum Creek in providing cold water to the Upper South Fork Nooksack and reducing water temperature. (Figure 75). During the June 2018 field visit, reductions in water temperature were measured relative to the average main channel temperature at the outlet with Skookum Creek (1.2°C lower) and 130 feet downstream of the confluence in a right bank secondary pool (ELJ 13; 1.5°C lower). Temperature probes placed in pools in the mainstem South Fork above and below the Skookum Creek confluence in 2019, indicate that the ELJ-13 secondary pool provides habitat in a thermal refuge (2°C below control) from August 4th to September 12th, likely starting as early as mid-July. This difference was maintained until the second week in September when water temperatures began to fall in both areas. Since the input of cool water from Skookum Creek can be detected, it is important that additional holding habitats be created in this reach to take advantage of this important thermal shift.

The second thermal refuge was detected during 2019 low flow habitat surveys at the augmented ELJ co-located at the hatchery outfall (labeled ELJ-2 for Skookum Reach project and ELJ-18 for Skookum-Edfro Phase 1 project; Appendix C). The hatchery outfall temperature was 2.5°C cooler than ambient mainstem water temperature (16.2°C). In the secondary pool underneath the ELJ and extending to ~30 feet downstream of the ELJ, water temperatures were 2.3°C cooler than ambient mainstem water temperature.

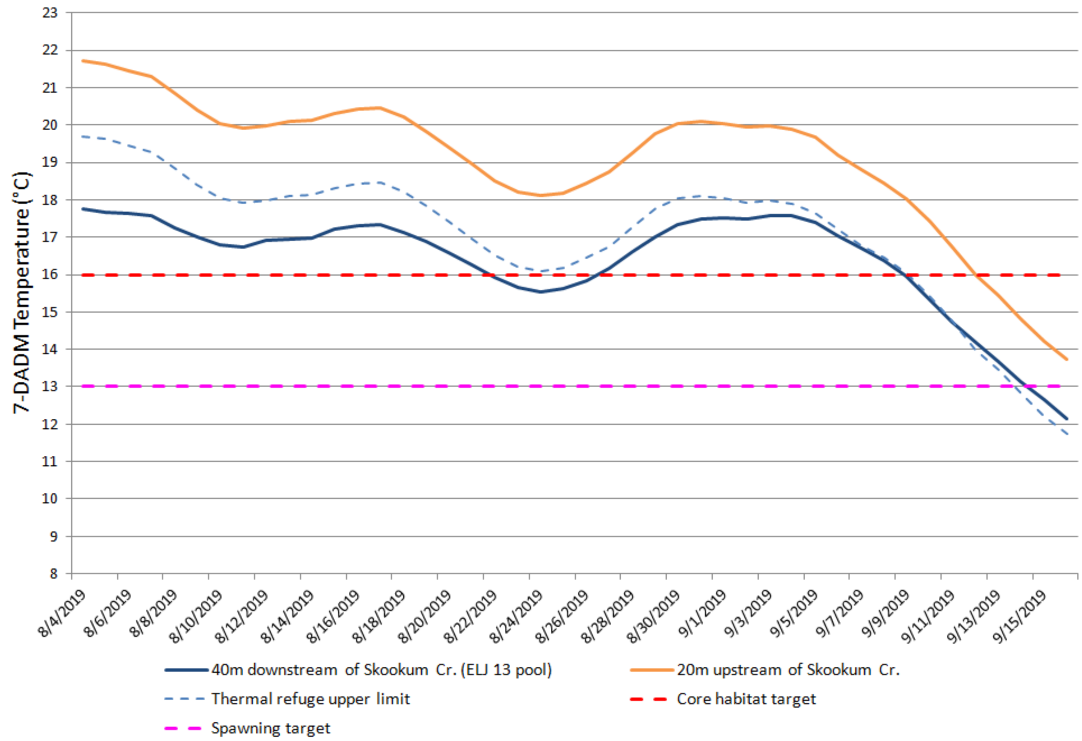


Figure 75. South Fork main channel temperature above and below the Skookum Creek confluence (paired probe controls) recorded in 2019 and presented as 7-day average maximum temperatures (7-DADM) (LNR 2019).

Objective 3 – Improve channel edge habitat by removing hydromodifications and adding four habitat log structures along the low flow island channel within five years

This objective has been achieved. Channel edge habitat has been improved within the low-flow island channel through the placement of habitat log structures. The structures are engaged with the low flow channel and are providing cover and hydraulic gradients for aquatic organisms. Approximately 330 feet of riprap was removed as part of the project construction.

Skookum 2010

Objective 1 – Increase key habitat quantity in 3,400 feet of South Fork channel

This objective was not met by the initial installation of the Skookum 2010 project in terms of meeting the requirements for primary pools; however, 2011 data show that two secondary pools formed as a result of the project (Maudlin and Coe, 2011). Additionally, edge habitat along the reach was improved, providing some benefit in key habitat.

Objective 2 - Relocate 3,800 feet of stream-adjacent road, well away from the river (replace with 3,000 feet of road)

This objective was met in terms of the physical movement of the road away from the channel. As trees grow and the road revegetates, this area may provide an additional source of large wood to the channel.

Objective 3 - Increase habitat diversity in 1,100 feet of South Fork channel

This objective was achieved. The habitat diversity in the South Fork Channel has increased from 8 channel units in 2005, with 5 unique types to 10 channel units with 3 unique types in 2019. These data include the influence of the Skookum Phase 1 project, but other channel unit specific data were not available (Maudlin and Coe 2011).

Objective 4 - Provide refugia from elevated water temperatures in three holding pools

This objective is not currently being met in the project area. Although an increase in the number of secondary pools was noted during the 2019 field survey, and two cold water refuges were documented, three holding pools providing cold water refuge were not created. The secondary pool near the mouth of Skookum Creek and the hatchery outfall provided thermal refuge, but they were not large or deep enough to qualify as holding pools for Chinook spawners.

Table 19. Skookum and Skookum-Edfro Phase 1 project objectives and success.

STATED PROJECT OBJECTIVES	OBJECTIVE GROUP	OBJECTIVE SUCCESS
Increase habitat diversity and key habitats by forming four primary pool units with ELJ placement within five years.	Pool formation	**Not Met**- primary pools were not present in the project reach during the 2019 surveys.
Create two thermal habitat refuge areas by co-locating new primary pool units with existing cool-water inputs within five years.	Thermal refuge creation	**Not Met**- cooler water areas are present along the bank, but no primary pools have been formed.
Improve channel edge habitat by removing hydromodifications and adding four habitat log structures along the low-flow island channel within five years.	Edge habitat improvement	**Met**- structures were providing complex wood edges and riprap was removed.
Increase key habitat quantity in 3,400 ft of South Fork channel	Pool formation	**Not Met**- two secondary pools were formed as a result of the Skookum 2010 project. No primary pools have been formed by ELJs.
Relocate 3,800’ of stream-adjacent road, well away from the river (replace with 3,000 ft of road).	Riparian habitat	**Met**- the road was relocated and the road grade was reforested.
Increase habitat diversity in 1,100 ft of South Fork channel	Habitat unit diversity	**Met**- based on the 2019 field survey the number of channel units has increased, although the number of channel unit types was reduced from 4 to 3.
Provide refugia from elevated water temperatures in three holding pools (previously two pools).	Thermal refuge creation	**Not Met**- OneTwo thermal refuge at ELJ-formed secondary pools were created, but no primary pools have been formed.

Recommendations

The ELJ placements in the Skookum Edfro Phase 1 project and the Skookum Reach Project are not hydraulically engaged enough to exert geomorphic influence on the channel to form deep, large primary pools. Structures placed to block 50 to 60 percent of the mainstem flow would be more likely to form primary pools. They are built along the channel banks and extend only a few feet into the main channel. Because of this, the channel has simply migrated slightly away from the jams instead of forming new and connected pools. When the river does interact with the structures, there is likely not enough sediment transport capacity to scour sediment deposited from Skookum Creek and thus, some pools have likely filled in. The limited channel response from the restoration actions is understandable, given the flood regulation constraints of the project and floodplain infrastructure; however, future efforts should analyze whether the expense of installing a project along the margins of the channel is cost effective for the benefits achieved.

If future restoration work is to occur in this reach, removal of floodplain infrastructure should be considered so that restoration actions can include ELJs at high enough densities (e.g 500 pieces/km) and blocking enough of the main flow (50 to 60 %) to have a substantial geomorphic influence on habitat conditions within the reach. This reach includes an important thermal asset in the South Fork in the form of Skookum Creek and the hatchery outfall. Additional acquisition to protect and increase flow in this important resource is recommended. Two secondary pool associated with a thermal refuge was documented at ELJ-13 and ELJ-18 and improvements in edge habitat were achieved by the project. Active restoration to increase the influence area of the Skookum Creek flow could help to address the primary limiting factor of high water temperature.

INTER-PROJECT ANALYSIS

The evaluation of each project on an individual basis is useful in terms of determining whether project-specific objectives have been achieved; however, additional information can be gained from an analysis of data across projects to look at the relative success of each effort and potentially identify factors related to success that can be adopted in future efforts. The Upper South Fork Nooksack presents a unique opportunity to look at past projects, evaluate adaptive management efforts, and continue that adaptation with further recommendations for improving restoration projects.

Data presented in the previous sections will be referred to in the sections below, but through the lens of comparative examples of project effectiveness. This includes compiled results for the pool frequency and large wood analyses. We will also discuss reach wide fish survey results and provide additional context to some of the earlier observations of fish use at the project level. Finally, this section will provide conclusions from the intra-project analysis that will feed into the recommendations for future design and monitoring in the Upper South Fork Nooksack.

Pool and Logjam Data

The amount, size, and frequency of pools can be compared between projects in order to draw conclusions about how different restoration actions influence habitat goals (Table 20).

Table 20. Summarized pool data for each of the current or proposed project reaches within the study area of the Upper South Fork Nooksack River. Statistics and values were calculated using the channel habitat units from the 2018-19 habitat survey.

PROJECT AREA	PROJECT REACH LENGTH (MILES)	NUMBER OF POOLS	POOLS/ MILE	PRIMARY POOLS	NUMBER DEEP POOLS (RESIDUAL DEPTH ≥ 3.28 FT (1 M))	TOTAL PROJECT REACH AREA (ACRES)	PERCENT POOL AREA IN PROJECT AREA (%)
River Mile 30	0.1	2	20.0	1	0	1.37	5
Elk Flats	0.7	4	5.7	2	2	9.33	14
Camp 18	1.5	8	5.3	4	7	21.09	9

PROJECT AREA	PROJECT REACH LENGTH (MILES)	NUMBER OF POOLS	POOLS/ MILE	PRIMARY POOLS	NUMBER DEEP POOLS (RESIDUAL DEPTH ≥ 3.28 FT (1 M))	TOTAL PROJECT REACH AREA (ACRES)	PERCENT POOL AREA IN PROJECT AREA (%)
Larson's Phase 2	1.5	37	24.7	19	20	14.99	52
Fobes Reach	1.4	17	12.1	7	4	19.53	15
Cavanaugh Island	0.8	7	8.8	2	2	7.96	20
Skookum Edfro Phase 2	0.6	10	16.7	4	3	5.71	41
Skookum Edfro Phase 1	0.3	7	23.3	1	2	5.55	9

There is a general lack of primary and deep pools (average residual depth ≥ 3.28 ft) within the Upper South Fork Nooksack River. Deep pools make up the majority of pools in only three of eight project reaches – Elk Flats, Camp 18, and Larson's Phase 2. Most of the pools within the study area are shallow and several reaches have fewer than five deep, primary pools (Table 20), which was a major target identified in the limiting factors for the South Fork. Causal factors for the formation of deep pools have been documented extensively (Abbe and Montgomery 1996, Beschta and Platts, 1986, Pleus et al. 1999.) and include logjams, rootwads, logs, boulders, bedrock, and other elements that increase channel roughness, as well as lateral scour pools along the outside of river bends. Although these elements are well documented, the interactions between wood, water and sediment are sufficiently complex that it is not always possible to predict whether a specific structure will result in the establishment of a deep, primary pool over the long-term. From a review of the structures at Larson's Phase 2, where 19 primary pools were formed, including 13 deep pools, blockage of the mainstem flow of the channel by 50 to 60 percent was an important factor in the creation of those pools.

Pool frequency is quite low in Elk Flats, Camp 18, and Cavanaugh where there are less than 10 pools per mile. Frequency is highest at Larson's, which given the intensity of wood treatment at the site relative to other reaches, is expected. River mile 30 and Skookum Edfro Phase 1 area are also high, but with the short length of the project, only 0.1 and 0.3 miles, the frequency metric is particularly sensitive and should be interpreted with caution. A target for pools/mile established by NOAA Fisheries was 18 pools/mile for larger rivers (NMFS 1996). Using this target, only RM 30, Larson's Phase 2, and Skookum Edfro Phase 1 are meeting the standard for properly functioning habitat conditions for salmonids. NOAA Fisheries also identified a target of >50% pool habitat by area, which only Larson's Phase 2 is currently meeting. Additional analysis on the percent of pools with cover by area would be helpful to assess holding habitat for adult Chinook.

