WRIA 1 MONITORING AND ADAPTIVE MANAGEMENT PROJECT

Nooksack River Instream Project Effectiveness

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Contributing Authors: Michael Maudlin, Nooksack Tribe; Alex Levell and Nathan Rice, Lummi Nation

Reviewers: Treva Coe and Eric Stover, Nooksack Tribe; Kelley Turner, Lummi Nation; John Thompson; Whatcom County Public Works; Analiese Burns, City of Bellingham.

CONTENTS

INTRODUCTION

Purpose and Scope of Report

The WRIA 1 Salmon Recovery Plan, which covers the Nooksack Watershed and the independent drainages of Whatcom County, split the Nooksack into 15 geographic areas, including mainstem reaches and groups of tributaries, based on the distribution of the early chinook population. The focus for instream habitat restoration in the watershed has been the 5 geographic areas representing the main channel areas in the three forks of the river: the upper and lower North Fork, the upper and lower South Fork and the lower Middle Fork areas. There areas are considered the highest priority areas for instream habitat restoration in the watershed (WRIA 1 Watershed Management Board 2019).

This report has two purposes. The first is to evaluate a selection of the WRIA 1 Status and Trends habitat indicators as a part of the Puget Sound monitoring and adaptive management process that are expected to respond to instream habitat restoration projects (WRIA 1 Watershed Management Board 2017). Each of these indicators will have targets presented for “Good” and “Very Good” conditions. Where targets have not been developed as a part of the regional monitoring and adaptive management plan, targets will be developed for this report. These indicators will be evaluated and summarized at the planning reach level that is included in the habitat restoration strategy to show change since the adoption of the Salmonid Recovery Plan in 2005 (WRIA 1 Salmon Recovery Board 2005). Each monitoring indicator will be summarized by reach and binned by whether it meets the targets. Reaches that include habitat restoration projects will be highlighted and the influence of the project on the indicator will be briefly described.

The second purpose of the report is to evaluate each of the 23 habitat restoration projects that have been constructed in the forks relative to their project objectives. The objectives will be taken from a variety of sources, including grant proposals, previous project monitoring reports and design documents. Often the project objectives are not stated as specific and measurable targets for success, in those cases it can be difficult to determine project success. More recently, projects have presented “SMART” objectives that are specific, measurable, achievable, results-oriented, and time-fixed. To help reframe the related objectives into a common format, the objectives were grouped into categories related to the habitat limiting factors and causal mechanisms that the objective was seeking to address. Then common monitoring metrics were applied. For example, the objective “*restore instream habitat and complexity by creating multiple complex pools*” was put into the “pool formation” objective group and the pool spacing, depth and forming features of the pools were assessed.

Following the grouping of the objectives, we will present the available monitoring data to determine the success of the project relative to the stated objectives. Since the projects have been implemented by a variety of different agencies, the amount and types of baseline information and subsequent monitoring data available will vary by project. Objectives will be considered met, partially met, not met or uncertain. In the case of projects in the Upper South Fork geographic area, a companion report was completed and the findings were only briefly summarized in this report (Natural Systems Design 2019 Draft).

NOOKSACK RESTORATION STRATEGIES AND STATUS AND TRENDS INDICATORS

North Fork Nooksack Restoration Strategy

The North Fork is split in the upper and lower geographic areas at the confluence of Glacier Creek. The Upper North Fork area lies between Glacier Creek at River Mile 57.6 and Nooksack Falls at River Mile 65. This area is largely confined in canyons, with the exception of the Deadhorse planning reach, which is a less confined reach covered by an early habitat restoration project. There is limited historic habitat data available for the upper North Fork and the area was not covered in the North Fork reach assessment, which was used for salmon recovery planning in the fork (Hyatt 2007). Because of this, the area was not covered in the analysis of the chinook habitat status and trends indicators, but was covered in the Upper North Fork Project monitoring section.

The Lower North Fork Nooksack area is between river mile 36.6 (the confluence with the South Fork Nooksack River) and river mile 57.6, the confluence with Glacier Creek. This reach is described in the WRIA 1 Salmon Recovery Plan (WRIA 1 Salmon Recovery Board 2005):

> The lower North Fork is characterized by unconfined reaches alternating with short reaches confined by ancient landslide deposits. The historic channel migration zone of the lower North Fork nearly fills its floodplain, occupying about 74% of floodplain width. Historically, the channel pattern was anastomosing, with multiple channels, sloughs, and forested islands; a more frequently shifting braided pattern characterizes current conditions (Collins & Sheikh 2004b). Dominant land use in the watershed is commercial forestry, although much of the lower North Fork valley is zoned rural and rural forestry. Some bank hardening is present, especially associated with river-adjacent roads in the reach (Mt. Baker Highway, North Fork Rd., Truck Rd.). Bridges that constrain the lower North Fork include Highway 9 and Burlington Northern railroad bridges (RM 36.7), Mosquito Lake Road bridge (RM 40.7), and Mt. Baker Highway downstream of Canyon Creek (RM 54.8).
>
> The lower North Fork represents 30% of the spawning distribution and 20% of the freshwater habitat for NF/MF Nooksack early chinook. Restoration of the lower North Fork will be very important in recovering abundance and productivity, as well as life history diversity, of NF/MF Nooksack early chinook. After restoration of passage upstream of the Middle Fork diversion dam, the next most important reaches for restoration are in the lower North Fork, from the South Fork confluence to Maple Creek. The lower North Fork is also important in maintaining current abundance and productivity, especially the upstream reaches. Channel instability, leading to redd loss due to bed scour and channel shifting, is considered the most important factor limiting NF/MF Nooksack early chinook productivity in the geographic area. Egg incubation is the most limiting life stage, followed by fry. Fine sediment load, key habitat quantity, and to a lesser extent high temperature, are considered to be limiting the population.

The causal mechanisms identified in the Salmon Recovery Plan and the monitoring indicators that are tied to the limiting factors for the lower North Fork geographic area are shown in Table 1. Targets for the monitoring indicators were developed as a part of developing the WRIA 1 Monitoring and Adaptive Management Plan (WRIA 1 Watershed Management Board 2017). The monitoring targets were based on a comparison to two conditions: an estimate of properly functioning conditions, which was considered “Good” and an estimate of early historic conditions, which was considered “Very Good”.

Monitoring indicators that are not included as viability indicators in the monitoring and adaptive management plan have a target relative to change in the historic conditions of the North Fork Nooksack. For consistency with the WRIA 1 monitoring plan, “Good” was based on a percentage of the historic conditions, while “Very Good” reflects the early historic conditions or the maximum measured value, depending on the indicator. Turbidity has not been monitored, so it will not be included as a project effectiveness indicator. For the key habitat indicators in the lower North Fork the “Good” and “Very Good” conditions are shown in Table 2. With the exception of side channel length, key habitat has not been monitored throughout the planning reaches, so changes in pools and wood function will be assessed at the project scale.

Table 1: High and moderate importance limiting factors, primary causal mechanisms and monitoring metrics for the Lower North Fork Geographic Area (WRIA 1 Salmon Recovery Board 2005).

Limiting Factor (Importance)	Causal Mechanism	Monitoring Indicator
Channel Stability (High)	Degraded riparian function leads to increased floodplain erosion, loss of forested islands and side channels	Forest Island Area and Count
		Floodplain Forest Encroachment
		Active Channel Area
Key Habitat Quantity (Moderate)	Degraded riparian function leads to loss of stable instream wood accumulations that provide complex cover and form pools	Pool Count by Type
		Wood Function
		Side Channel Length
Sediment (Moderate)	Elevated mass wasting from land use practices	*Turbidity- Unmonitored*

Based on the limiting factors and causal mechanisms, habitat restoration strategies were identified and prioritized to guide project development in the planning reaches of the Lower North Fork Geographic Area (Table 3). Tier 1 represents the highest priority action in the highest priority geographic area, while Tier 2 represents that the action is considered a lower priority in the reach. For this report, the fourteen planning reaches that are identified in the WRIA Restoration Strategy are used for the Lower North Fork Nooksack (WRIA 1 Watershed Management Board 2019). These reaches were originally identified in the *Lower North Fork Nooksack River: Reach Assessment and Restoration Recommendations* (Hyatt 2007), which underpins the habitat restoration planning for this section of the river (Figure 1).

Table 2: WRIA 1 habitat indicators and targets relevant to the Lower North Fork Geographic Area (adaptive management viability status and trends indicators are shown with an asterisk). Condition targets in italics are suggestions for indicators that lack tiered targets that are based on project-level effectiveness targets.

Monitoring Indicator	"Good" Condition	"Very Good" Condition
Forest Island Area and Count*	>75% of "Very Good" Condition	Maximum of historic photo period (1933-1998)‡
Side Channel Length	*30% of the main channel length (where less than historic)*	Pre-2005 historic maximum
Floodplain Forest Encroachment*	Stand age >80% of natural condition	Stand age characteristic of natural condition (>40% older than 25 yrs., >10% older than 75 yrs.)
Active Channel Area	*>Recent historic mean (1933-1998)*	Early Historic Conditions (GLO surveys)
Pool Count by Type*	<1.4 channel widths per pool;	<1.0 channel width per pool
Wood Function*	>70% of pools formed by wood	>70% of pools formed by wood

‡Revised from "Early historic conditions".

Figure 1: Lower North Fork Nooksack Planning Reaches (Hyatt 2007).