Table 21. South Fork logjam loading pre and post projects. Pre-project aerial imagery was interpreted for logjams at each project prior to implementation. RM 30 (2006), Larson's Phase 2 (2013), Fobes (2009), Cavanaugh (2011), Skookum Edfro Phase 2 (2018), Skookum Edfro Phase 1 (2016) (Source LNR data).

PROJECT AREA	REACH LENGTH (MI)	PRE-PROJECT			POST-PROJECT		
		COUNT	LOGJAMS/ MILE	LOGJAMS AREA (FT2)	COUNT	LOGJAMS /MILE	LOGJAMS AREA (FT2)
River Mile 30	0.1	0	0.0	0	4	14.2	8,355
Larson's Phase 2	1.5	11	7.5	23,356	25	17.0	89,561
Fobes Reach	1.4	19	13.6	50,943	33	23.6	63,620

PROJECT AREA	REACH LENGTH (MI)	PRE-PROJECT			POST-PROJECT		
		COUNT	LOGJAMS/ MILE	LOGJAMS AREA (FT2)	COUNT	LOGJAMS /MILE	LOGJAMS AREA (FT2)
Cavanaugh Island	0.8	4	5.0	3,732	26	32.5	12,676
Skookum Edfro Phase 2	0.6	1	1.8	1,699	16	28.6	9,971
Skookum Edfro Phase 1	0.3	6	18.9	4,471	11	34.7	6,375

At most projects implemented in the South Fork, the count of logjams increased and wood area increased at all projects (Table 21). Larson's Phase 2 and Fobes, had the largest increases in absolute wood area. Large wood jams used as holding cover by adult Chinook salmon are a critical habitat component for reducing spawning mortality – a known issue in the Upper South Fork. In addition, wood structures can help to reverse incision and increase floodplain reconnection by aggrading the channel bed, storing sediment, and diverting flow into off-channel areas and side channels.

Data collected during the field surveys supports the recommendations for building logjams directly in the low flow channel (rather than perched on gravel bars or along the margins of the channel) that are large enough to substantially increase roughness and obstruct the channel in order to form deep pools. The cause of deep (average residual depth ≥ 3.28 ft) pool formation was identified during both the 2005 and 2019 field surveys from a list of potential features (e.g. boulder, bedrock, resistant bank, beaver dam, rootwad (Pleus et al. 1999)). We selected out the data for pools formed by large woody debris and the data are presented below (Table 22). The total percent of pools formed by large woody debris has increased between 2005 and 2019 for six project reaches and a larger percentage of deep pools were formed by wood in three of six reaches. Overall, the total number of deep pools has increased from 21 to 30, although all these increases were in the Larson's Phase 2 project reach. It is well known that log jam frequency (e.g. Montgomery et al., 1995) is an important factor in forming pools in Pacific Northwest (PNW) streams, however many of the logjams in the study area are perched on gravel bars and do not interact with the low flow channel. Because of this, they have not formed deep pools that are accessible at low flow (when spawners need pools for holding) and instead boulders, bedrock outcroppings, and meander bends are other primary processes for deep pool creation in three of six reaches. Exceptions to this observation are found in Larson's Phase 2, and Skookum Edfro Phase 1, in which the majority of deep pools were formed by wood.

Table 22. Percent of large woody debris (LWD) formed pools in the Upper South Fork Geographic Area for pre-project and post-project monitoring. Results for all pools and deep pools only (mean residual depth ≥ 3.28 ft (1 m)) shown.

REACH	YEAR	TOTAL NUMBER OF POOLS	TOTAL % LWD-FORMED	NUMBER OF DEEP POOLS	% LWD-FORMED DEEP POOLS	YEAR	TOTAL NUMBER OF POOLS	TOTAL % LWD-FORMED	NUMBER OF DEEP POOLS	% LWD-FORMED DEEP POOLS
River Mile 30	2005	2	0%	0	0%	2019	2	100%	0	0%
Larson's Phase 2	2005	9	44%	6	50%	2019	37	65%	20	80%
Fobes Phase 1	2005	6	50%	4	50%	2019	17	53%	4	25%

REACH	YEAR	TOTAL NUMBER OF POOLS	TOTAL % LWD-FORMED	NUMBER OF DEEP POOLS	% LWD-FORMED DEEP POOLS	YEAR	TOTAL NUMBER OF POOLS	TOTAL % LWD-FORMED	NUMBER OF DEEP POOLS	% LWD-FORMED DEEP POOLS
Cavanaugh Island	2005	5	0%	4	0%	2019	7	43%	2	0%
Skookum Edfro Phase 2	2005	3	0%	3	0%	2019	10	60%	3	33%
Skookum Edfro Phase 1	2005	1	0%	1	0%	2019	7	86%	2	50%
TOTAL:		**26**	**27%**	**21**	**29%**		**80**	**63%**	**31**	**61%**

Fish Survey Data

Fish data were collected during snorkel surveys in August 2018 of six project reaches along the South Fork Nooksack; Elk Flats, Camp 18 Upper, Camp 18 Phase 1, Larson's Phase 2, Fobes, and Cavanaugh. Due to budget limitations, not all project areas could be surveyed. Data were collected during an August 2018 snorkel survey and represent a snapshot in time of observations of fish across projects. Additionally, while juvenile rearing for coho, winter and summer steelhead, and age 1+ Chinook occurs at this time, outmigration of a large portion of the spring Chinook juveniles occurs earlier in the year. The data were collected in August to allow for coordination with the habitat survey data that are also collected at this time of year, and to allow for safe survey of the project sites. The data are meant for comparative purposes across projects, so that any reductions in spring Chinook densities would be comparable across sites.

The observations of juvenile salmonids can be used to quantify the relative use between projects, but also to observe behavioral differences between species using the Upper South Fork Nooksack River. Figure 76 shows the relative use of structures and channel types in the reach by species. Coho were most commonly observed in naturally occurring off-channel types with secondary preferences for wood structures, both natural and placed. Chinook juveniles were most commonly observed using placed wood structures (ELJs) (Figure 76 and Figure 77) but were also found in natural wood and naturally occurring off-channel types. *O. mykiss* were most likely to be found in areas without structure, but also used boulders and naturally occurring off-channel types. Created off-channel habitat types were not frequently used during the observational survey. This could be due to lack of connectivity, or that most off-channel habitat was naturally formed, but additional flow was added as a result of structure placement, so they were not considered newly created. Placed wood and natural wood account for more than 60% of the observations for juvenile Chinook, while coho observations are dominated by natural off-channel use and *O. mykiss* are most commonly found in areas without structure. This information can be used to compare with the habitat descriptions for each of the project sites in terms of understanding the causes behind differences in fish distribution by project.

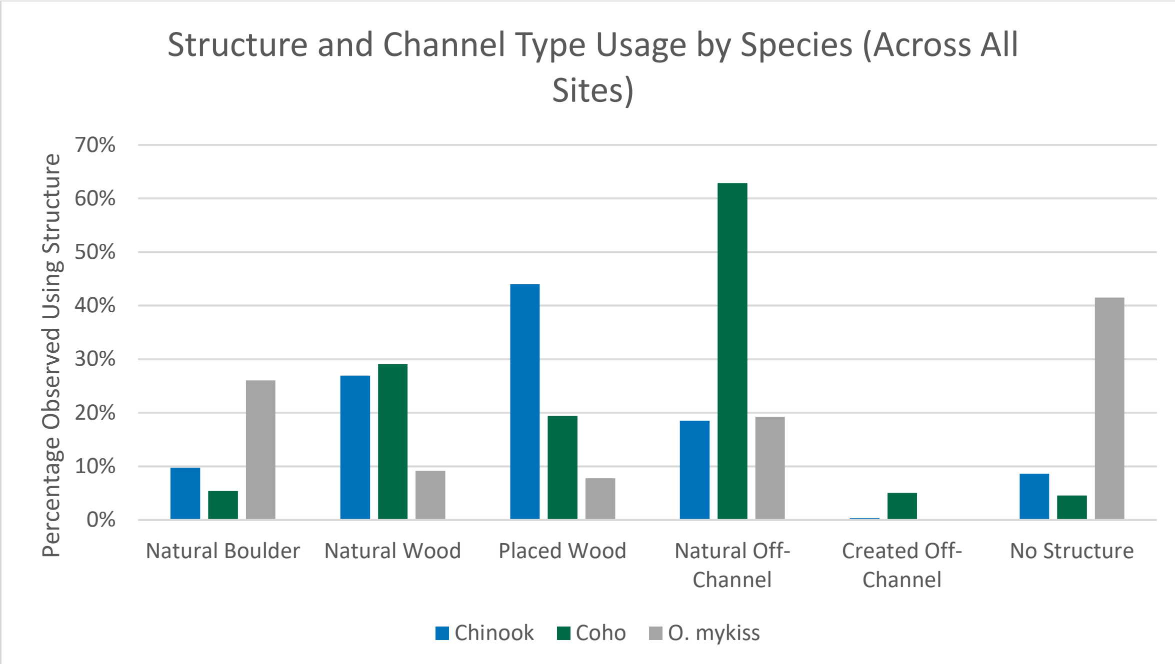


Figure 76. Structure use at the reach scale by species. Coho show a clear preference for off-channel habitats and wood, while Chinook juveniles are more likely to use placed and natural wood, as well as off-channel areas. *O. mykiss* were most common in areas with no structure and natural boulders, with some use of off-channel habitat.

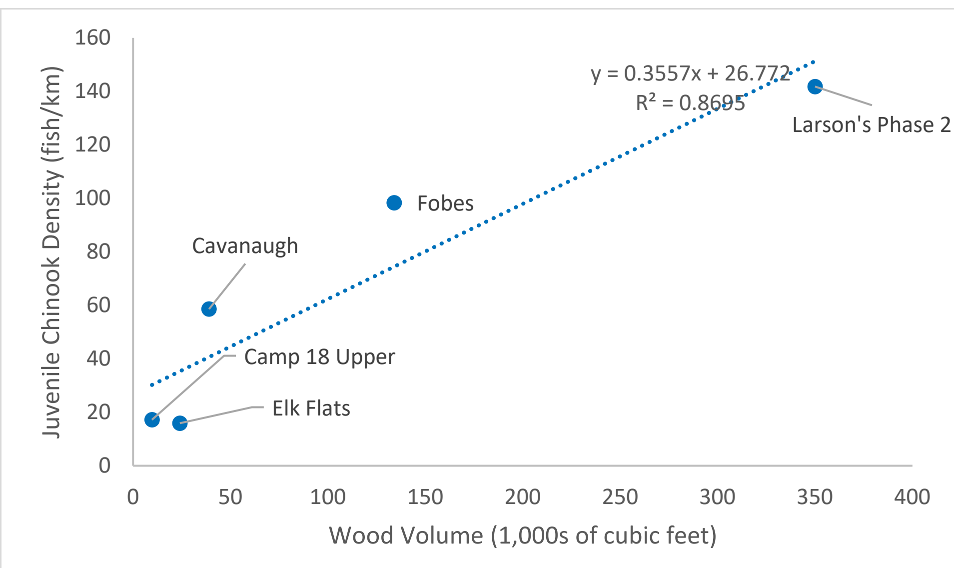


Figure 77. Juvenile Chinook densities observed in the Upper South Fork Nooksack as compared to wood volume. Labeled points represent project reaches. Wood volume in project reaches was determined using a using the 2017 LiDAR point cloud data and a semi-automated process based on methods presented in Abalharth et al., 2015, and Atha and Dietrich, 2015, Hyatt, 2017- personal communication. The method involves using the entire array of LiDAR return data (and not solely the bare earth) to create a filtered digital surface model (DSM) of features above the ground and water surface. It is based on the assumption that in a river environment, the only features within a certain height range (in this case 0-3m) above the ground or water are large wood or vegetation. However,

because shrubs and short trees may also fall within this height range, it is necessary to remove all vegetated areas from the identification scheme which also removes logjams that are also vegetated. This is a limitation in this analysis, as several of the logjams in the project areas (particularly ELJs that had alluvial ballast) are currently vegetated, and thus, were excluded from the analysis. If those ELJs racked additional wood and that wood has not become vegetated, however, they were detected by the method.

Understanding the relative distributions of fish between sites should also be informed by information about the size and length of the restoration sites, and the relative distribution by species between sites, as well as spawner use by site. We used fish density across sites as a way to normalize by differences in site length. Figure 77 identifies the relative density for each species across sites surveyed in August of 2018. Densities for Chinook were highest at Larson's, Fobes and Cavanaugh (Figure 78a), while coho densities were highest at Fobes and Cavanaugh. *O. mykiss* showed the highest densities at Fobes, and an untreated control site (Control 1), with secondary use at Larson's and Cavanaugh (Figure 78c). Across all three species, Larson's, Fobes, and Cavanaugh are supporting the highest densities of juvenile fish.

For spawner use, we examined Spring Chinook redd data, and used the proportion of redds found in each reach compared to the total South Fork Nooksack Run for each year from 1986 and 1999-2018. Across all years of data, Fobes has the highest use, followed by Larson's, and Cavanaugh Island. Spawning use at Fobes is particularly heavy; a quarter of the entire SF Nooksack spawning occurs in Fobes, when averaged across all years. The Larson's Phase 2 and Phase 1 project areas contained on average, 20% and 12% of redds detected, respectively. It is important to note that there is some overlap between these project areas. The Cavanaugh Island project reach contained 10% of all redds detected across all years. Spawning use at Camp 18, Elk Flats, and the Skookum reaches is low, with Skookum Edfro Phase 2 containing 6% of redds on average, and Camp 18, Skookum Edfro Phase 1, Skookum, and Elk Flats all containing less than 5% of redds. River Mile 30 had no spawning use in any year (Table 23, Appendix H). Redd data were provided by LNR, and spatially joined to project areas using GIS data for project extents also provided by LNR. Some 2018 redd data were missing from the GIS dataset due to GPS data loss and/or corruption. The total number of redds for each reach by year, and the proportion of redds for each year are found in Appendix H.

Of the projects surveyed for fish use, Camp 18, Fobes and Larson's Phase 2 have the largest total habitat area (21.08 acres, 19.52 acres, and 14.98 acres respectively). Larson's Phase 2 contains 48.5% pools, Fobes contains 14.7% pools, Cavanaugh contains 19.6% pools and Camp 18 contains 15.7% pools. Larson's Phase 2, Fobes, and Camp 18 have the highest wood area across project reaches. In addition, there are larger quantities of spawning gravel between the Saxon Bridge and Larson's Bridge than above Larson's Bridge, where channel habitat is steeper and less likely to retain large areas of suitable gravel (Brown and Maudlin 2007). The combination of spawning gravel, pool, and wood areas are likely driving the distribution of fish use across project sites.

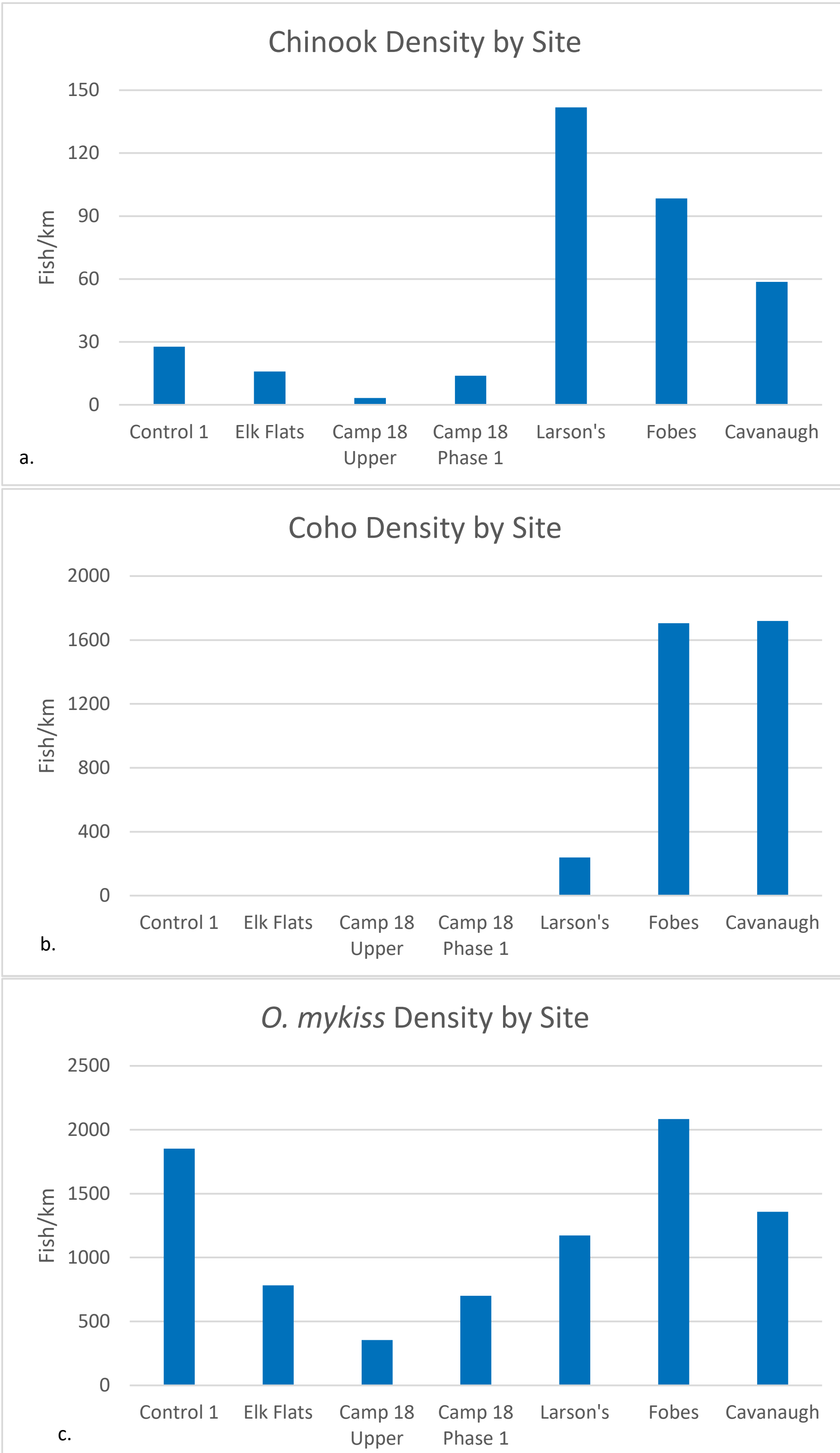


Figure 78. Juvenile fish densities by site and by species: a. Chinook densities by site, b. coho densities by site, c. O. mykiss densities by site.

Table 23. Average percentage of Chinook redds in the South Fork Nooksack found in each project area. Redd data from 1986, 1999-2018. Note that 2018 is missing some redd data due to GPS data loss and/or corruption.

CAMP 18	CAVANAUGH ISLAND	ELK FLATS	FOBES	LARSON'S PHASE 1	LARSON'S PHASE 2	RIVER MILE 30	SKOOKUM EDFRO PHASE 1	SKOOKUM EDFRO PHASE 2	SKOOKUM REACH
3%	10%	0.1%	25%	12%	20%	0%	2%	6%	2%

Intra-Project Conclusions

The previous sections have demonstrated that there are differences in the effectiveness of each project at achieving objectives and the subsequent response in fish usage at the site. These differences can be attributed to many factors including the geomorphic context of the reach, the restoration approach, and to the validity of the objectives established at the start of the project. Thus, in order to understand ***what*** makes a project successful, ***why*** there is a difference between project outcomes, and ***how*** to improve future projects and adaptively manage existing ones, the projects must be evaluated in context with each other in order to derive meaningful conclusions.

The following section synthesizes the conclusions provided in the *Project Level Evaluation* by focusing on our holistic understanding of the entire Upper South Fork Nooksack study area. These conclusions will then form the basis for identifying future restoration opportunities, as well as recommendations for both design and monitoring.

Geomorphic Context Matters

The geomorphic context of a project reach directly influences the response that the river will have to restorative actions and helps define the timescale at which that response will occur. Furthermore, the existing geomorphic conditions establish what is possible (and what is not) within a reach and should be used as a guideline for setting the objectives of a project. For example, it is critical to know about the degree of confinement in a reach, as well as the sediment supply in order to set appropriate and realistic objectives. Bedrock canyons are natural features that have little wood loading because they act as flumes that transport any wood that enters from above. When using wood to reverse channel incision, or reconnect floodplain habitat, the spacing of the wood structures matters. With higher sediment supplies, wood will trap sediment upstream of a jam and generally create a pool on the downstream side, but the jam must be stable, in direct contact with the flow, and have low enough permeability to hold water. In most steep, confined channels, there is plenty of sediment supply, but not enough natural stable wood to retain the sediment, however there are exceptions. Sediment supply can be reduced artificially by 1) urbanization which reduces sediment supply due to impervious surfaces and stormwater detention, or 2) channels in which enough wood has been placed to temporarily diminish downstream sediment supply (although that would be very temporary in most systems).

The causes of pool formation in different types of channels are also governed by geomorphic factors. Pool frequency in steeper channels is tied to frequency of channel obstructing wood steps; more steps result in more pools in these systems. For channels with shallower slopes, wider valleys, and higher sediment supply, pool frequency is directly dependent on: 1) frequency of wood structures impinging the mainstem flow (blockage coefficients at least greater than 10%), 2) channel sinuosity (an increase in sinuosity is tied to an increase in pool frequency (e.g. lateral scour pools) and 3) number of channels (a higher number of channels correlates with a higher number of pools) (T. Abbe, 2020, pers. comm).

Intensity of treatment, and project length and size also play a role. For example, the treatment at RM 30 was effective in terms of direct interaction with the channel, but it was implemented over a small area, so may not have as much benefit as a larger project. Below are some project specific examples from the Effectiveness Monitoring program that describe how the geomorphic context of a project reach may influence the response of a particular design.

Floodplains can only be connected if there is room to do so

Increasing floodplain connectivity was a thematic goal for all of the projects in the Upper South Fork Nooksack study area because additional side channel and off-channel habitat can provide potential areas for thermal refuge, spawner holding areas if connected during low flow, and high water velocity refuges for Age 0+ Chinook juveniles. Reaches confined by valley walls and high terraces (e.g. Elk Flats and Skookum Edfro Phases 1-2) can only be so effective at increasing floodplain connectivity because there is a physical limit to the amount of low elevation terraces that water can inundate without significantly obstructing the channel width. In these reaches, substantial bed aggradation is needed to establish broad expanses of additional floodplain and form new floodplain channels, which, given the difference in elevation, may not be feasible in a short time frame (i.e. less than a decade). An initial step in evaluation of these projects, prior to design, should be whether the terraces targeted for reconnection were part of the historical floodplain. Montgomery and Abbe (2006) and Brummer et al. (2006) found that wood can engage terraces up to 5 m high in extreme cases. As general guidance, terraces within 2 m that were historically connected can likely be re-engaged if there are no constraints on raising water levels (Larson’s Phase 2 has some examples of this type of effort). In developed areas, or areas with a “no rise” requirement, this is more challenging and the focus will generally be on stopping further incision, or developing a more functional inset floodplain.

In reaches with a higher degree of low elevation floodplain features and channels such as Larson’s and Fobes, however, increases in floodplain connectivity can occur on shorter time-scales with small (a few feet) increases in bed and water surface elevations. Because these reaches already have an established (albeit disconnected) floodplain template, new channels do not need to be formed (which could take significant aggradation) but can be reconnected directly. Furthermore, the presence of historical floodplain features within a reach demonstrates that the river is capable of forming floodplains given the geomorphic conditions of that reach, and thus, restorative actions will be working *with* instead of *against* geomorphic processes. When planning and designing restoration projects targeted at floodplain reconnection, it is critical to use elevational data along with geomorphic context to determine the potential for floodplain reconnection, and the timeframe over which is it likely to occur.

Sediment transport dynamics and channel slope influence the response to restorative actions

There was a high level of variability in the speed at which each project reach responded to restorative actions. While this is due to many factors such as structure layout (described below) and hydrology (when did big storms happen?), the sediment transport dynamics, channel slope, and confinement are major geomorphic influences on the speed and intensity of those responses. Both aspects of a river help define the existing and possible channel morphology of a given reach. Depositional reaches with low slopes and sediment supplies can form multi-threaded anabranching morphologies, whereas transport reaches that are steeper may only form plane-bedded morphology because sediment is unable to deposit and help form new channel networks. While actions, such as ELJ placement, can decrease the slope of a reach and create depositional areas, structure placement may not be able to overcome the slope of the valley and drastically shift channel morphology.

The Larson's and Fobes reaches are located at grade breaks where sediment deposits after being transported through several miles of steeper plane-bed segments upstream, so the sediment supply is adequate to store sediment and aggrade the channel in these reaches. Aggradation can lead to formation of braided and multi-threaded channel networks after restoration, but there was also evidence of channel migration and avulsion around jams where the flow had space to do so. Floodplain reconnection was supported by the historical floodplain topography and also by the ELJ placements at Larson's, when the placements were dense enough and had high enough blockage coefficients (e.g. 50-60% of mainstem flow) to aggrade sediment. Conversely, other structures in Larson's Phase 2 allowed flows to flank the structure, and so sediment was not stored. Sediment storage from a process perspective is all about shear stress partitioning. For wood to store sediment and aggrade the channel it must either 1) extend across the entire channel width, thereby trapping bedload and dissipating shear stress where flow plunges over the wood, or 2) be placed densely enough to cumulatively reduce the gradient of the river. The wood must be placed densely enough that the ELJs create enough roughness to significantly partition shear stress so that sediment transport capacity is reduced. This can also result where wood increases channel sinuosity and the number of channels, thereby significantly decreasing channel energy due to additional roughness from banks for the same volume of water.

In the Larson's reach, sediment aggradation has caused a braided channel network to form around hard-points in some areas, such as ELJs, that can transition into an anabranch planform as vegetation becomes established. In the Fobes reach, the results have not been as effective because the structures did not affect hydraulics and sediment transport to cause sediment to form channel networks, however the floodplain topography indicates that further channel network formation is possible in that reach.