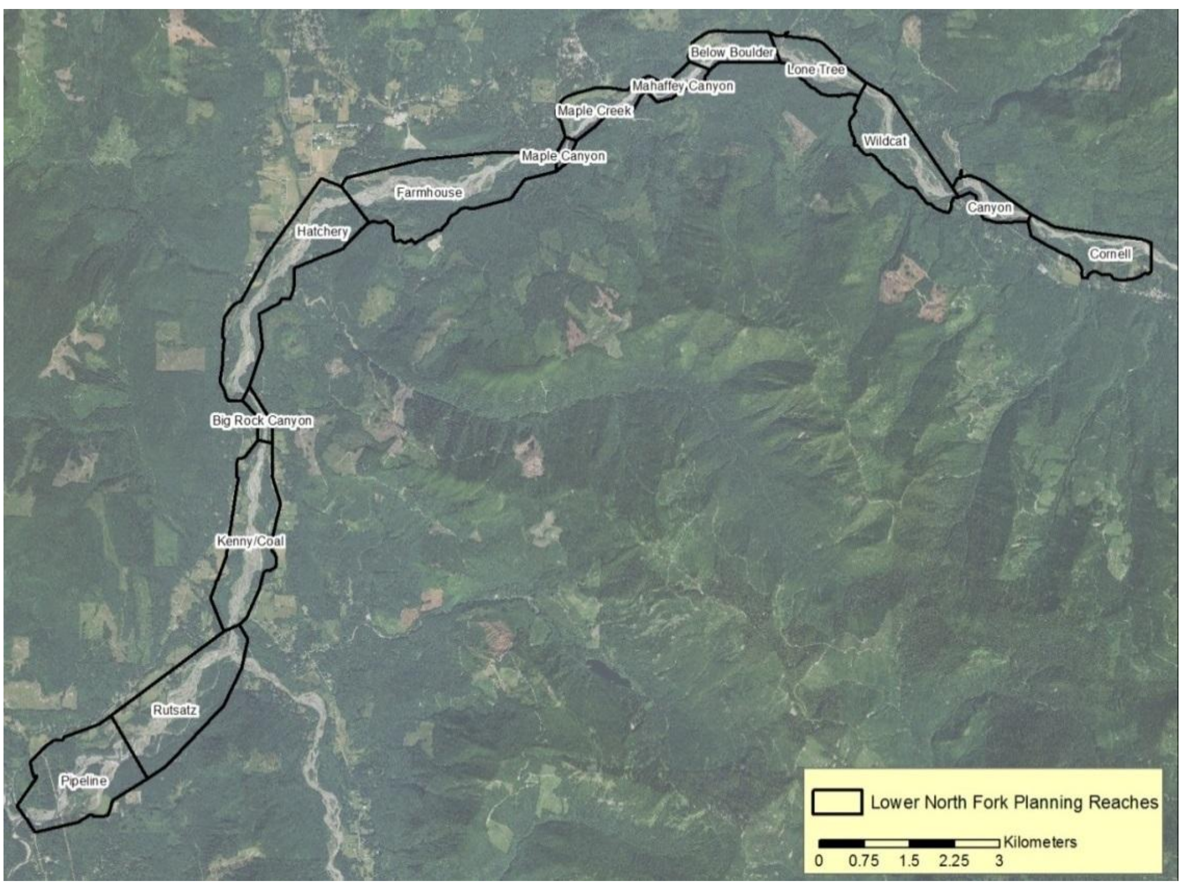


Table 3: The three restoration strategies that have been identified as Tier 1 (highest priority) for the North Fork Nooksack River (WRIA 1 Watershed Management Board 2019). Italics: Upper North Fork planning area and not included in the discussion of habitat indicators. Other lower priority strategies have been identified in the strategy, but are not included in this table.

Reach Name	Upstream RM	Restoration Strategies		
		Construct/augment log jams to protect, encourage formation and growth of forested islands	Log jams to reconnect side channels	Promote floodplain forest encroachment on active channel area
Pipeline	38.3	Tier 2	Tier 2	Tier 2
Rutsatz	40.6	Tier 2	Tier 2	Tier 2
Bell/Kenny	42.9	Tier 2	Tier 2	Tier 2
Big Rock Canyon	43.7			
Hatchery	46.7	Tier 1	Tier 1	Tier 2
Farmhouse	49.4	Tier 1	Tier 1	Tier 1
Maple Canyon	49.8			
Maple Creek	50.6	Tier 1	Tier 1	Tier 2
Mahaffey Canyon	51.1			
Below Boulder	52.3	Tier 1	Tier 1	Tier 2
Lone Tree	53.3	Tier 1	Tier 1	Tier 1
Wildcat/Warnick	54.8	Tier 1	Tier 1	Tier 2
Canyon	55.8	Tier 2	Tier 2	Tier 2
Cornell	57.8	Tier 2	Tier 2	Tier 2
Horseshoe	*61.9*			
Deadhorse	*65.0*	*Tier 1*	*Tier 1*	*Tier 2*

North Fork Habitat Indicators

Forest Island Formation

Forest island area and count was selected as a viability indicator for chinook habitat for the North Fork Nooksack. Forest islands are vegetated patches within the active channel area of the river that are separated from the channel margin vegetation by an unvegetated channel. Forest islands were mapped from historic maps (1885-1918) and aerial photos (1933-1998) to measure historic changes in floodplain habitat (Collins and Sheikh 2004). Habitat mapping and spatial analysis to characterize the 2005 conditions (recovery plan adoption conditions) was done to support the North Fork Nooksack reach assessment (Hyatt 2007). Photo and high-resolution topography interpretation using similar methods was done by the Nooksack Natural Resources Department for 2010 and 2016 to inform this monitoring report. To ensure that the methods were mapping similar patches of forested islands, the minimum patch size from the different mapping was compared and a minimum area of 100 m^2 was used to define an island. For each of the North Fork analysis reaches, as defined by Hyatt (2007), forest island area and count were summarized and compared to targets established as a part of the chinook monitoring and adaptive management plan.

Both forest island area and island count have a considerable amount of variation in them through time (Table 4). Generally, the less confined reaches from Farmhouse downstream to the Pipeline Reach have a wider range for both of the island count and island area (Figure 2, Figure 3). Looking across reaches at changes in the island area through time, it is evident that island erosion and growth varies by reach through the lower North Fork (Figure 4). The exceptions appear to be a strong decrease in island area across all reaches in the late-1930s and again between 1994 and 2005 to the lowest historic value with a subsequent recovery of island area after 2005 to levels that have exceeded the historical average (Figure 5). All of the habitat restoration work focused on increasing island area and count that has been completed in the North Fork has occurred in this period of increasing forest island area throughout the lower North Fork, making it difficult to sperate the response to the project from the broader recent trend of increased island area.

Figure 2: Maximum, minimum and mean forest island area through time (1933-2016) and 2016 conditions by monitoring reach.

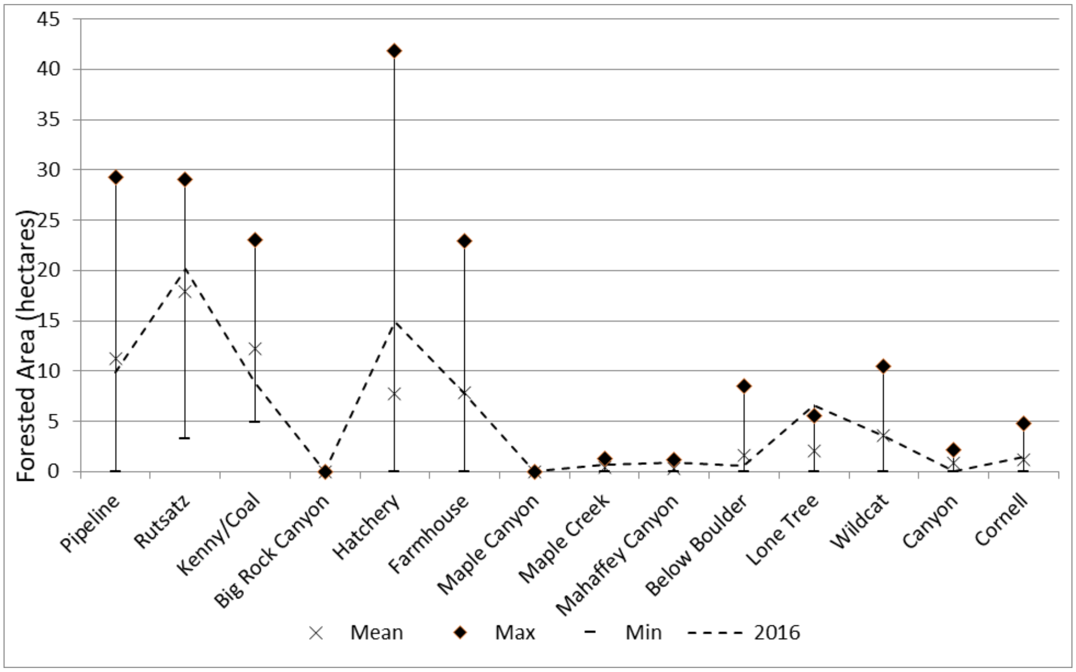


Figure 3: Maximum, minimum and mean forest island count through time and 2016 conditions by monitoring reach.

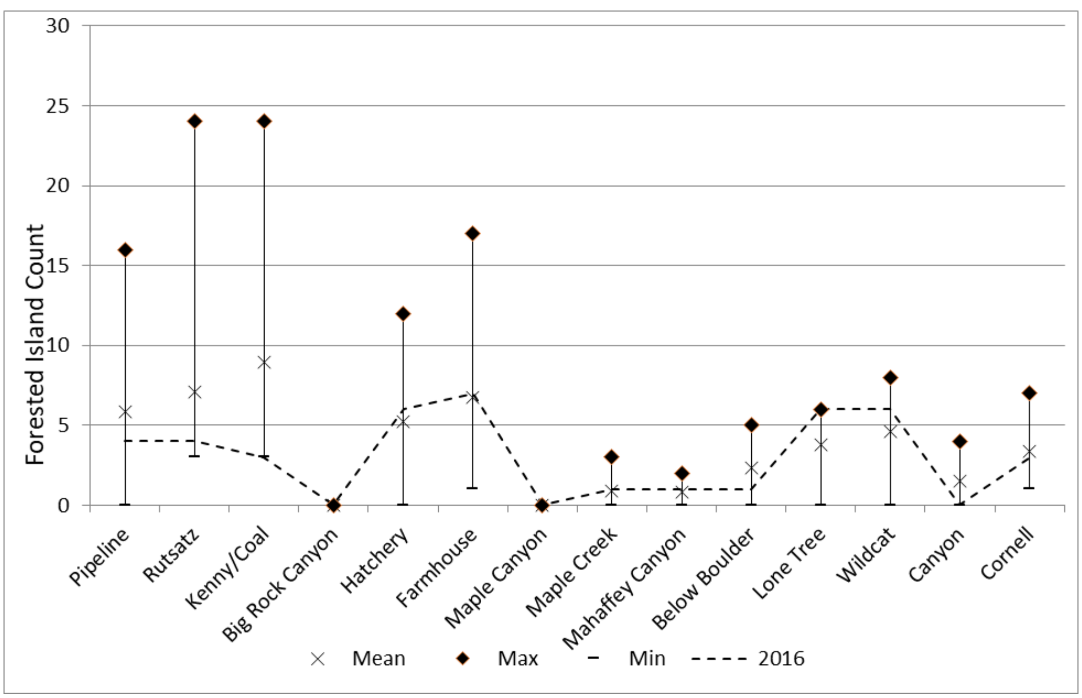


Table 4: Forested island and active channel area (hectares) change through time for the North Fork Nooksack analysis reaches. The reaches are listed from downstream to upstream in the table. The 1933-1998 island area is based on aerial photograph interpretation (Collins and Sheikh 2004). More recent mapping was done by Nooksack Natural Resources. Empty cells were not covered by the aerial photo flight for that year and maximum pre-adoption of the Salmon Recovery plan area for each reach is highlighted.

Reach	Year													Mean/ St. Dev
	1933	1938	1950	1955	1966	1976	1980	1986	1994	1998	2005	2010	2016	
Pipeline	4.6	0.9	6.8	6.1	0.0	9.0	17.0	25.7	29.3	12.7	11.2	21.5	9.9	11.9±9.1
Rutsatz	29.1	19.7	13.9	19.9	28.3	3.3	12.2	6.9	27.7	18.3	9.3	24.7	20.1	18.0±8.4
Kenny/Coal	20.5	6.6	5.9	7.4	23.0	14.0	17.9	16.7	5.2	4.9	4.6	8.8	8.9	11.1±6.5
Big Rock Canyon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N/A
Hatchery	41.8	1.8	2.8	6.5	6.7	8.8	0.0	5.1	2.7	0.4	0.8	6.7	14.9	7.6±11.1
Farmhouse	21.2	1.6		3.1	5.5	22.9	9.5	10.1	3.8	1.0	0.9	8.6	7.7	8.0±7.3
Maple Canyon	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	N/A
Maple Creek	0.3	0.0		1.3	0.3	1.0		1.0	0.0	0.0	0.0	1.8	0.7	0.6±0.6
Mahaffey Canyon	1.2	1.2		0.1	0.2	0.1		0.2	0.3	0.0	0.0	0.0	0.9	0.4±0.5
Below Boulder		8.5		0.4	4.1	0.5		1.8	0.9	0.0	0.0	2.5	0.6	1.9±2.6
Lone Tree		4.5		0.0	0.3	3.1		5.6	4.0	2.8	0.6	4.1	6.6	3.2±2.2
Wildcat		0.0		4.9	6.9	10.5		4.4	8.8	0.0	0.0	3.6	3.5	4.3±3.7
Canyon		0.5		2.2	2.1	1.9		1.2	0.3	0.0	0.2	1.3	0.0	1.0±0.9
Cornell		4.8		0.5	1.6	1.8		2.9	0.8		0.6	1.0	1.4	1.7±1.4
Total forest island area	*118.7*	*50.1*	*29.4*	*52.5*	*79.0*	*76.8*	*56.6*	*81.7*	*83.9*	*40.1*	*28.0*	*84.7*	*75.2*	
Total high flow area	*403.8*	*464.7*	*233.5*	*439.6*	*417.2*	*443.2*	*305.4*	*404.7*	*553.7*	*476.2*	*714.2*	*671.3*	*696.0*	
Total low flow area	*138.9*	*127.8*	*111.7*	*187.4*	*235.5*	*191.2*	*166.4*	*263.2*	*209.7*	*172.0*	*60.1*			
Active channel area	*542.7*	*592.5*	*345.3*	*627.0*	*652.7*	*634.4*	*471.8*	*667.9*	*763.4*	*648.1*	*774.3*	*671.3*	*696.0*	

Figure 4: Forest island area for all NF planning reaches, with non-project planning reaches shown in blue and planning reaches containing projects shown in green for comparison. All projects were implemented after 2005.

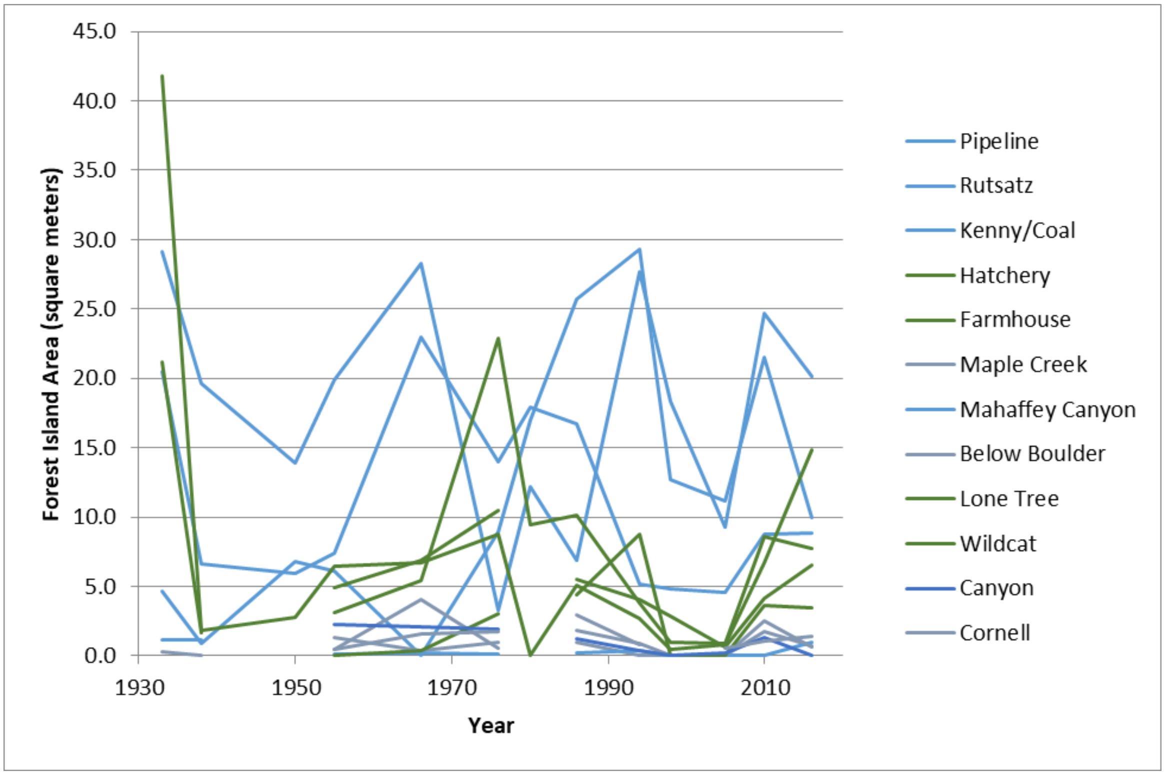
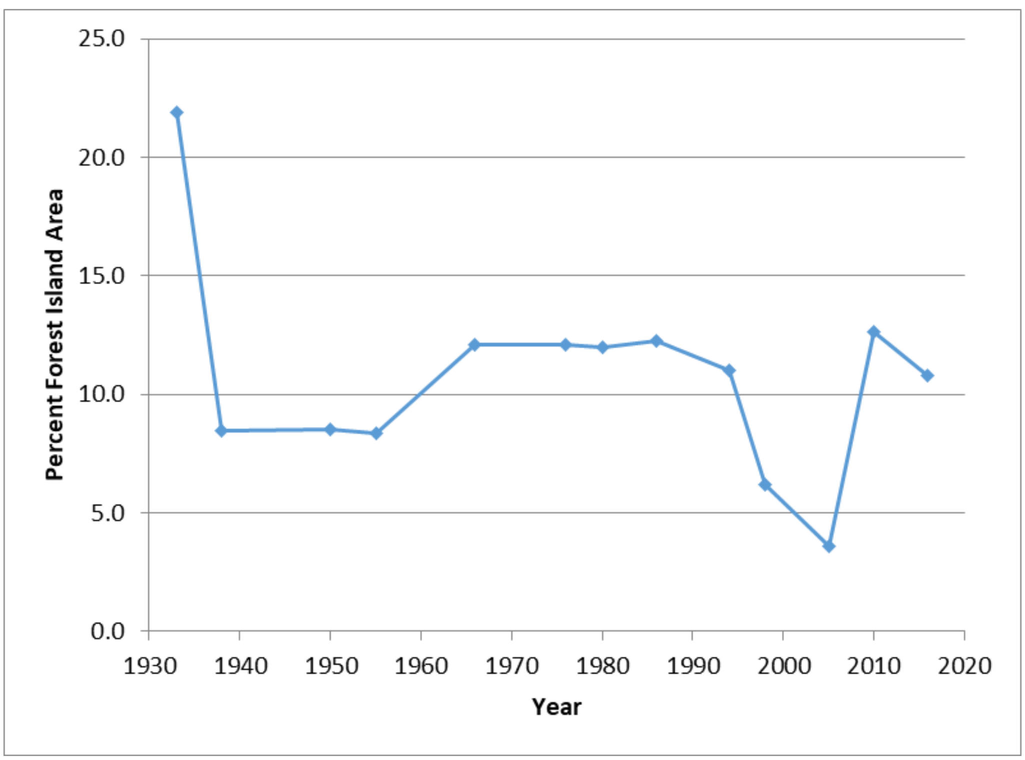


Figure 5: Percent of high flow channel area classified as forested island in the Lower North Fork Geographic Area.



Restoration has occurred in four of the planning reaches (Lone Tree, Wildcat, Hatchery and Farmhouse) with the goal of increasing side channel length and channel stability. This should be reflected in an increase in the forest island area and count following project implementation. The NSEA island augmentation project consisted of using log posts to stabilize existing woody debris piles in the floodplain in the Hatchery reach, while the other three projects were engineered logjam projects in the Lone Tree, Wildcat and Farmhouse reaches. Two of the project reaches have seen an increase in forest island area following the projects- the Lone Tree reach and the Hatchery reach, although this is within the context of the entire river showing an increase in island area in that period (Figure 4, Figure 6). After an increase between 2005 and 2010, both the Wildcat and Farmhouse reaches have seen a slight decrease in island area, but in 2016 both remained near their historic mean value (Table 4). All four reaches have also seen an increase in forested island count between 2005 and 2016 (Table 5).

Figure 6: Forest island area (hectares) in North Fork Nooksack analysis reaches where restoration has been done.