Other reaches such as Elk Flats are likely too steep to form a complex anabranching channel network and quickly establish new floodplain areas. Placing structures in the mainstem flow to obstruct greater than 50 percent of the flow would increase the chances of reconnecting any available floodplain habitat in this reach.

Structure size and placement influences impact of restorative actions

The design philosophy and regulations surrounding restoration design has changed since work began on the Upper South Fork Nooksack. Early work conducted on the river utilized small ELJ designs with some geomorphically effective designs (RM 30) and some that worked from the channel edges (e.g. project work from 2009 through 2012) due to permitting limitations for isolation and work within the low flow channel, whereas more recent work involved building larger ELJs and channel spanning structures such as log riffles (Larson's Phase 2). Additionally, flood reduction regulations such as "no-rise" stipulations in the Skookum reaches has limited the hydraulic effect, or rise, associated with the structures. This limitation was noted in the project description for Skookum 2010, but the regulations were changed prior to 2016 to allow a 0.2 ft average cross-sectional rise allocation. This change allowed for more placement of ELJs in the main channel in Skookum Phase 1 which was constructed in 2016-2017. Subsequent to many of the projects being described herein, interpretations for allowable work under restoration programmatic permits have changed allowing opportunities for more isolation and construction within the lowflow channel. The next section focuses on conclusions drawn by comparing individual project designs.

Working from the channel margins is less effective at creating geomorphic change

Of the projects evaluated in this study, those that installed structures solely on the channel edges and "in the dry" on gravel bars have had limited effectiveness in terms of causing enough geomorphic change to shift channel morphology, create or reconnect floodplain habitats, and sustain stable habitat features, such as deep pools. This is context and site dependent, but there are several project examples. In most of these cases (upstream log riffle in Larson's Phase 2, Fobes, Cavanaugh Island, Skookum Edfro Phase 1), the river has simply migrated towards the path of least resistance in gaps between the structures and away from the areas of elevated roughness near the ELJs. This migration is due to the density of the structures not being high enough and obstructing a significant portion of the low flow channel, or that the structures are not built in the main flow path and so are easy for the river to migrate away from.

Effects have also been reduced by the geomorphic setting of some placements on the inside of meander bends (downstream jams in Fobes, Cavanaugh Island), which has further encouraged channel migration in the direction of the bend and away from the ELJs. For Cavanaugh Island, this may have been intentional to maintain the size of the island, but in the Fobes project, the ELJs were intended to interact with the low flow channel, and in some cases, that is no longer occurring. These processes have disconnected the ELJs from the low flow channel and prevented the formation of deep, low flow pools, because the ELJs only engage during large floods and the deep pools that are formed become filled in by sediment during smaller floods. Furthermore, it has created areas of fast velocity habitat between the structures instead of more slow velocity habitat.

Working in the middle of the channel and at dense frequencies increases the probability of achieving pool creation and floodplain reconnection objectives

Installing structures within the middle of the low-flow channel and at a high enough frequency to force hydraulic engagement has been more effective at pool creation than placement of structures along the margins of the channel (Appendix C). This is best exemplified by the work conducted in the Larson's Phase 2 reach where ELJ placements were dense (especially around RM 20) and log riffles were placed in the middle of the low flow channel. This treatment strategy blocked a significant amount of channel area and forced the river to split into multiple channels in the narrow spaces between structures. Because the structures were so close together, the full channel could not flow between any single channel pathway and migrate away from the ELJs. This has allowed the structures to remain connected to the low flow channel and form deeper pools. Compared to a target of 13 primary pools, the Larson's Phase 2 project contained 19 primary pools by 2019. Most of the ELJ's in Cavanaugh are along the Cavanaugh side channel although there are a few in the mainstem flow at the upstream end of the side channel inlet. The goals for pool formation were not fully met for the Cavanaugh project. Skookum Phase 1 and Skookum 2010 projects both had primary pool goals that were not achieved and most of the ELJ's are on the channel margins. Skookum Phase 2 has just been constructed and contains both lateral jams and mid-channel jams. This project has not yet met the pool targets, but since it was just constructed, additional time is needed to allow for scour around ELJs.

Floodplain reconnection is another common objective across multiple projects which is more likely to be achieved with bar apex and/or channel spanning ELJs. The log riffle strategy at Larson's Phase 2 has helped aggrade the channel bed and raise water elevations to sustain flow into the split channels year-round and inundate floodplain channels during floods. Sediment is aggrading in the lee of these structures and forming forested island landforms which should further stabilize the multi-threaded morphology. The project has met the target of creating 1.33 miles of side channels, although the total target for acres of floodplain reconnected (13.8 acres) has not been achieved. RM 30 also included a floodplain reconnection target and a small inset floodplain has been activated, although the floodplain is limited due to channel confinement. The Fobes project, which did integrate bar apex jams, has increased the amount of off-channel habitat from 0.82 acres to 2.84 acres. Using an array of bar apex jams is one of the best ways to have a significant effect on increasing water elevations, floodplain connectivity, and reach-scale sediment retention.

The size of an engineered logjam relative to the unobstructed cross-sectional area of channel, typically referred to as a “blockage coefficient” has a significant effect on hydraulics, geomorphic response and habitat. The scale of response resulting from wood can range from meters to kilometers, largely based on the blockage coefficient. Wood structures with blockage coefficients of 10% or less can be effective at creating and sustaining pools with complex cover. Wood structures with blockage coefficients greater than 10% begin to influence flow conveyance and thus have larger scale effects which increase non-linearly as blockage coefficients increase above 20%. Blockage coefficients over 20% can increase water elevations upstream, decrease radius of curvature, increase the frequency and duration of floodplain inundation, trigger formation of new channels and islands, contribute to channel avulsions, and other effects that diversify and increase the quality of aquatic habitat. These effects generally increase as a function of blockage coefficient. Several closely spaced small wood structures can increase the blockage coefficient with similar results. In alluvial valleys with actively migrating channels, arrays of engineered logjams must be constructed that are spaced no more than 80% of the unobstructed channel bankfull width (Wc) apart from one another so that any path the river takes ensures it will encounter a structure that imposes a blockage of at least 20%. The smaller the spacing, the more positive the response, spacing structures about 0.6Wc is a good design target. If structures are spaced at distances equal or greater than Wc, the river is likely to follow an obstructed path between the structures. The structures will only have a significant effect when they are directly engaged with flow. So, if structure spacing is equal or greater then Wc, then structures should be positioned so that flow between two structures is directed into a downstream structure. It is best to cluster tighter spaced structures across the active channel migration zone than to disperse structures over a larger area.

Measurable objectives should be developed based on project specific geomorphic and hydraulic conditions

Developing objectives for projects is an important part of the restoration process. They help guide design actions, coordination with other projects, communication with stakeholders and can even increase potential funding opportunities. Realistic objectives, that are consistent with site conditions and geomorphic context, allow for implementation that is set up to succeed. When objectives are established without taking site specific geomorphic and hydraulic conditions into account however, projects can be set up to “fail” from the beginning, even if they are effective at restoring geomorphic and habitat conditions. This can negatively affect future design actions and funding opportunities and may be a result of the objective definition instead of restorative actions.

One of the keys to successfully increasing off-channel habitat is having evidence of an alluvial valley, which is not always easy to detect. Many rivers along the Oregon Coast Range once had alluvial valleys that are now bedrock. Careful inspection of banks and terraces is needed to detect this evidence and determine whether the sediments are “geologic” (from a different climatic time many thousands of years ago) or “historic” (Stock et al. 2005, Schanz et al. 2019).

The Elk Flats, Larson’s, and Upper Cavanaugh-Fobes Phase 2 project objectives all include connecting floodplain habitats at the 1-year flood return interval which represents the “bankfull” flow in the Pacific Maritime Mountain region that the project area is in (Castro and Jackson, 2001). By definition, “bankfull” flow occurs when water reaches the top of the river’s banks but does not spill into the floodplain (Knighton, 1998). While overbank flow may occur in some regions of a channel that are not in “equilibrium” and aggraded, most channels in the study area show some degree of incision and thus, it will take greater than 1-year flows to connect floodplain habitats. This is demonstrated in the hydraulic modeling results presented in Appendix F where there is minimal floodplain engagement at the 1-year flow level. More floodplain areas become engaged during the 2-year flow level, which is a better target for future project objectives (Appendix G). We recommend that this objective be modified to target a specific acreage of floodplain at the 2-year flow level, rather than the one-year flow.

In addition to being appropriate for the geomorphic and hydraulic context of the project areas, objectives should also be able to be quantified in order to determine if they have been achieved. While many of the objectives listed for the projects in the study area have quantifiable goals (e.g. create one thermal refuge or enhance activation of 1.33 miles of side channel), others do not have measurable metrics nor do they state goals. For example, improvement in channel complexity, while an action that could improve habitat, is not a measurable or a well-defined project objective. Channel complexity is not defined nor is the amount of increase. Thus, achievement of this objective would be based on subjective observations and does little to improving future projects. Instead, a more appropriate and quantifiable objective would be: “To increase the percentage of slow velocity habitats by 15% within 5-years”, which is measurable, objective, and time-bound. Development of “S.M.A.R.T” (Specific, Measurable, Achievable, Relevant, and Time-bound) objectives for Upper South Fork projects have improved over time as state and local habitat restoration targets and guidelines have been developed (Cramer 2012, WRIA 1 Watershed Management Board 2017).

Understanding fish use patterns can help in optimizing design strategies

Specific observation of fish use across project areas can provide valuable insight for targeting actions for the benefit of listed species. A primary goal of restoration in the Upper South Fork Nooksack is increasing the populations of Spring Chinook using the system, which are most limited by water temperatures during low flow and holding habitat for returning spawners. Information on the habitat preferences for both adult and juvenile spring Chinook can be used to optimize actions that result in benefits to Spring Chinook and other species. Spawning records for Chinook in the Upper South Fork back to 1986 reveal the highest level of Chinook spawning in Fobes, Larson’s Phase 2 and Cavanaugh project areas, which would suggest a source for juveniles that could later use those areas for rearing habitat (Table 23). Chinook redd spatial data can be used to understand how Chinook spawners are using a project reach and facilitate improved restoration design and understanding of restoration response. Larson’s Phase 2 showed an increase in the average proportion and average number of Chinook spawners using the project area after restoration actions and spatial data showed increased number of redds in aggraded areas upstream of the channel spanning logjams. At Fobes, although the average proportion of redds detected has stayed relatively the same before and after restoration actions, the average number of redds has decreased. We have documented continued incision in this project reach. Other factors, such as survey effort, marine survival rates, escapement estimates, and flow levels must also be taken into consideration. The overall number of spawners in the South Fork Nooksack River has increased in recent years due to the early success of the South Fork Chinook Rescue Program. The 2012 – 2017 escapement estimates for the South Fork were 116, 10, 22, 7, 319, and 145 natural-origin spawners for the South Fork Chinook population (Nooksack Co-Managers, unpublished data).

Using the observations from the snorkel survey conducted in August 2018, we saw clear preferences for juvenile Chinook for placed wood, specifically in the Larson’s 2 project, which had the highest density of Chinook, and the highest area of placed wood, as well as a relatively high average spawner use (20%). Chinook preference for wood is also indicated by findings of the Nooksack Tribe in the lower South Fork during snorkel surveys (Coe, 2005). Figure 77 shows a relationship between wood volume and Chinook densities based on the observations from this study. The Larson’s Phase 2 Project stood out from the others in terms of providing refuge for juvenile Chinook.

RECOMMENDATIONS FOR DESIGN AND MONITORING

Design Recommendations

The recommendations for future design work in the Upper South Fork Nooksack River are linked to the Inter-project conclusions described above. Study of project effectiveness both within and across projects resulted in several recommendations for future project design.

- Focus floodplain restoration areas in river reaches with less confined floodplains.
- Creating or enhancing anabranching channel networks should be targeted in areas with appropriate slope and sediment transport.
- ELJ placement in the mainstem flow that blocks substantial flow (e.g. not only on the channel margins, blocking at least 10-20% of flow) is needed to create and maintain pool formation and aggrade the channel bed.
- Thermal refuge is not tied specifically to primary pool formation, and the formation of primary pools in the study reach is limited. Key objectives for thermal refuge should be revised to identify targets for depth, connection with existing cold water sources, and separation from the main stem flow to prevent mixing, which dilutes the thermal signal.
- Density of ELJ placement affects the channel response and adequate density is required to achieve geomorphic goals.
- Measurable objectives are critical to determining project success and quantifying habitat benefits.
- Understanding fish use preferences can better optimize project designs for intended biological responses.

Building on the conclusions of this report, additional areas for potential restoration are identified below. Initial observations and suggestions for restoration actions are provided, but additional information is needed to evaluate these sites with a full understanding of the above recommendations.