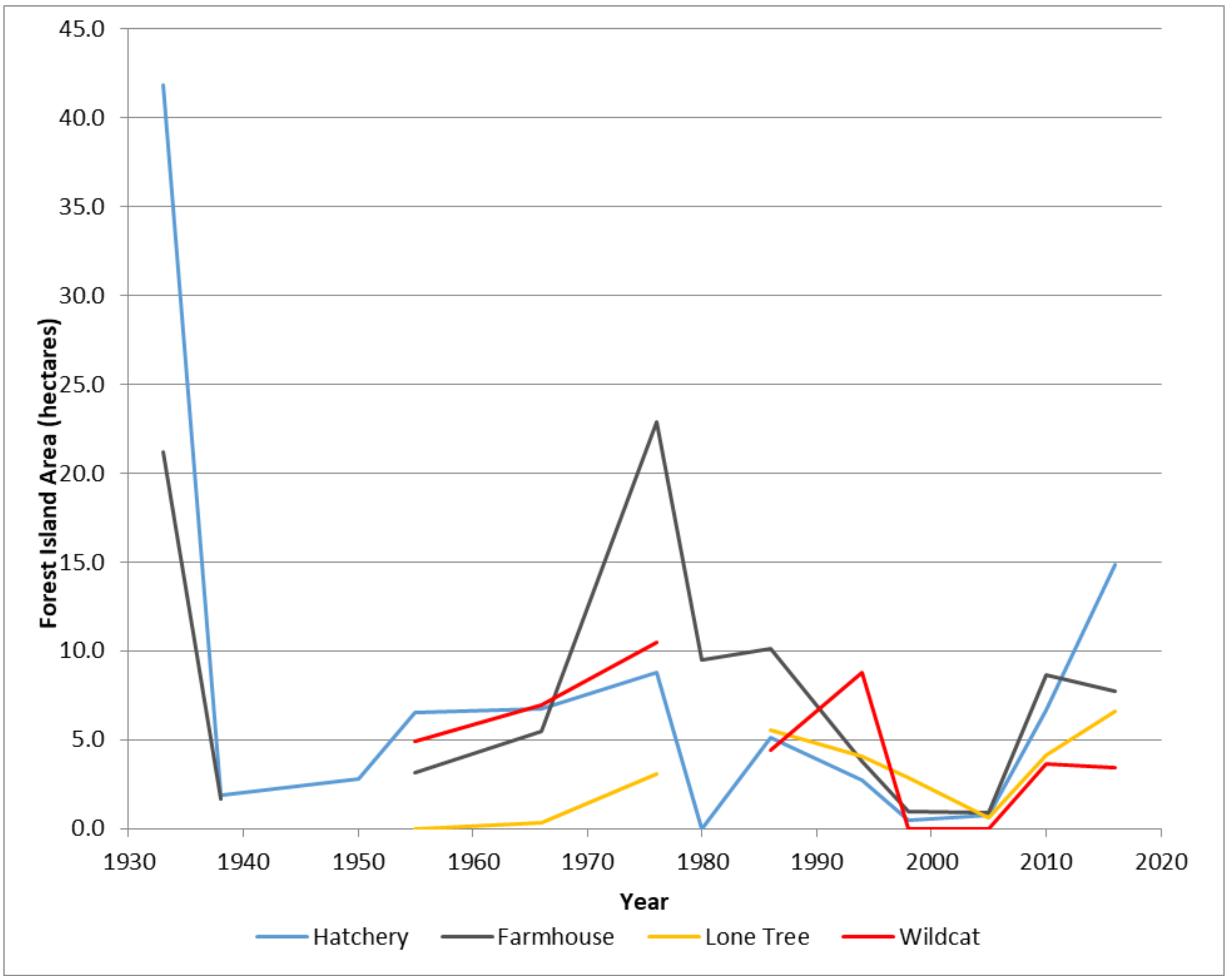


Table 5: Island count in the project reaches from salmon recovery plan adoption to 2016.

Reach	2005	2010	2016
Wildcat	0	5	6
Lone Tree	3	4	6
Farmhouse	3	7	7
Hatchery	2	12	6

Comparing the changes in the forested island area to the targets for “Good” and “Very Good” conditions, one of the reaches (Lone Tree) has exceeded the historic (1933-1998) maximum island area and one has reached 75% of the historic maximum area (Table 6). Ten of the twelve reaches that historically contained islands, including all four project reaches, have seen an increase in area since the adoption of the Salmon Recovery Plan. Forest island count has seen a similar change; with one reach (Lone Tree) exceeding the historic island count and the Wildcat project reach exceeding 75% of the historic maximum island count (Table 7). Eight of the twelve reaches that historically contained islands, again including all of the project reaches, saw an increase in island count since the adoption of the recovery plan.

Table 6: Forest island area (hectares) targets and conditions for the North Fork monitoring reaches. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects, canyons with no historic islands are shown in italics.

Reach	Targets		Conditions	
	Historic Max. Area ("Very Good")	75% of Historic Maximum ("Good")	2005 Recovery Plan	2016 Conditions
Pipeline	29.3	22.0	11.2	9.9
Rutsatz	29.1	21.8	9.3	20.1
Kenny/Coal	23.0	17.3	4.6	8.9
Big Rock Canyon	*0.0*	*0.0*	*0.0*	*0.0*
Hatchery	41.8	31.4	0.8	14.9
Farmhouse	22.9	17.2	0.9	7.7
Maple Canyon	*0.0*	*0.0*	*0.0*	*0.0*
Maple Creek	1.3	1.0	0.0	0.7
Mahaffey Canyon	1.2	0.9	0.0	**0.9**
Below Boulder	8.5	6.4	0.0	0.6
Lone Tree	5.6	4.2	0.6	**6.6**
Wildcat	10.5	7.9	0.0	3.5
Canyon	2.2	1.7	0.2	0.0
Cornell	4.8	3.6	0.6	1.4
NF Total	*180.2*	*135.2*	*28.0*	*75.2*

Table 7: Forest island count targets and conditions for the North Fork monitoring reaches. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects, canyons are shown in italics.

Reach	Targets		Conditions	
	Historic Max. Count ("Very Good")	75% of Historic Maximum ("Good")	2005 Recovery Plan	2016 Conditions
Pipeline	16	12	6	4
Rutsatz	24	18	6	4
Kenny/Coal	24	18	11	3
Big Rock Canyon	*0*	*0*	*0*	*0*
Hatchery	12	9	2	6
Farmhouse	17	13	3	7
Maple Canyon	*0*	*0*	*0*	*0*
Maple Creek	3	2	0	1
Mahaffey Canyon	2	1	0	1
Below Boulder	5	4	0	1
Lone Tree	6	4	3	**6**
Wildcat	8	6	0	**6**
Canyon	4	3	1	0
Cornell	7	5	1	3
NF Total	*128*	*96*	*33*	*42*

Continued monitoring of forest island area and count will be important to determine if the restoration projects have been effective in reducing island erosion relative to reaches without projects. While all of the project reaches have seen an increase in both island area and count, this has apparently occurred during a period when there is widespread island formation and vegetation encroachment on bars throughout the North Fork Nooksack, possibly driven by regional climate patterns that have been hypothesized to drive bed elevation changes in the North Fork Nooksack (Anderson and Konrad 2019).

A consideration could be whether it is appropriate to use a percentage of the historic maximum from the photo record as the basis for our targets for all reaches. The planform of the channel varies by year through the length of the North Fork from a sinuous single thread, braided, to island-braided. These changes in response to watershed changes in sediment, wood and flow, related to both regional climate patterns and land use, will have a strong influence on the ability to meet this monitoring metric. The monitoring of floodplain forest encroachment, active channel width and side channel length likely more directly capture secondary channel development and stability.

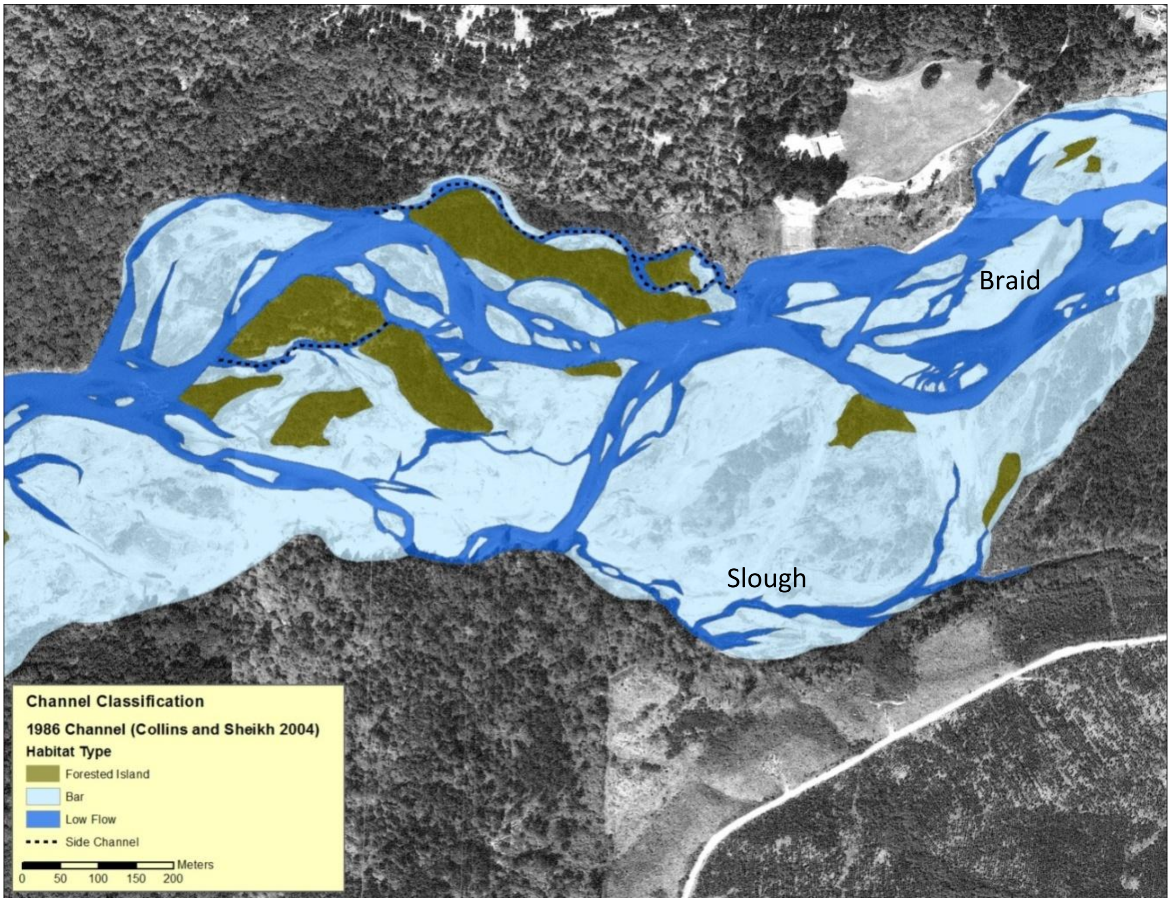
Side Channel Connectivity

The habitat mapping that is used for monitoring and adaptive management in the Nooksack Watershed is broadly based on four channel types: main channel, braid, side channel, and slough (Coe 2013). The main channel is the channel or channels that contain the dominant flow of the river. For the historic channel mapping, this determination is based on channel width, with the widest channel being considered the main channel. Braided channels are those secondary channels that are split from the main channel by gravel bars or sparse, young vegetation. Slough channels are disconnected at the upstream end by sediment deposition or organic debris and are often groundwater-sourced. Side channels are defined as smaller (contains less than half of the river discharge) perennial channels that are connected to the main channel of the river at both the upstream and downstream ends and separated from the main channel area by patches of persistent woody vegetation (Beechie et al. 2017). For the purposes of this monitoring report, historic (pre-2005 Salmon Recovery Plan adoption) side channel length is taken from habitat mapping of high flow, low flow, and forested islands done by Collins and Sheikh (2004) (Figure 7). These channels were mapped from spatially referenced aerial photos taken at various flow conditions, so seasonal changes in side channel connectivity is not captured.

Side channel length is a primary focus of habitat restoration projects in the braided and anastomosing channel of the North Fork Nooksack because of the higher incubation success associated with these environments, when compared to main channel or braided habitats (Hyatt and Rabang 2003).

For this analysis, side channels that span analysis reaches are segmented and measured by project reach. Channels split by unvegetated bars within the side channel area are classified as braids, rather than additional side channel length. In this case, the dominant (widest) channel is considered for the side channel length measurement, or if the braids appear to carry approximately equal flow, then the longest flow path is measured.

Figure 7: Habitat types mapped for the Nooksack River by Collins and Sheikh (2004). Side channels were identified from the historic mapping based on the channel width relative to the main channel and the associated floodplain vegetation.



Side channel length has varied considerably by reach through time in the North Fork Nooksack (Table 8). Similar to forest island area and count, the greatest length and range of values occurs in the unconfined reaches from the Farmhouse reach downstream to the Pipeline reach. Channel migration and seasonal changes in flow has a strong influence on side channel length, causing the length of side channels to increase or drop drastically between photo years within a reach.

Cumulative side channel length through time in the North Fork rose from the historic minimum length (~2,900 m) in 1938 until it reached approximately 10,815 m in 1966, which was slightly more than the average side channel length of the North Fork through the historic photo record. By 1976, the length had dropped to approximately half this length before increasing to its historic maximum in 1986. Side channel length fell continuously until 2005, when the salmon recovery plan was adopted and the focus of restoration in the North Fork became increasing the length of perennial side channels. By 2016, the length had again increased to approximately the historic average, with 8 of the 12 unconfined reaches showing an increase in length. In the four reaches where restoration projects have occurred since the adoption of the salmon recovery plan in 2005, two of the four have seen an increase in side channel length (Wildcat and Lone Tree), while two have seen a decrease in side channel length (Farmhouse and Hatchery). These changes are within the context of overall increases in side channel length throughout the North Fork between 2005 and 2016.

Table 8: Side channel length (meters) for each of the analysis reaches through time. Bolded areas are reaches that include habitat restoration projects designed to increase side channel length. Highlighted cells show the pre-2005 maximum value.

Reach	Aerial Photo Year								Mean\ St Dev
	1938	1955	1966	1976	1986	1994	2005	2016	
Pipeline	0	628	0	839	2,427	4,500	0	0	1049±1623
Rutsatz	0	1,502	1,787	1,085	1,411	1,930	0	760	1059±750
Kenny/Coal	0	1,838	1,989	1,497	6,168	3,007	1,137	1,718	2169±1823
Big Rock Canyon	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*N/A*
Hatchery	0	519	2,337	0	1,441	1,411	3,793	2,821	1540±1371
Farmhouse	0	1,288	2,218	746	1,425	1,039	1,599	793	1139±661
Maple Canyon	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*N/A*
Maple Creek	0	0	0	486	424	0	0	350	158±220
Mahaffey Canyon	563	0	0	122	0	522	0	406	202±252
Below Boulder	1,470	67	0	267	782	90	0	467	393±513
Lone Tree	340	0	330	0	451	0	0	1,218	292±419
Wildcat	0	2,118	1,748	364	434	621	0	228	689±802
Canyon	0	0	406	0	592	760	345	0	263±307
Cornell	530	391	0	545	493	0	0	1,243	400±402
TOTAL:	*2,903*	*8,351*	*10,815*	*5,951*	*16,048*	*13,880*	*6,874*	*10,004*	*9353±4280*

Comparing the changes in side channel length to the targets for “Good” and “Very Good” conditions, three of the reaches show that they are currently above the historic maximum length for side channels. Additionally, two of the reaches meet the “Good” threshold of having the side channel length be at least 30% of the main channel length (where this value is less than the historic value). Two of the five that are above the threshold (Kenny/ Coal and Hatchery), were also above the threshold in 2005. Of the five reaches that meets the “Good” or “Very Good” thresholds, two are project reaches. The Hatchery reach has seen the greatest decline in side channel length since 2005, but has remained above the historic maximum. The Farmhouse Reach has also seen a sharp decline in this period and no longer meets the target. Overall, the North Fork exceeded the 30% “Good” target for side length in 2016.

Table 9: Side channel length (meters) relative to planning targets for the North Fork Nooksack. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects.

Reach	Targets		Conditions	
	1938-2005 Historic Maximum Length ("Very Good")	30% of Mainstem Length ("Good") 2010/2016	2005 Recovery Plan	2016 Conditions
Pipeline	4,500	782/ 696	0	0
Rutsatz	1,930	834/ 846	0	760
Kenny/Coal	6,168	1008/ 1024	**1,137**	**1,718**
Big Rock Canyon	*0*	*0*	*0*	*0*
Hatchery	2,337	1334/ 1316	**3,793**	**2,821**
Farmhouse	2,218	1121/ 1154	**1,599**	793
Maple Canyon	*0*	*0*	*0*	*0*
Maple Creek	486	540/ 465	0	350
Mahaffey Canyon	563	448/ 413	0	406
Below Boulder	1,470	463/ 415	0	**467**
Lone Tree	451	504/ 481	0	**1,218**
Wildcat	2,118	796/ 830	0	228
Canyon	760	471/ 452	345	0
Cornell	545	692/ 668	0	**1,243**
NF Total	*23,546*	9413/ 9186	*6,874*	***10,004***

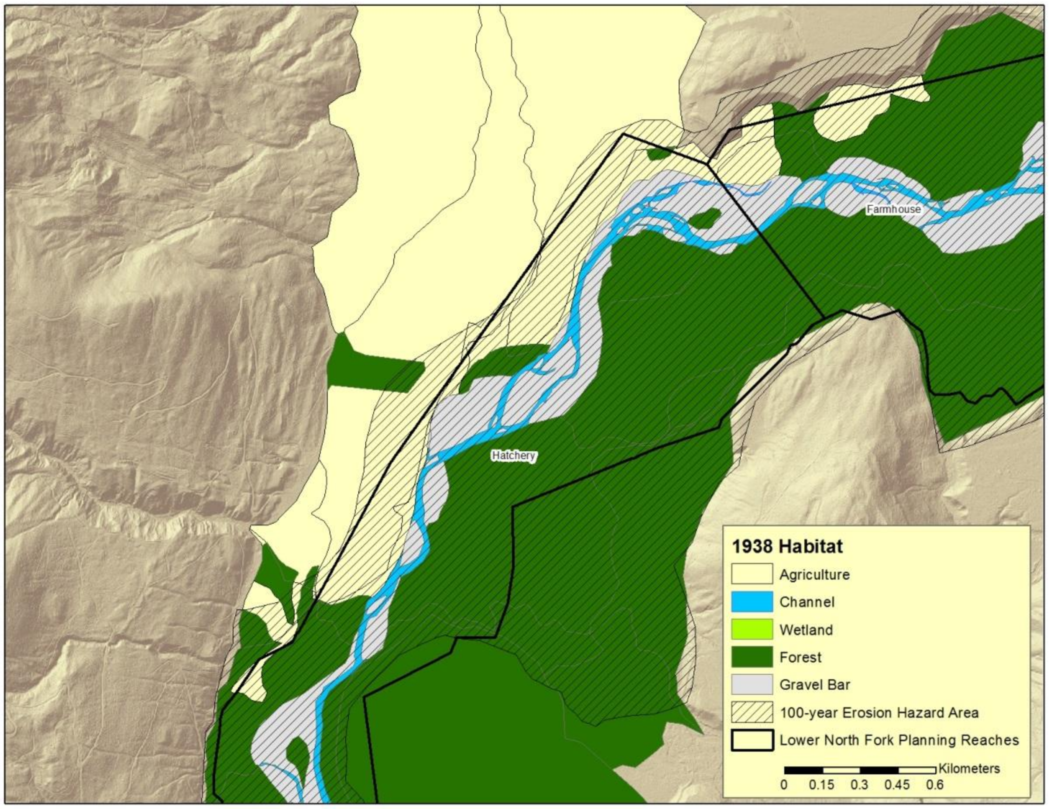
Similar to the forest island area and count metrics, continued monitoring of the side channel length through time will be important to determine if the restoration projects have been effective in increasing and maintaining side channel length relative to reaches without projects. While two of the project reaches have seen an increase in side channel length since 2005, this has apparently occurred during a period when there has been an increase in side channel length in most of the analysis reaches in the North Fork Nooksack. This difference is also likely affected by a difference in the river stage between the 2005 and 2016 conditions.

In spite of the difficulty of controlling for differences in the river stage and the limitations of the historic photos to document the target conditions, side channel length is an important direct measurement of habitat diversity in the North Fork. Since side channel habitat has been tied to incubation success and channel stability as a limiting factor, it will be more important to assess seasonal side channel connectivity and habitat quality at the project scale, while understanding the broader context presented in the historic record.