Monitoring Recommendations

Extensive information and insight into project effectiveness were gained through this study on the Upper South Fork Nooksack. The availability of quantified data from the past monitoring by the LNNR made assessment of most of the project level objectives possible and greatly contributed to the conclusions of the report. Monitoring recommendations focus on the key monitoring elements that were most closely tied to a larger proportion of project objectives and those data sets that provided the greatest utility in project evaluation and reach level conclusions.

Habitat Data

Spatially explicit habitat unit data is one of the cornerstones of project effectiveness and channel units are the operational unit of habitat that define fish use in a project reach. Having georeferenced habitat data from past field surveys was critical in looking for information on pre-project conditions. Remote sensing data can be used for larger scale changes and floodplain effects through use of hydraulic modeling results.

Sediment objectives were identified in the Upper South Fork Nooksack, but primarily related to the stabilization of landslides in specific areas. Observations using the photo sequence in Google Earth were generally adequate to evaluate the level of change in the stability of major landslides based on the presence and density of vegetation. Wood structures placed as part of project efforts could also be identified in these images. Further field sampling for sediment should be included in specific objectives regarding the level of fine sediment in pools, or the distribution of sediment sizes throughout a reach, as well as mapping the availability of spawning gravels. General information on sediment condition can also be gained by looking at the model output for shear stress from hydraulic modeling at the project level.

Temperature

Temperature data was pivotal to the evaluation of effectiveness for most of the projects in this study and high water temperature is identified as one of the primary limiting factors in the watershed. Recommendations for existing and future temperature data include the following:

- Organize and name continuous logger in a consistent way for easier processing;
- Set up hypotheses to test related to temperature and pair observations; use control points to test for control-impact. Preferably collect before and after data at each project to set up a Before-After-Control-Impact (BACI) analysis.
- Provide comprehensive metadata to support hypothesis testing.
- Continue temperature profile monitoring for pools using depth specific temperature measurements.
- Repeat FLIR to update continuous data set, and combine with future topobathymetric data collection events.

Biological Data

Fish data collected using snorkel surveys and spawner/redd surveys were instrumental in evaluation of biological project objectives, and to provide insight into species preferences for habitat use. Salmon recovery is one of the major drivers behind restoration work and funding in the Nooksack, and as such, direct measurements of salmonid response to project actions are necessary.

Recommendations for fish monitoring include continuation of spawner surveys that include mapping of spawners and redds in GIS, and repeated snorkel surveys in August and potentially in June to assess the relative level of use by juvenile fish at project areas and throughout the reach. The level of effort for the snorkel survey should be increased over what was possible in this study, so that more continuous spatial coverage is provided in the survey, and channel unit level observations can be mapped in GIS.

Future Restoration Opportunities

The lessons learned through the Effectiveness Monitoring Program can be incorporated into future projects that restore channel processes and address limiting habitat factors in the Upper South Fork Nooksack River. In addition to adaptive management of existing project areas, there are numerous restoration opportunities that could be targeted by LNNR for future work. The following section describes a unified restoration approach based on our evaluation of existing projects and identifies nine restoration opportunity areas that could be the focus of future projects. We suggest the following thematic restoration goals that can be incorporated into *all* future projects:

Thematic Restoration Goals:

- Reconnect floodplains in areas of cool water refugia to increase the residence time of water in contact with cold water sources and reduce overall stream temperatures
- Create key habitats such as primary pools, areas of thermal refuge, complex edge habitat and side channels
- Decrease fine sediment load through sediment storage in log riffles and forested islands and by stabilizing point sediment sources, such as landslides or high sediment load tributaries
- Increase habitat diversity by creating slow velocity channel units and holding pools with cover

To address these goals, we suggest following a consistent restoration approach that builds on previous work in the basin. In general, our findings illustrate that wood structures with larger blocking coefficients of the mainstem flow and at a high enough density (e.g. 500 pieces/km (Montgomery et al. 2003)) are more capable of aggrading the channel bed and forming sustainable pools needed to adequately restore channel processes in the system. Focusing on riparian restoration in addition to in-channel work will also be essential to re-start the floodplain large wood cycle in the system and generate local large wood sources that can be recruited to the river over the long-term, as wood structures decay through time. We propose the following general restoration approach for future restoration projects:

Restoration Approach:

- High density and obstruction of the low flow channel of ELJ placements to encourage channel development and narrowing, sediment aggradation, island formation and formation of floodplain landforms
- Log riffles to aggrade bed (where appropriate) and increase inundation of multi-threaded channel network and floodplain habitats
- Restoration of floodplain forest to encourage successional processes and conifer growth

We suggest that these actions be included on ***all*** opportunity areas outlined below on a conceptual level. Any call-out and note presented with the opportunity areas would be ***in addition*** to the actions outlined above.

We evaluated the entirety of the Upper South Fork Nooksack study area for restoration potential in order to identify opportunity areas. Our screening included the criteria listed below. A project area did not need to address all conditions to be included.

- No project work already completed or planned
- Available floodplain areas to connect
- Lack of wood and straight stream channel (high proportion of high velocity channel units)
- Cool water sources
- Point sediment source locations (landslide deposits or tributaries with high sediment load [e.g. Howard Creek])
- Review of Q2 flow level to understand feasibility of side channel and floodplain connection

Based on these criteria, we identified nine opportunities that could be targeted for future restoration projects (Figure 80). Many of these areas are above RM 25.5 which is a partial barrier to Chinook salmon. Each area is discussed in detail below.

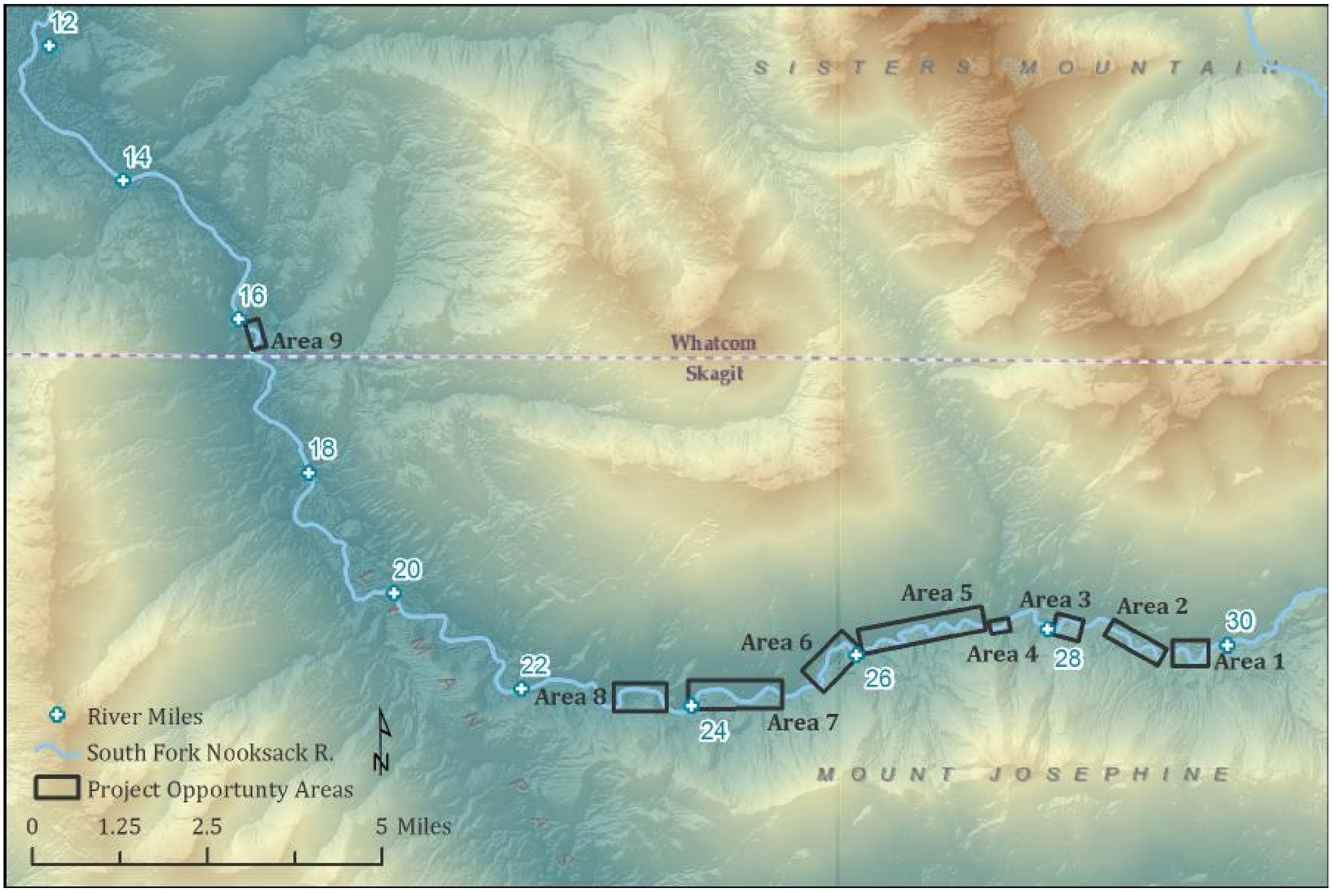


Figure 79. Locations of future restoration opportunity areas within the Upper South Fork Nooksack River. Flow is from right to left.

Opportunity Area 1

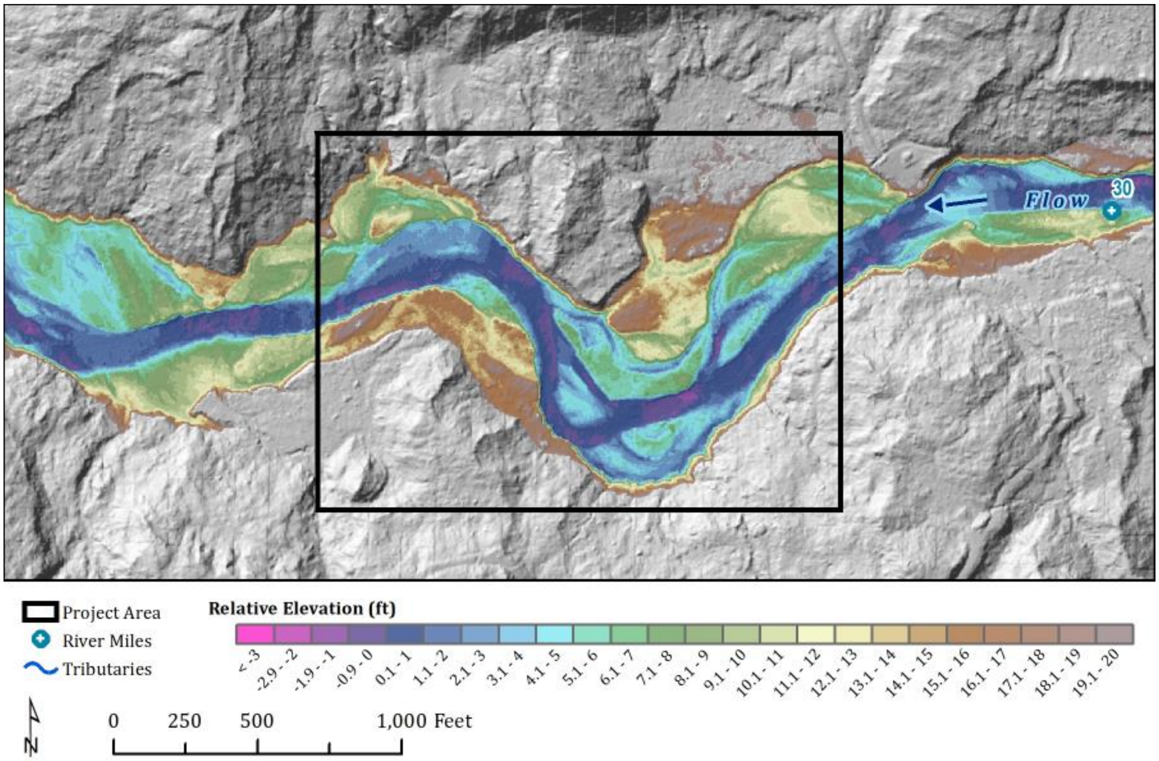


Figure 80. Restoration Opportunity Area 1 in the Upper South Nooksack River.

Reach Description

Opportunity Area 1 is located near RM 29.5 and is directly downstream from the RM 30 project reach (Figure 80). The reach has a single-threaded channel morphology with two side channels that are inundated at the Q2 flow level. One side channel is along the right bank at the upstream end of the reach and the other is along the left bank at the start of the meander bend. The reach contains few large wood pieces and has wide, expansive gravel bars which indicate a high sediment supply. There is a developing riparian forest between the left bank side channel and the main channel.

Restoration Opportunity

There is an opportunity to increase the inundation frequency of both side channels and create a multi-threaded channel planform with anabranching morphology in this reach. Since the channels are already inundated at Q2 and there is likely a high sediment supply, aggrading the bed with stable wood structures should be feasible. Additionally, increasing the frequency of stable hard points could help shift the morphology to sustain several channels by increasing sediment transport capacity within the active channel and storing sediment in riparian islands instead of active gravel bars. This approach would increase the available edge habitat, channel unit diversity and floodplain habitat.