Floodplain Forest Encroachment

The floodplain forest viability indicator was selected to reflect an increase in channel stability and improved riparian stand conditions in the North Fork Nooksack watershed, while acknowledging that channel migration will create a patchwork of forest stands. The targets are related to amount of the riparian zone that is greater than 25 years old (>40%) and greater than 75 years old (>10%). To evaluate stand age, a map of the forest cover from the earliest complete aerial photo flight (1938) was compared to subsequent photo years to determine the fate of forest patches (Collins and Sheikh 2004 data). If the forest patch still appears to be forested in the subsequent photo year, it will be counted as the same stand. Patches that were not reset by channel migration or cleared for land use by the 2016 aerial photo year are considered >75 years old. There may be cases where trees were removed from the patch between photo years, but the patch still appeared to be a forest that may lead to overestimations of the forest age. To evaluate the stands older than 25 years, habitat mapping based on the 1998 aerial photos was used and the indicator adjusted to reflect 20 years of stability. To compensate for changes in the size of the riparian area through time due to changes in the active channel width, the channel area from the 1890s Government Land Office surveys was subtracted from the floodplain area to come up with the potential vegetated area for each reach. This is consistent with the "Very Good" target for Active Channel width. To define the riparian area for this indicator a combination of the historical floodplain habitat mapping from 1938 and 1998 by Collins and Sheikh (2004) and the 100-year Erosion Hazard Zone (Whatcom County 2007) was used to define the boundaries (Figure 8). The restoration strategy planning reach boundaries from Hyatt (2007) were then projected across this area and the amount of forest summarized for each reach (Table 10).

Figure 8: 1938 habitat mapping was clipped to the 100-year erosion hazard area and areas classified as "forest" were assessed through time by planning reach to evaluate the amount that remained forest by 2016.



The target for "Very Good" conditions will be 100% of the riparian zone meets the target stand conditions (>40% of trees greater than 25 years *and* >10% greater than 75 years old) and the target for "Good" conditions will be 80% of the riparian condition. A reconstruction of the floodplain based on the Government Land Office bearing tree data showed that the North Fork was either forested or active channel- there were no non-forested areas outside of the channel. Since the active channel width of the river has changed through time, an active channel area was selected based on the early historic conditions interpreted from the 1890s Government Land Office Surveys and subtracted from the planning area to define the "potential forest area". This value is consistent with the "Very Good" conditions for the Active Channel Area monitoring indicator. The analysis shows that all of the reaches meet the required 10% of forested area older than 75%, although both the Maple Creek and Kenny/Coal reaches are close to failing the threshold (Table 13). Four of the project reaches have seen the areas mapped as forest reduced by more than 50% of the GLO vegetated area: Pipeline, Kenny/Coal, Farmhouse, and Lone Tree.

Table 10: Fate of forested floodplain mapped from the 1938 aerial photos (Collins and Sheikh 2004). All reaches have retained at least 10% of the vegetated area in forest patches that are older than 75 years. Data was not available in 1938 or 1998 for the Cornell Reach.

Reach	Potential Forest Area (GLO mapped forest) (hectares)	Area of Potential Forest Area Forested in 1938 (hectares)	Percent of Potential Forest Area Forested in 1998	Percent of 1938 forest remaining (2016)	Percent of 1998 forest remaining (2016)
Pipeline	222.03	187.62	137.88	31.2	40.6
Rutsatz	315.17	172.71	159.48	22.2	36.6
Kenny/Coal	251.50	154.67	79.22	10.9	19.9
Big Rock Canyon	15.31	12.62	10.43	44.2	68.1
Hatchery	296.83	236.57	216.69	33.2	56.4
Farmhouse	266.50	203.07	152.97	19.0	36.4
Maple Canyon	1.01	1.01	1.01	83.0	100.0
Maple Creek	69.47	21.47	34.46	10.9	43.6
Mahaffey Canyon	17.57	12.35	16.85	44.1	93.5
Below Boulder	43.29	24.37	17.01	15.5	38.3
Lone Tree	49.91	46.34	34.74	36.8	48.8
Wildcat	106.30	92.16	95.03	50.7	62.6
Canyon	15.44	14.24	11.53	51.4	70.2
Cornell	N/A	N/A	N/A	N/A	N/A
NF Total	*1670.3*	*1179.2*	*967.3*	*25.5*	*50.3*

To evaluate vegetation growth on the floodplain more directly, two LiDAR flights were analyzed. The first flight occurred in 2005, at the time of the adoption of the salmon recovery plan, and the second occurred in 2017. For each of these flights, the height of the vegetation was estimated using a subtraction of the first (highest) return surface and the bare earth surface for the historic migration area. The two vegetation height surfaces were then compared to identify areas where vegetation had grown on a stable floodplain surface and areas where the forest had been eroded. This subtraction was then reclassified into four classes that represent loss of large trees (<-80 feet), loss of immature trees (-79 to -20 feet), the dynamic zone showing erosion and growth of brush and pioneer forest at some point within the monitoring period (-20 to 20 feet), and stable floodplain forest growth (>20 feet of growth over the period) (Figure 9). The percent of the floodplain that remained stable over the period between the two LiDAR flights was then calculated for each analysis reach.

Figure 9: Floodplain vegetation change in the Lone Tree project reach (2005-2017).

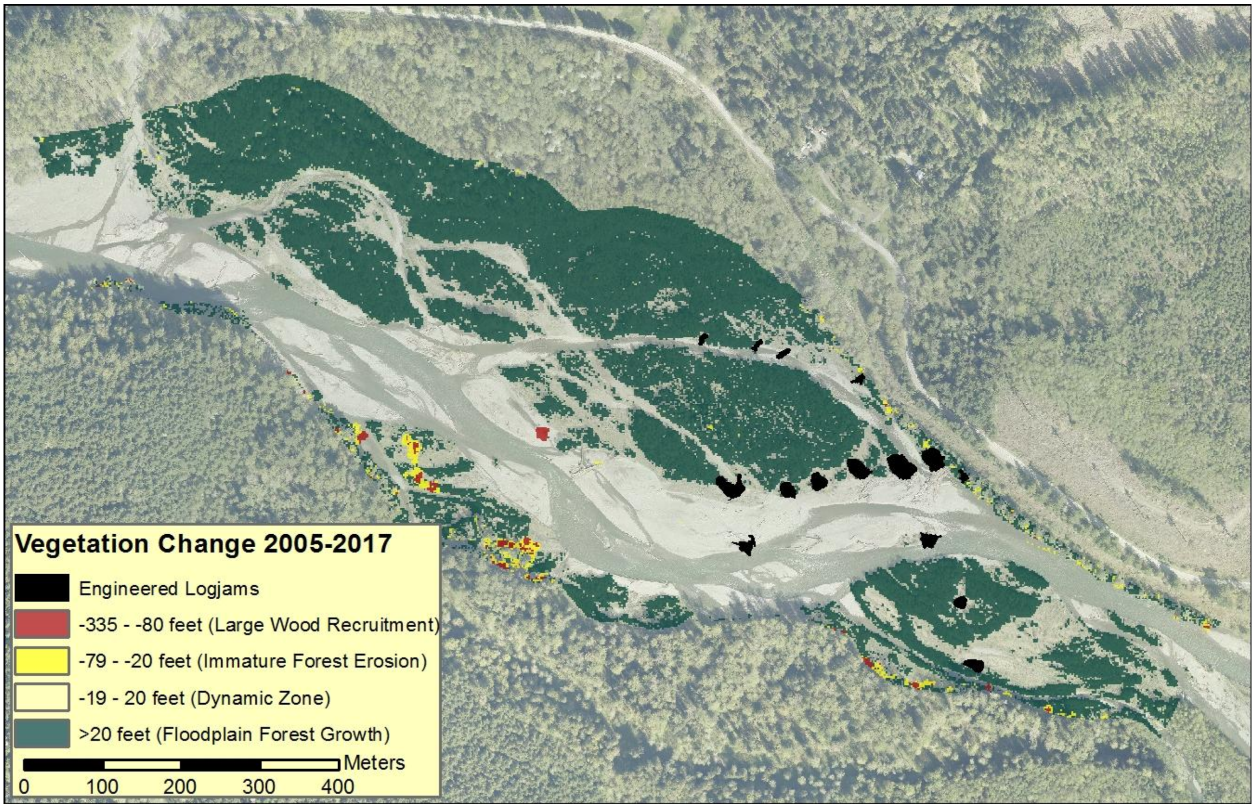


Table 11: Area (square meters) and percent total reach area for each of the riparian vegetation classes (2005-2017).

Reach	Area (%) Large Wood Recruitment	Area (%) Immature Forest Erosion	Area (%) Dynamic Zone	Area (%) Stable Floodplain
Pipeline	21,196 (1.7%)	68,232 (5.6%)	849,384 (69.7%)	280,036 (23.0%)
Rutsatz	18,144 (1.4)	60,408 (4.6)	907,112 (69.1)	326,788 (24.9)
Kenny/Coal	1,692 (0.2)	37,312 (3.8)	762,528 (77.9)	177,872 (18.2)
Big Rock Canyon	128 (0.2)	2,492 (3.5)	60,276 (84.1)	8,736 (12.2)
Hatchery	17,948 (1.5)	78,688 (6.5)	923,232 (76.2)	191,496 (15.8)
Farmhouse	4,448 (0.4)	41,412 (3.6)	949,516 (83.1)	147,316 (12.9)
Maple Canyon	60 (0.3)	580 (2.6)	18,960 (84.8)	2,764 (12.4)
Maple Creek	872 (0.3)	11,440 (3.4)	223,244 (67.0)	97,576 (29.3)
Mahaffey Canyon	376(0.3)	3,332 (2.6)	102,176 (78.4)	24,436 (18.8)
Below Boulder	1,356 (0.4)	13,056 (4.3)	228,256 (74.4)	64,032 (20.9)
Lone Tree	1,608 (0.3)	3,980 (0.8)	284,272 (60.5)	179,632 (38.3)
Wildcat	4,428 (0.8)	13,620 (2.4)	362,148 (63.4)	191,136 (33.5)
Canyon	832 (0.4)	6,760 (2.9)	162,436 (70.6)	60,052 (26.1)
Cornell	13,440 (3.7)	20,140 (5.5)	204,384 (55.7)	128,940 (35.1)
NF TOTAL	*86,528*	*361,452*	*6,037,924*	*1,880,812*

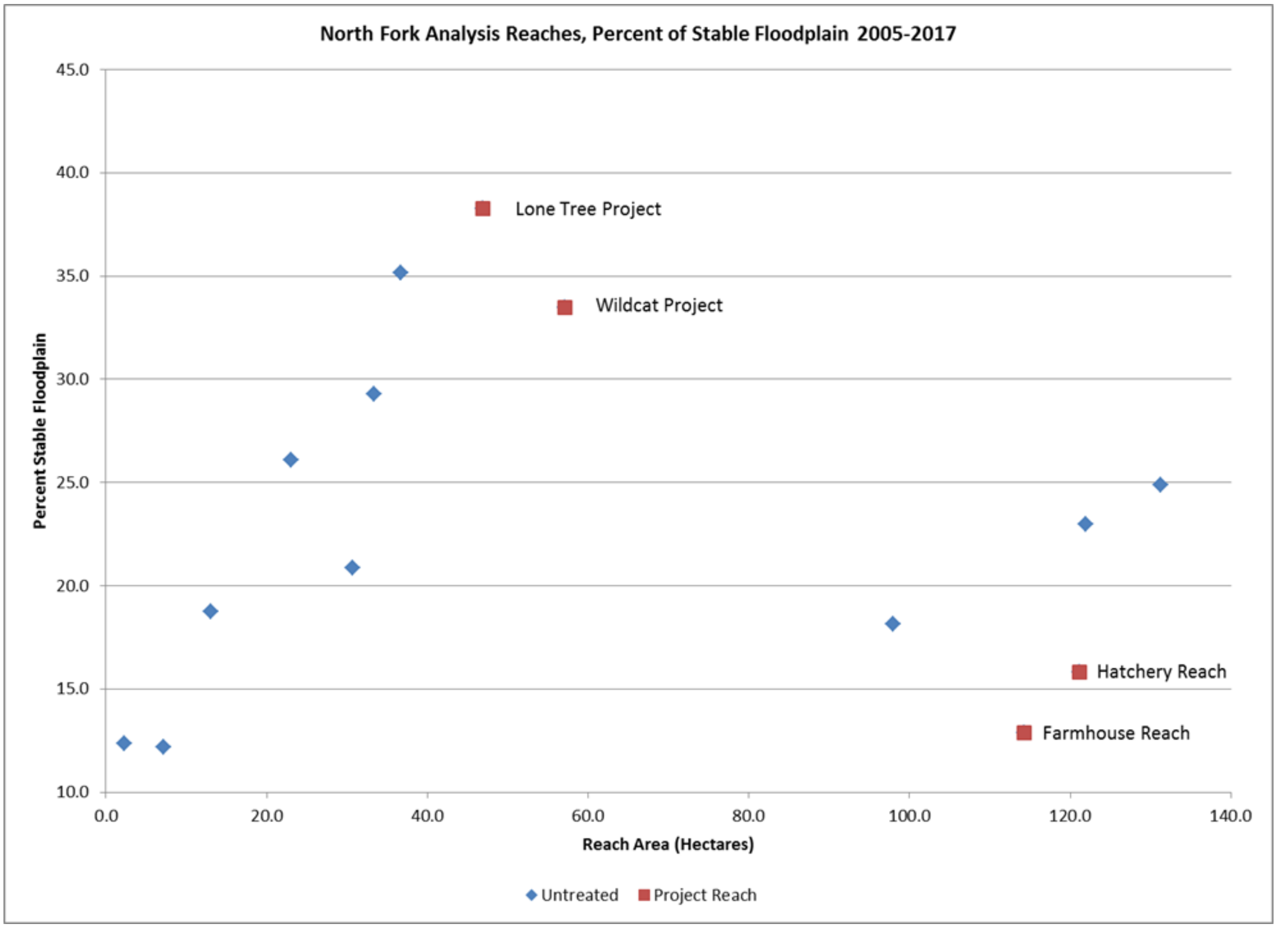
Comparing the area of forest eroded, with the area of stable floodplain between 2005 and 2017, there were 44.8 hectares of mature and immature forest eroded and 188.1 hectares of stable floodplain throughout the lower North Fork. Floodplain stability varied by analysis reach, with the two unconfined reaches that included early projects, showing a relatively high level of floodplain stability (Figure 10). The percent of recently eroded floodplain within that period ranged between 61.7% in the Lone Tree reach and more than 87% in the Farmhouse Reach. The greatest sources for large wood recruitment came from the Pipeline, Rutsatz, Hatchery, and Cornell reaches. When the area eroded in each reach is compared over the period of time between the LiDAR flights, it shows that the turnover rate is greatest in the most unconfined reaches- Pipeline, Rutsatz, Kenny/Coal, Hatchery and Farmhouse (Table 12).

Table 12: Floodplain turnover rates for the North Fork Nooksack reaches.

Reach	Area (hectares) of Floodplain Eroded 2005-2017	Floodplain Turnover Rate (hectares/year)
Pipeline	93.9	7.82
Rutsatz	98.6	8.21
Kenny/Coal	80.2	6.68
Big Rock Canyon	6.3	0.52
Hatchery	102.0	8.50
Farmhouse	99.5	8.29
Maple Canyon	2.0	0.16
Maple Creek	23.6	1.96
Mahaffey Canyon	10.6	0.88
Below Boulder	24.3	2.02
Lone Tree	29.0	2.42
Wildcat	38.0	3.17
Canyon	17.0	1.42
Cornell	23.8	1.98
NF TOTAL	*648.6*	*54.05*

Comparing the floodplain forest age and area to the targets for “Good” and “Very Good” conditions, nearly all of the reaches show that they are currently above the target values (Table 13). When the whole lower North Fork Geographic area is summed, it exceeds the “Very Good” targets. Only two reaches failed to reach the threshold for “Very Good” conditions (Kenny/Coal and Below Boulder), and both failed based on the area of forest older than 20 years, rather than the amount of forest older than 75 years. All of the project reaches currently meet the targets for floodplain forest encroachment.

Figure 10: Percent of stable floodplain (defined by continuous tree growth) for the North Fork Nooksack analysis reaches between 2005 and 2017. Orange boxes show project reaches treated during that timeframe. The Farmhouse project was initiated late in the monitoring period. Reaches with the largest area are generally less confined than that the reaches with less area.



The stand age analysis doesn't reflect the area of the riparian zone, but rather the age classes of the existing riparian zone. For example, "Very Good" conditions could be given if only 40% of the riparian zone were forested, if it was all older than 20 years and met the 10% criteria for older trees. By comparing the 1998 forested area column to the potential forest area column in Table 10, it is clear that the riparian area along the North Fork is heavily disturbed due to land clearing and rapid channel migration. This analysis also included portions of the Erosion Hazard Area that were beyond man-made barriers to channel migration, such as roads and structures, that will likely provide little near-term benefit for instream habitat for the mainstem channel. Isolating the extent to the portion of the floodplain that is currently accessible to migration with an associated riparian buffer might provide a better estimate of the forest conditions that can provide wood to the channel.

Table 13: Forest area (hectares) relative to planning targets for the North Fork Nooksack. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects.

Reach	Targets				2016 Conditions	
	100% of stands meet criteria (10% >75 years old) ("Very Good")	80% of stands meet criteria (10% >75 years old) ("Good")	100% of stands meet criteria (40% >20 years old) ("Very Good")	80% of stands meet criteria (40% >20 years old) ("Good")	Area older than 75 years	Area older than 20 years
Pipeline	22.2	17.8	88.8	71.0	69.4	104.7
Rutsatz	31.5	25.2	126.1	100.9	70.1	134.5
Kenny/Coal	25.1	20.1	100.6	80.5	27.4	66.2
Big Rock Cyn	1.5	1.2	6.1	4.9	6.8	10.4
Hatchery	29.7	23.7	118.7	95.0	98.5	193.0
Farmhouse	26.6	21.3	106.6	85.3	50.7	135.6
Maple Cyn	0.1	0.1	0.4	0.3	0.8	3.1
Maple Creek	6.9	5.6	27.8	22.2	7.6	30.6
Mahaffey Cyn	1.8	1.4	7.0	5.6	7.7	16.4
Below Boulder	4.3	3.5	17.3	13.9	6.7	16.6
Lone Tree	5.0	4.0	20.0	16.0	18.3	29.0
Wildcat	10.6	8.5	42.5	34.0	53.9	88.3
Canyon	1.5	1.2	6.1	4.9	7.9	10.8
Cornell	N/A	N/A	N/A	N/A	N/A	N/A
NF Total	*167.0*	*133.6*	*668.1*	*534.5*	*425.8*	*839.3*

Using the interpretation of the LiDAR provided a more detailed look at the growth and erosion of the floodplain forest. This analysis is limited by the length of time between the flights, but provides an estimate for the rate of floodplain turn-over. This will be a better metric for assessing floodplain growth going forward, but will require continuing periodic LiDAR flights of the channel. It is possible to develop age estimates of the floodplain forest using tree height by species, but species data is currently lacking. There is currently no metric associated with this analysis, but developing a target rate for floodplain turnover could be considered.

Active Channel Area

The active channel area is the unvegetated area of the channel that reflects frequent flow and recent migration. Changes in the active channel width reflect both watershed-scale changes in sediment and flow from weather and climate variation and site-specific conditions such as bank materials and floodplain vegetation characteristics. Increases in channel stability will likely be reflected in a narrowing of the active channel area through time as floodplain vegetation encroaches and increases the bank resistance to erosion. The goal is to reverse the trend of increasing active channel width through time, although short-term fluctuation in width in response to flood events is anticipated (Figure 11).

The target active channel area is based on the historic conditions high flow channel area of the river. The high flow and low flow channel areas were determined from aerial photo and map-based habitat mapping by Collins and Sheikh (2004). The target for a "Good" condition was based on the aerial photo record that was available at the time of their assessment (1933-1998). The average area for each reach was measured by photo year and the mean was compared to the conditions at the time of the Salmon Recovery Plan adoption in 2005 and the current conditions (2016 aerial photo year). The "Very Good" target was based on the high flow channel area from the Government Land Office surveys in the 1890s, as interpreted by Collins and Sheikh.

Eleven of the fourteen of the analysis areas reached their historical maximum active channel area in the 2005 or 2010 photo years; shortly after the adoption of the Salmon Recovery Plan. The three exceptions are the Kenny/Coal, Farmhouse and Wildcat reaches, which all reached their maximum areas in 1994 (Figure 12). The trend of rapidly increasing channel area at the expense of floodplain forest through the 1990s and early 2000s drove the restoration strategy to focus on forest encroachment and island formation (Hyatt 2007).

The four reaches with habitat restoration projects in them generally show a similar trend, with a peak in the 1990s and early 2000s and a more recent decline in active channel area. Of these reaches, only the Lone Tree project reach has narrowed to a degree that is less than the 1933-1998 mean (Figure 13). There is a several year lag between project implementation and when vegetation would be mature enough to be considered forested instead of high flow channel. The Wildcat project was only recently completed and the Farmhouse project is still being implemented, so it is expected that these project reaches will continue to narrow in response to the project as the stable bars begin to revegetate.