Opportunity Area 2

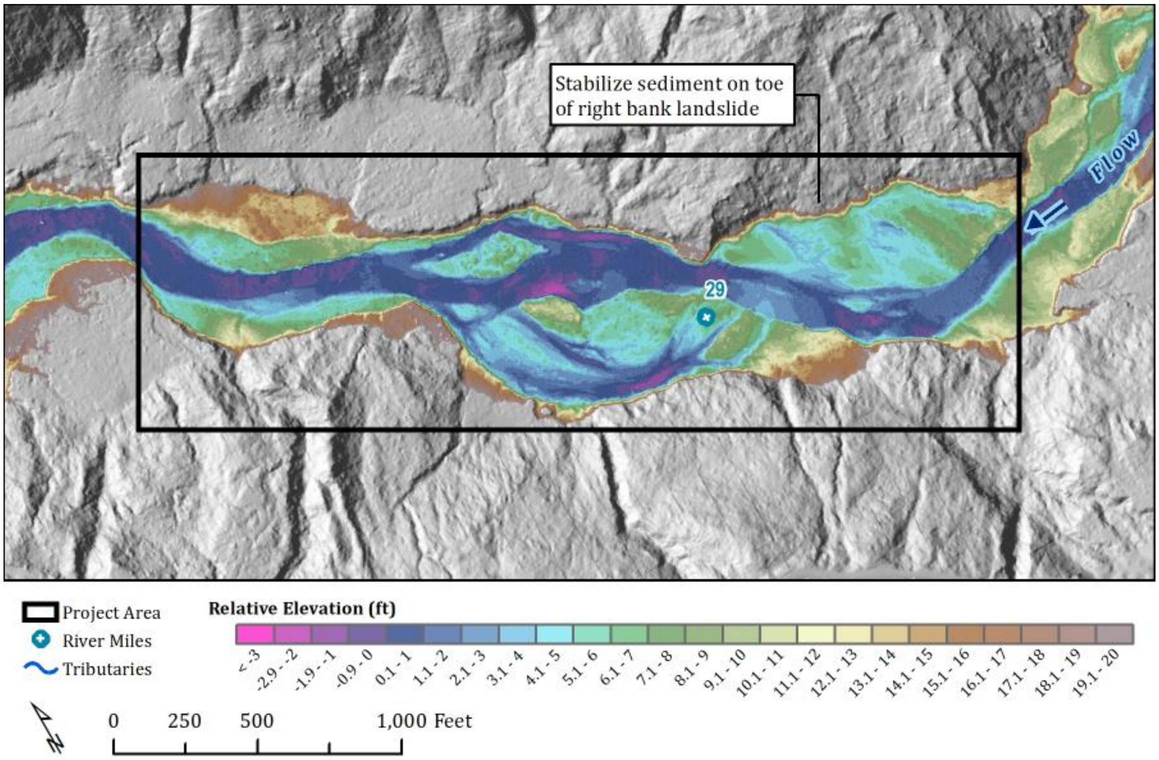


Figure 81. Restoration Opportunity Area 2 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 2 is located between RM 28.5-29.25 and is located directly downstream from Opportunity Area 1 (Figure 81). The reach has both a single threaded and multi-threaded channel morphology with the multi-threaded areas showing both anabranching (stable channels separated by forested islands) and braided (unvegetated channels across gravel bars) character. The anabranching morphology is located near RM 29 where there are two forested islands on the left and right side of the valley. Upstream of this section, there is a right bank landslide and subsequent braid channels at the toe where fine hillslope sediment has deposited. These braid channels are inundated at the Q2 flow level.

Restoration Opportunity

There is an opportunity to maintain areas of anabranching morphology and stabilize hillslope sediment sources within this reach. This reach demonstrates that it is capable of creating stable multi-threaded channel networks based on existing topography. The addition of stable hard points would help maintain this morphology while allowing riparian islands enough time to grow trees large enough to remain stable in the river and provide functional large wood. Work could also be done to stabilize the large right bank landslide and reduce fine sediment loads downstream.

Opportunity Area 3

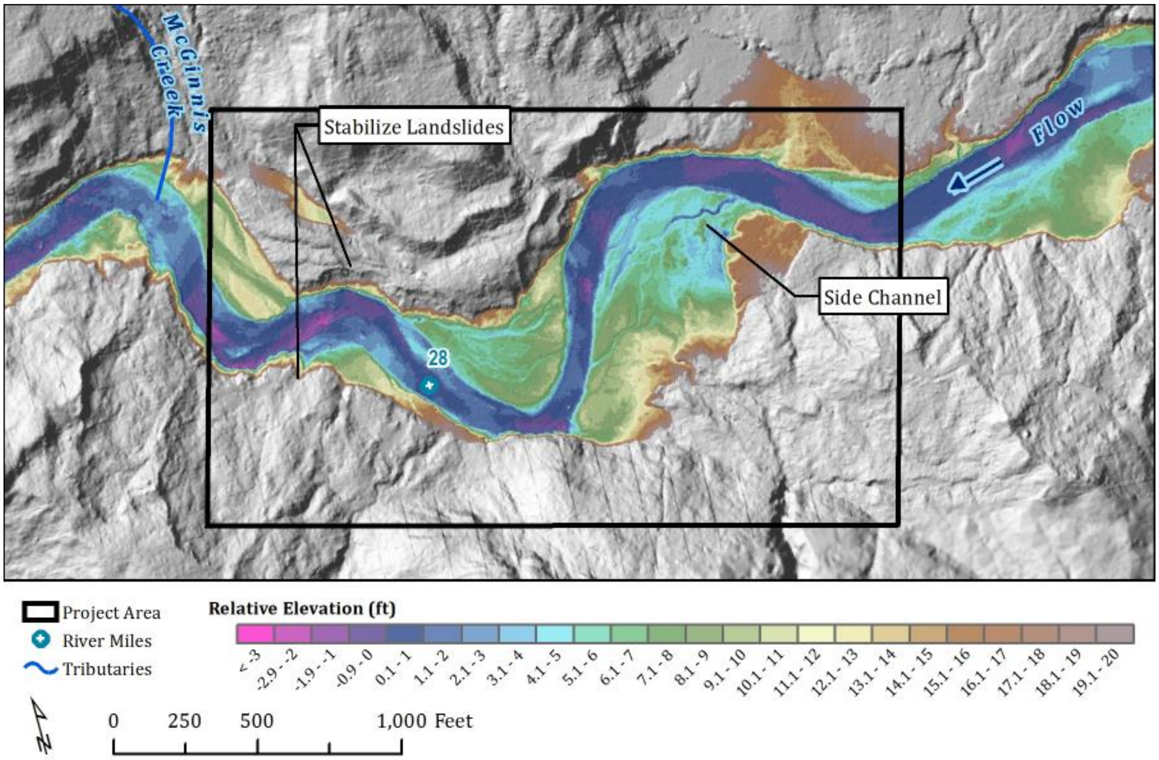


Figure 82. Restoration Opportunity Area 3 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 3 is located between RM 27.75 and RM 28.25 and is downstream from Opportunity Area 2 (Figure 82). The reach contains a single-threaded plane-bed morphology upstream of RM 28 and a braided channel morphology downstream. The morphology shift occurs in the location of landslides along both banks – a larger and older left bank slide and a newer and smaller right bank slide. Both slides appear to be contributing sediment to the river. There is also a right bank side channel at the upstream end of the reach that is inundated during the Q2 flow level with shallow (<2’) depths.

Restoration Opportunity

There is an opportunity to stabilize major landslide sediment sources, increase the frequency of side channel and floodplain inundation within this reach, and increase habitat diversity in a plane-bed reach. The two landslides in this reach are actively delivering sediment to the river system and stabilizing them will help reduce sediment loads downstream. Work to do this could utilize the existing large wood input from both slides and help create floodplain habitat and riparian forests on the sediment deposits that are currently there. Installing log structures in the upstream end of the reach could both help increase inundation of the existing side channel and increase the quantity of slow water channel units in the plane-bed reach. One challenge to restoration in this reach is that it is difficult to access.

Opportunity Area 4

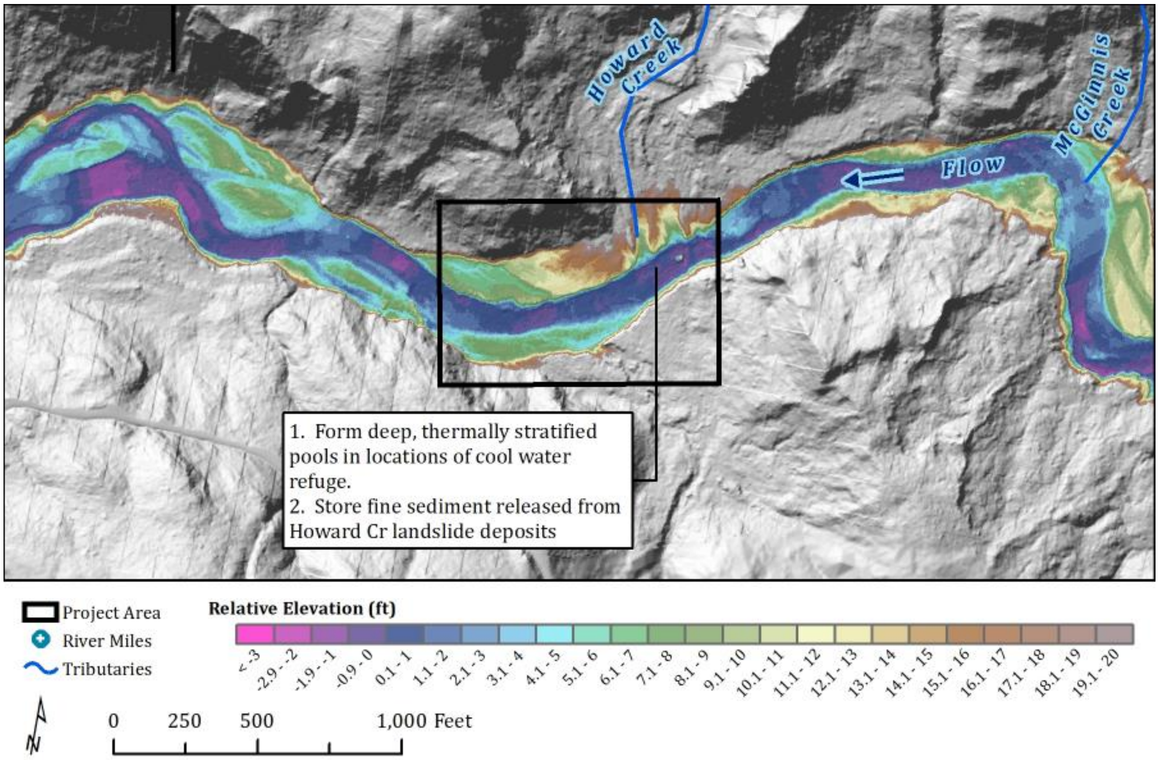


Figure 83. Restoration Opportunity Area 4 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 4 is located at the confluence of Howard Creek near RM 27.5 (Figure 83). The river has a plane-bed channel morphology with many in-channel boulders within the project reach. Howard Creek is both a source of cold water *and* fine sediment to the Upper South Fork Nooksack River. It drains the southwest side of the Twin Sisters and thus, provides high elevation snow melt and cold water. However, there are also numerous landslides within its drainage, which contains primarily erodible glacial drift lithology, and has a dense road network and active forest management.

Restoration Opportunity

There is an opportunity to develop deep pools to collect cold water and create areas for storing fine sediments released from Howard Creek. The area currently exhibits characteristics of a transport reach, as there are no visible gravel bars and only large boulders. Work could be done to reduce the slope (and thus, sediment transport capacity) of the reach and store sediment in the confluence area and 6' terraces directly downstream. ELJs could be used to form pools in any remaining high energy locations of the reach to reduce the possibility of them filling in with sediment deposited from Howard Creek. One challenge to restoration in this reach is that it is difficult to access.

Opportunity Area 5

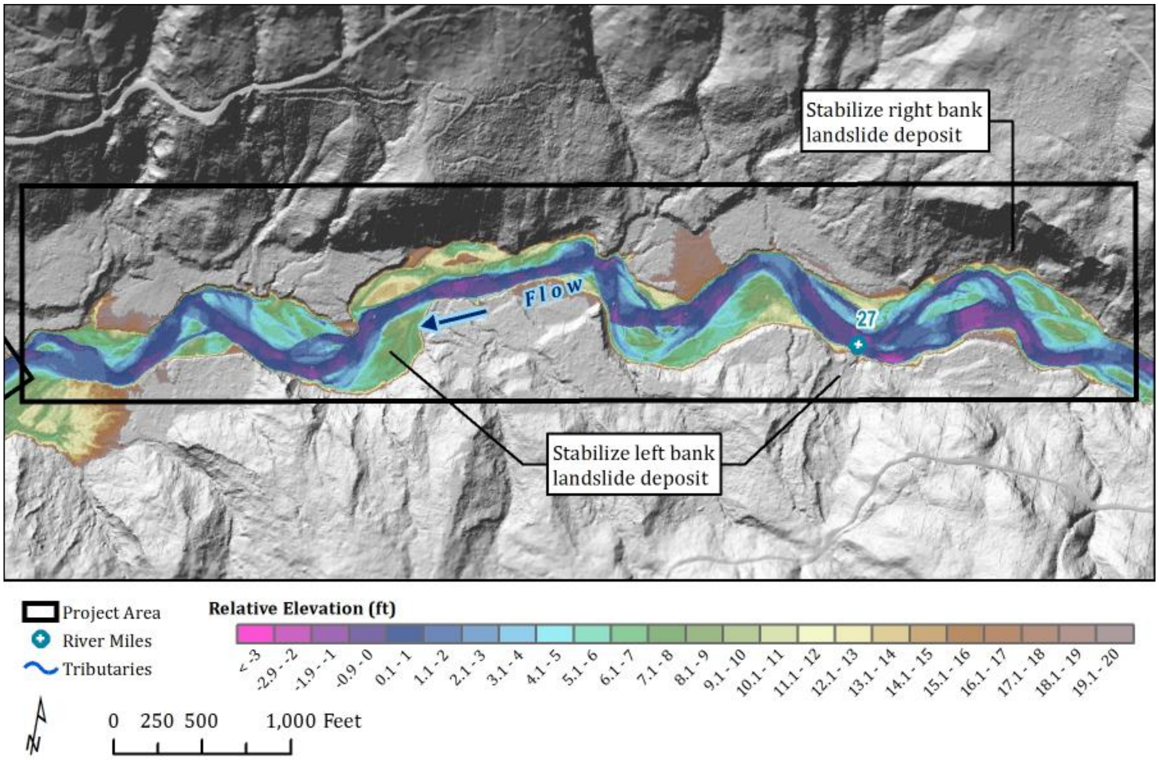


Figure 84. Restoration Opportunity Area 5 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 5 is located between RM 26.1 and RM 27.25 and is directly downstream from Opportunity Area 4 (Figure 84). The reach exhibits both single thread and multi-threaded channel morphology throughout its length, as the river interacts with numerous landslide deposits along both left and right banks. There are two large deposits along both banks at RM 27 with the river forming a thread through the toe of the right bank deposit that is separated from the main channel by a riparian forest. The reach also contains poorly sorted sediment with wide gravel bars, boulders, and sand deposits. This is also likely due to the high sediment loads from the landslide deposits.

Restoration Opportunity

There is an opportunity to stabilize the numerous landslides in this reach while benefiting habitat by converting the deposited sediment into a stable floodplain forest and anabranching channel network. Using log structures to stabilize the toes of the landslide deposits could help reduce future input of sediment to the river system and allow riparian vegetation to develop in the area. In-channel structures would also help better sort the sediment that does reach the channel and increase the quantity of slow velocity habitat units. The existing riparian forests and log accumulations could be stabilized and serve as a template from which future work could be built. One challenge to restoration in this reach is that it is difficult to access.

Opportunity Area 6

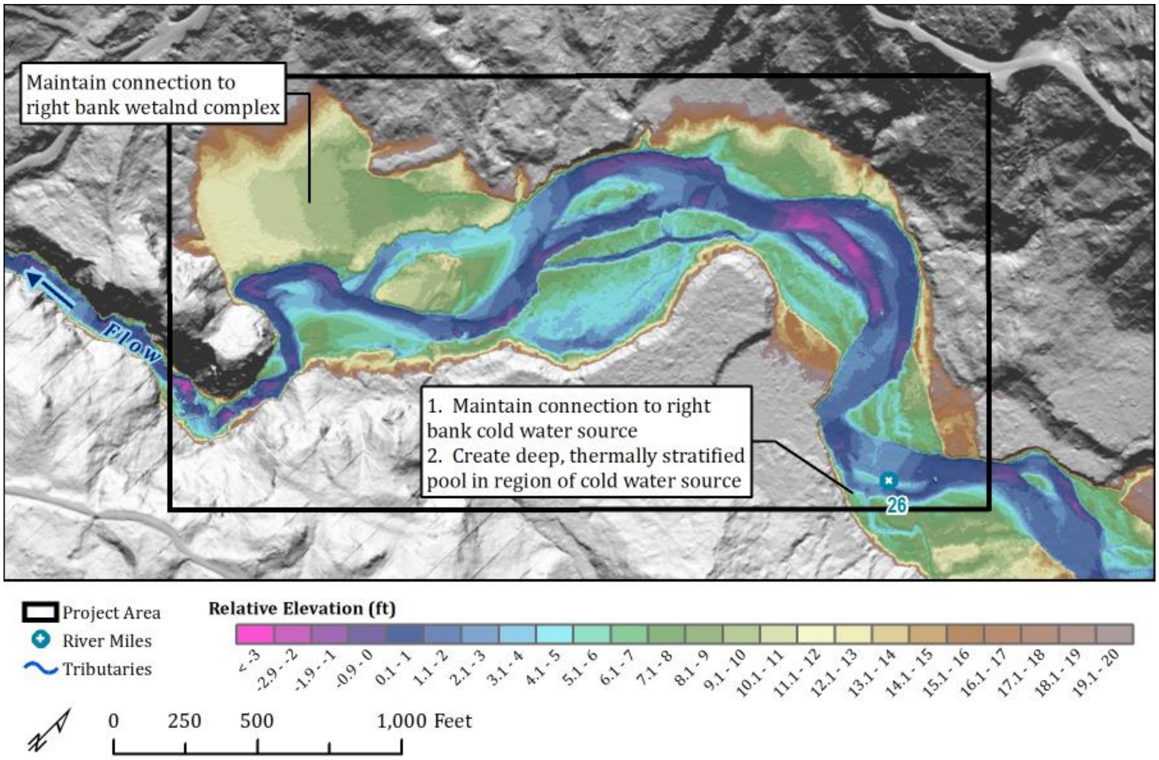


Figure 85. Restoration Opportunity Area 6 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 6 is located between RM 25.5-26 and is directly downstream from Opportunity Area 5 (Figure 85). The reach is also directly upstream from a cascade at RM 25.5, which is a partial barrier to chinook migration. The reach also contains a cool water seep on the left bank at RM 26. The reach contains a multi-threaded channel morphology where vegetated islands have formed in the lee of wood accumulations that were previously braided channels. There is also a side channel along the left bank in the middle of the reach that is inundated at Q2 and a large wetland complex on the right bank at RM 25.5. There are wide gravel bars throughout the reach which are likely due to deposition caused by the backwater from the cascade.

Restoration Opportunity

There is an opportunity to maintain and stabilize the multi-threaded channel morphology, maintain a connection to the right bank wetland complex, and create a cool water refuge in the vicinity of the cold water seep (Figure 82). Stable hard points could be added to existing vegetated islands to protect the vegetation from scour and allow it to grow to stable sizes. The structures would also increase water surface elevations which would maintain a connection to the right bank wetland complex. Additional work could be conducted near the cool water seep to create a deep, thermally stratified pool. The structure placements could also help store sediments and reduce loads to downstream reaches that Chinook can access. One challenge to restoration in this reach is that it is difficult to access.

Opportunity Area 7

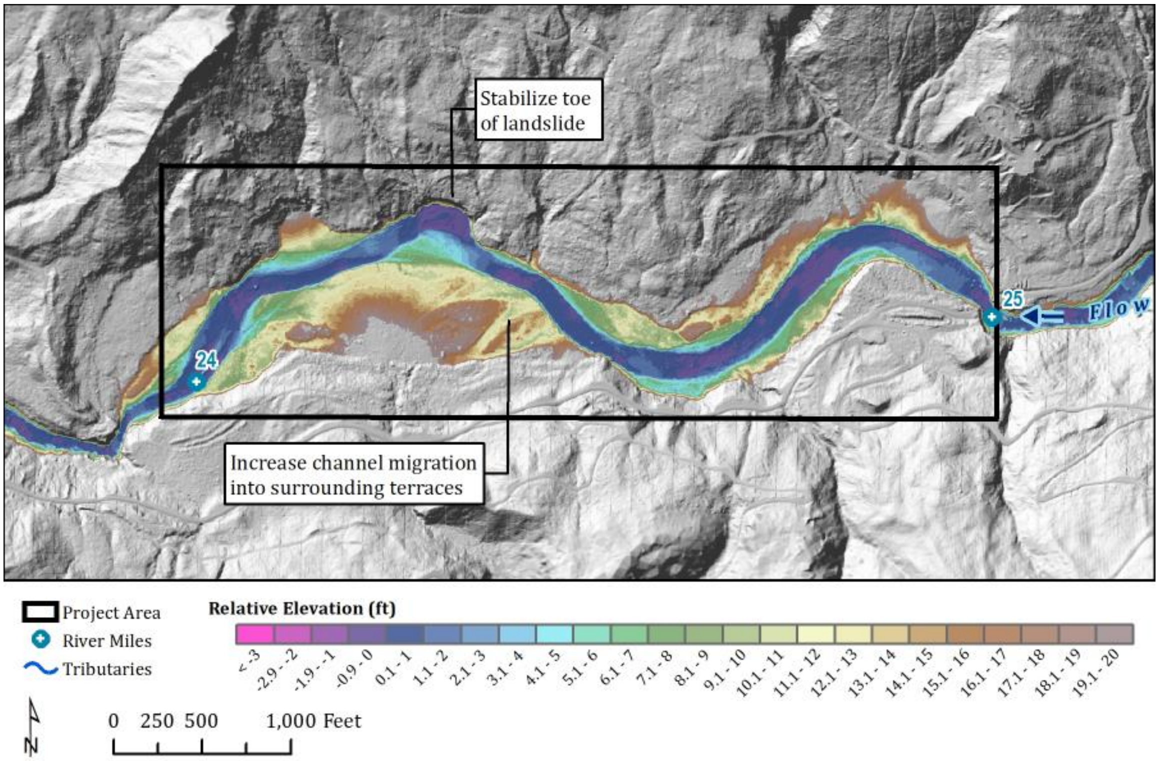


Figure 86. Restoration Opportunity Area 7 in the Upper South Fork Nooksack River.

Reach Description

Opportunity area 7 is located between RM 24 and RM 25 and is directly upstream from Opportunity Area 8 (Figure 86). The reach is the most upstream project area that is below the canyon reach at RM 25.5 that is a partial chinook barrier. The reach contains a single-threaded plane-bed channel morphology and a narrow, inset floodplain corridor. There is also a landslide along the right bank near RM 24.4 that is contributing sediment into the system. The terraces within the alluvial valley are forested.

Restoration Opportunity

There is an opportunity to increase the quantity of slow velocity habitat units and floodplain inundation frequency by increasing channel migration into the left bank floodplain. This would increase channel length and wood recruitment in addition to the thematic goals presented above. Additionally, work could be done to stabilize the toe of the right bank landslide to reduce fine sediment loads. Work in this area to increase the areas of slow velocity habitat would have significant benefit to habitat diversity, as the reach is currently plane-bed and high energy.

Opportunity Area 8

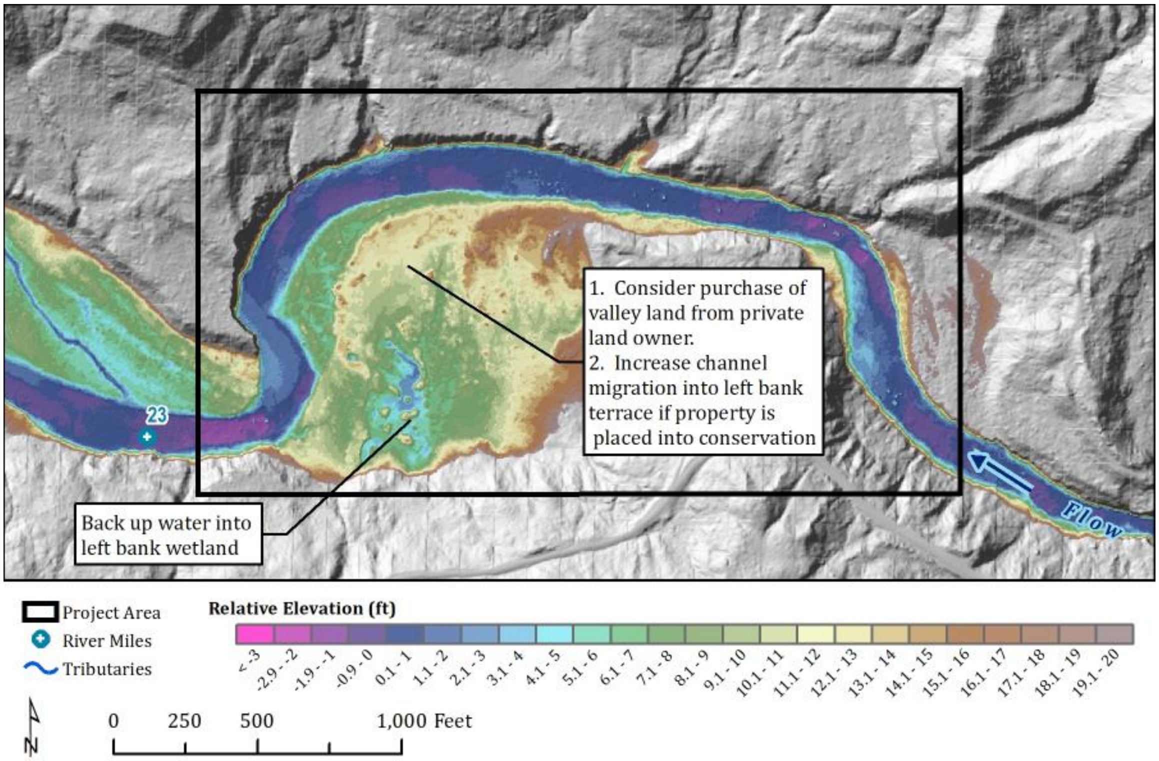


Figure 87. Restoration Opportunity Area 8 in the Upper South Fork Nooksack River.

Reach Description

Opportunity Area 8 is located between RM 23 and RM 23.75 and is directly upstream from the Elk Flats project area (Figure 87). The area includes a right bank meander bend and the floodplain and wetland on the inside of the meander bend. The channel exhibits a single-threaded plane bed morphology in this reach. There is a private landowner on the left bank terrace in the middle of the reach.

Restoration Opportunity

There is an opportunity to protect the left bank terrace land from further development, as well as increase habitat diversity, by reducing velocities in parts of the main plane bed channel. The left bank terrace contains a privately-owned homestead property directly adjacent to the river. LNNR and others could consider trying to purchase this property (similar to what occurred in the Skookum Reach and in Elk Flats with Whatcom Land Trust) to reduce any potential river associated hazards to the landowners and conserve the land indefinitely. If the land is ever purchased, restoration actions could occur that would encourage channel migration into the terrace to create floodplain habitats and recruit wood and coarse sediment to the system. Water could also be backed up into a floodplain wetland complex on the downstream end of the reach.

Opportunity Area 9

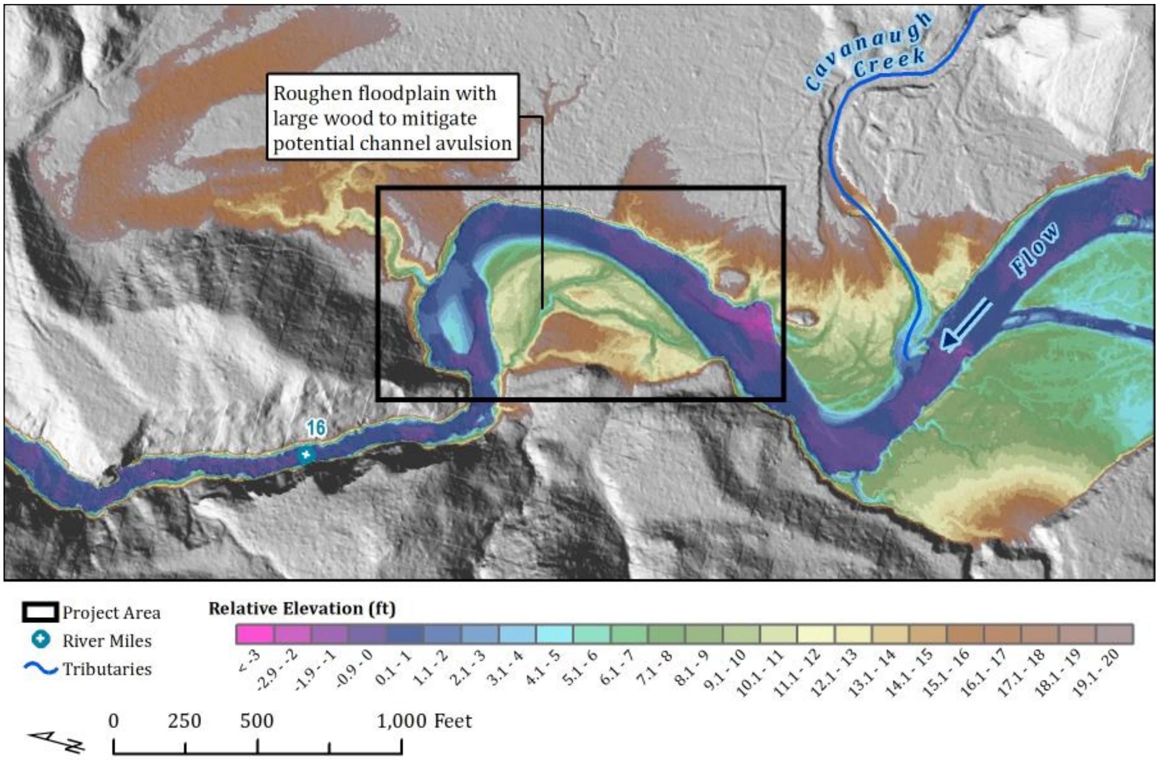


Figure 88. Restoration Opportunity Area 9 in the Upper South Fork Nooksack River.

Reach Description

Opportunity area 9 is located between RM 16.25-16.5 and is directly downstream from the Cavanaugh Island project area (Figure 88). The area includes a right bank meander and is directly upstream from a small rapid and canyon constriction that flows into the Skookum reach. The river has a single threaded channel morphology in this reach.

Restoration Opportunity

There is an opportunity to re-engage the floodplain channels on the inside of the meander bend by aggrading the bed and raising water surface elevations in addition to the thematic goals presented above. The work could build on adaptive management activities in the Cavanaugh Island reach. Care should be taken to not encourage an avulsion that would cut off the meander bend and decrease channel length. Roughening the floodplain with large wood could help reduce this risk. This effort could be integrated into the Upper Cavanaugh-Fobes Phase 2 project implementation, although access for construction to this area may be an issue.

CONCLUSION

The development of this Project Effectiveness Study for the Upper South Fork Nooksack River represents an effort to integrate past data collected throughout large section of river (17 miles) across multiple projects. This information provides insight on the performance of completed projects that will be used to inform the implementation of future projects in the same area and through lessons learned. Many of the objectives identified for each project have been achieved by the restoration efforts (e.g. pool creation, increasing cover and holding habitat, creation of some thermal refuge, floodplain reconnection), however, additional attention to the feasibility and quantification of project objectives is warranted (Table 24). Further, some past projects were limited in their effects and benefits by restrictive floodplain management approaches that have since been adjusted (e.g. no rise requirements).

Table 24. Project objectives achievement summary by objective type. M = Met, NM = Not Met, PM = Partially Met, UN = Uncertain, Blank = No objective. If objective type includes more than one objective per project, achievement is included for both objectives and short description is included in parentheses.

OBJECTIVE TYPE	RM 30	LARSON'S BRIDGE PHASE 1	LARSON'S PHASE 2	FOBES	CAVANAUGH ISLAND	SKOOKUM EDFRO PHASE 1	SKOOKUM EDFRO PHASE 2 & SKOOKUM (2010)
Pool formation		PM	M	M	PM	M (pool frequency); PM (primary pools)	NM
Thermal refuge creation			UN	UN	PM	PM	NM
Habitat unit diversity	M	NM		M			M
Floodplain reconnection	M		PM	PM		UN	
Secondary channel length		NM	M (enhance activation); PM (reestablish anabranching planform)		NM	UN	
Sediment source reduction	M	M (relocate thalweg); UN (reduce fine sediment)					
Spawning gravel retention	M					UN	
Riparian habitat					M		M
LWD Loading	PM	M					
Salmon abundance	NM	UN					
Edge habitat							M

As restoration techniques advance, project designs have integrated new lessons from older projects. Early projects in the South Fork Nooksack (RM 30, Larson's Bridge Phase 1) were successful at addressing acute problems, such as landslide stabilization and road removal, but had limited success in more process-based objectives such as increasing habitat diversity and reconnecting floodplain habitat. Projects built in 2010 (Fobes and Skookum 2010) had more success in achieving some increase in habitat units, but were limited in the ability to create primary pools based on some of the no-rise regulations in place at the time. Further, the goals of creating thermal refuge were either partially met or unable to be assessed based on lack of adequate monitoring data. Further, the combination of creation of primary pools with creation of thermal refuge in the same location may be very difficult to achieve.

Projects constructed from 2012 through 2017 (Cavanaugh Island, Larson's Phase 2, Skookum Edfro Phase 1) had more success with process-based restoration goals such as reconnecting side channels. Larson's Phase 2 has met its objectives for side channel length, but not yet for floodplain and wetland acres reconnected. Cavanaugh Island reconnected the Cavanaugh side channel, but did not maintain that connection during low summer flow to allow for benefits to adult Chinook. These projects generally increased the number and diversity of habitats, but still lacked adequate monitoring to assess achievement of thermal refugia creation goals in many instances. Skookum Edfro Phase 2 was completed in 2018, and is still in the early stages of monitoring. It is on pace to achieve several of the monitoring objectives, but more information is needed to further evaluate project success.

Important elements that emerged from the evaluation of effectiveness across multiple projects included the need for improved objectives, and ensuring that pre- and post-project monitoring data are collected to report back on the achievement of those objectives. Quantified objectives provide clear project targets that can be evaluated for achievement in an objective, transparent manner. Vague objectives, or undefined terms (e.g. habitat complexity, range of hydraulic textures) lead to ambiguity in evaluations, and reduce the ability to provide clear insights for future projects. Objectives should also be attainable in the context of the project site, as discussed in the recommendations above. For example, combining the objectives of primary pools and thermal refuge creation in the same location may be difficult to achieve. Primary pools, by definition, cover more than half the width of the mainstem channel, whereas the creation of cold water refuges (2 deg C cooler than the mainstem) are advanced by maintaining a separation of flow from the mainstem flow. Grouping these objectives together may reduce the probability of achievement. Using clear objectives as guidelines, relevant data collection for baseline conditions can be collected prior to project implementation. Several projects had specific objectives for sediment in terms of reducing fines, or increasing spawning gravel area, but no quantified sediment data were collected to establish the base line, or to evaluate change post-implementation. Some projects were targeted at aggrading the channel, but additional information on bed elevation is needed to assess changes. Additionally, many projects had clear objectives to create thermal refuges, but little information on pre-project temperatures was available, and post-project thermal monitoring was not adequate to detect change (e.g. no control for comparison). Additionally, the specific locations of seeps and springs at some sites had not been researched or mapped, even though creation of thermal refuge was a target for the project. Additional review of objectives and collection of baseline monitoring data relevant to those objectives would benefit the effectiveness monitoring effort.

Two of the most common objectives across projects were 1) the creation of primary pools and 2) the reconnection of floodplain habitats. Actions to achieve both of these objectives generally involved the placement of ELJs to cause changes in geomorphology in the treated reaches including: to split flow into side channels; to scour pools; aggrade the channel; and create multi-threaded channels. The size of an ELJ relative to the unobstructed cross-sectional area of a channel (blockage coefficient) has a significant effect on hydraulics, geomorphic response, and habitat. Blockage coefficients over 20% can increase water elevations upstream, decrease radius of curvature, increase the frequency and duration of floodplain inundation, trigger formation of new channels and islands, and contribute to channel avulsions. All of these actions contribute to increased diversity and quality of aquatic habitat. These effects increase nonlinearly as a function of blockage coefficient such that coefficients of 50-60% are recommended for substantial change in many projects. Wood structures with at least 10% blockage coefficients are likely to create pools with complex cover, but are unlikely to store sediment. In alluvial valleys, like some sections of the Upper South Fork Nooksack, arrays of ELJs must be constructed that are spaced apart by no more than 80% of the bankfull width (Wc), to avoid flanking the structures. Spacing of 0.6 Wc is a good design target. At spacing greater than 0.6 Wc, the flow is likely to follow the unobstructed paths between or around the structures. To further prevent flanking, spacing of ELJs should be no more than 4 ELJ widths apart (defined as the dimension orthogonal to the stream flow, or incident angle of flow). ELJs will only have significant effect when directly engaged with the flow, so if the channel is likely to move, there needs to be enough structures throughout the channel migration zone to ensure direct flow engagement as the channel moves (Abbe and Montgomery 1996, Montgomery and Abbe 2006, Abbe and Brooks 2011, BOR and USACE 2016, and Abbe et al. 2018). These types of guidelines can be used to guide the development of new projects toward greater levels of success and habitat benefit.

This thoughtful approach to the evaluation of past project performance has the potential to increase the effectiveness of future work. Upper Cavanaugh Fobes Phase 2 and Elk Flats are both currently in design development and recommendations have been included in this report for additional baseline sediment and temperature data, quantified objectives for pools and placed wood, and more clarity on terms used in objectives, and design specifications. Design specifications for these projects included placement of ELJs with enough density to affect flow and sediment dynamics (e.g. 50-60% blockage coefficient, 500 pieces/km), and using referenced depth and velocity preferences for Chinook spawning as low flow design criteria to optimize the potential for creation of suitable spawning habitat.

The implementation of similar approaches to project effectiveness in watersheds across Puget Sound and the Pacific Northwest could provide an invaluable resource for documentation of our efforts in restoration in terms of project successes and opportunities for learning. The implementation of repeatable, cost effective approaches for monitoring large areas with multiple projects is an important tool for working towards salmon recovery.

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