Figure 11: Active channel area (the combined areas of the mapped high flow and low flow channels) through time for the North Fork Nooksack from the South Fork confluence to RM 57.8

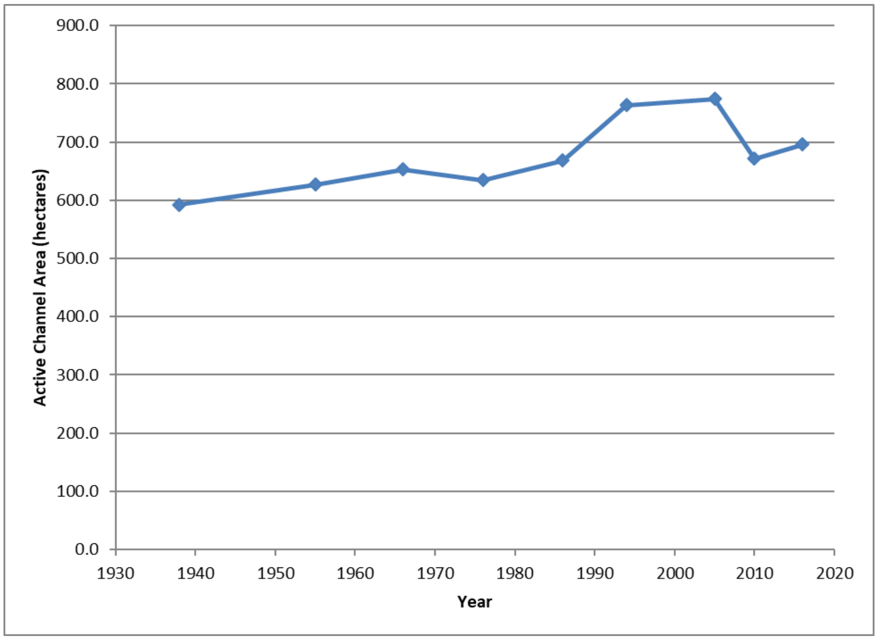


Figure 12: Active channel area changes through time for the eleven unconfined analysis reaches of the Lower North Fork area. Restoration project reaches include Hatchery (2008), Farmhouse (2008, 2014-20), Lone Tree (2008-09) and Wildcat (2014-18).

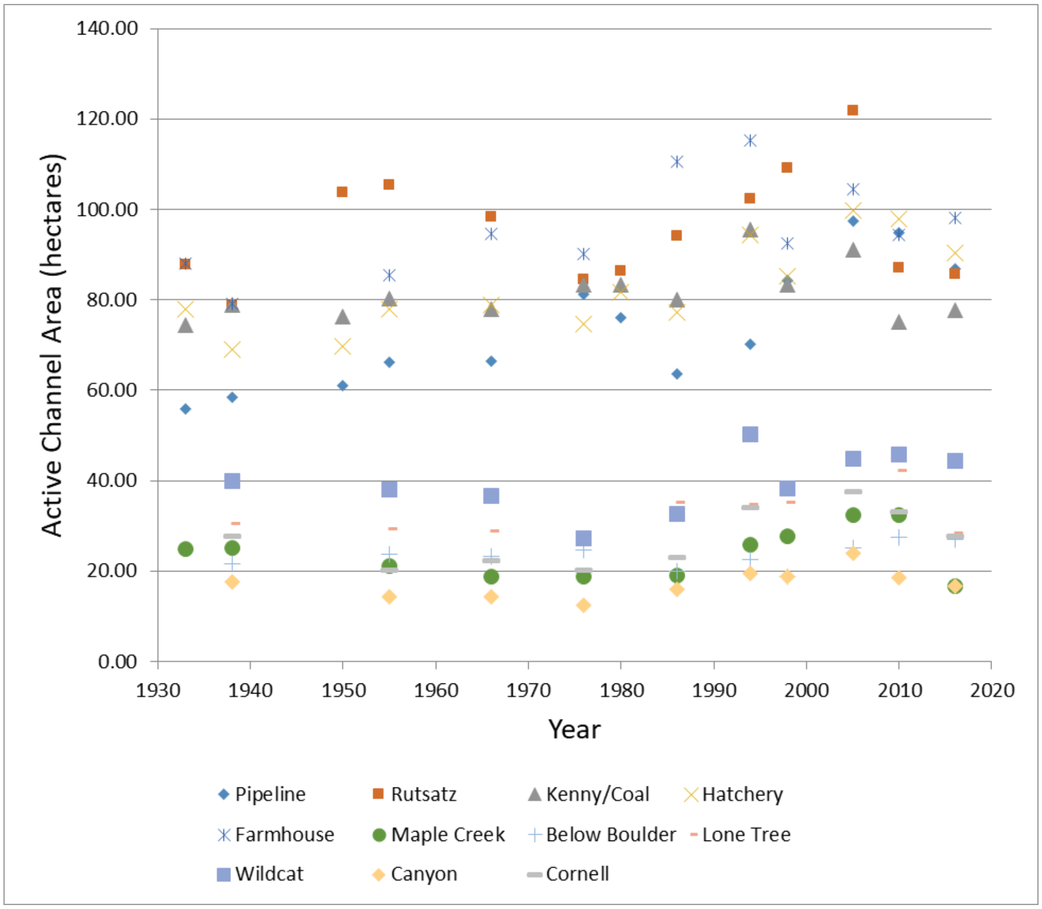
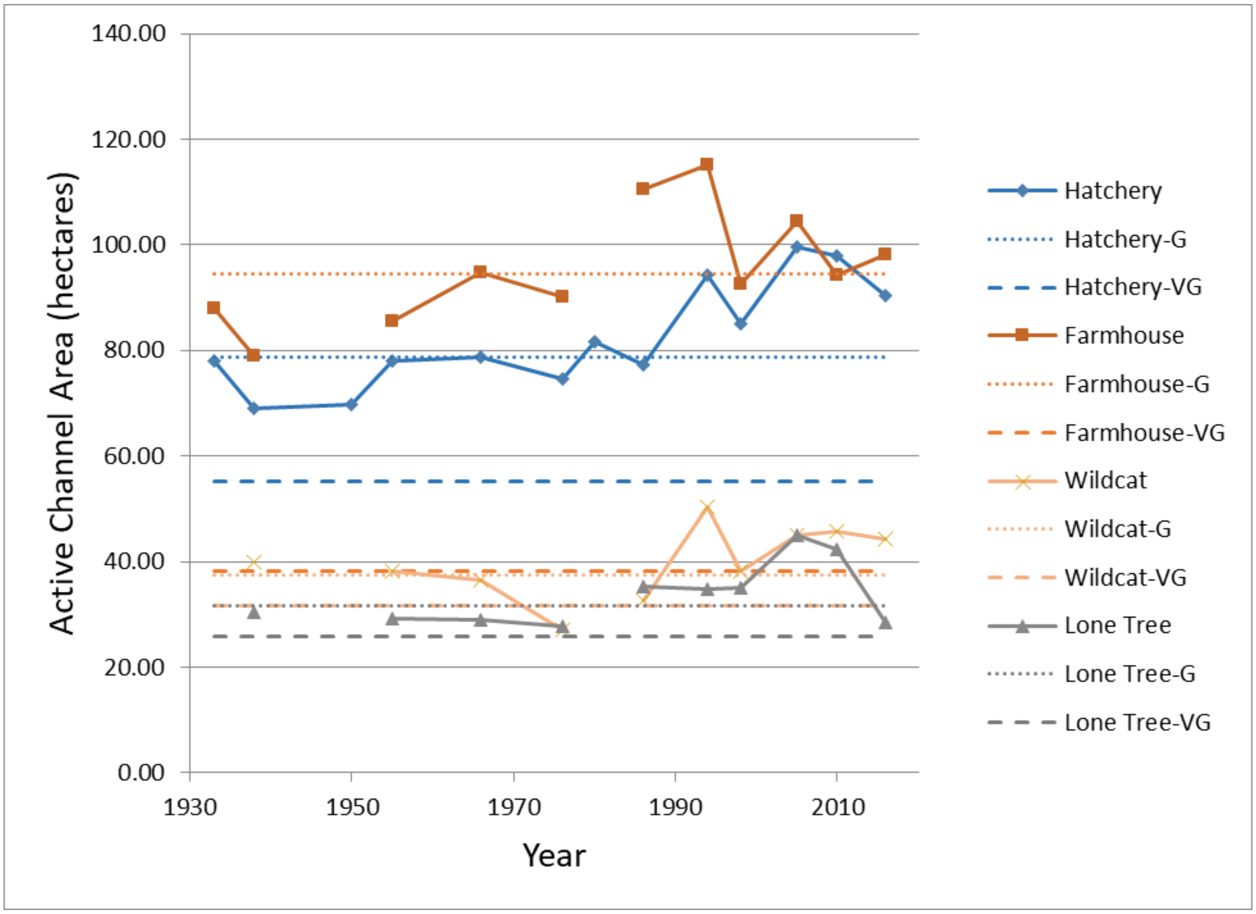


Figure 13: Active channel area changes through time for the four North Fork project reaches relative to the targets for "Good" and "Very Good" habitat targets.



The North Fork Nooksack met the active channel area target for the "Good" condition in four of the reaches and met the target for the "Very Good" condition in the Maple Creek reach (Table 14). In several cases, the active channel area mapped in the GLO surveys was greater than the 1933-1998 mean area. This generally occurred in the confined canyon reaches, where changes in active channel area would be small due to erosion resistant banks. An exception was the Canyon Reach, where the GLO survey area and the 1933-1998 mean was very close (16.3 hectares for the GLO survey and 16.2 hectares for the 1933-1998 mean). In these cases, the 1933-1998 mean value is assumed to represent the early historic conditions of the reach. Only the Lone Tree project reach currently meet the target for active channel area, but an expected lag in response due to the time it takes to revegetate bar surfaces, likely is affecting this metric for the reaches with recent projects.

Table 14: Active channel area (hectares) relative to planning targets for the North Fork Nooksack. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects. In several cases, the Historic Area was greater than the mean 1933-1998 area, likely due to mapping errors in the GLO survey maps.

Reach	Targets		Conditions	
	Historic (GLO) Area ("Very Good")	Mean 1933-1998 ("Good")	2005 Recovery Plan	2016 Conditions
Pipeline	45.71	68.37	97.43	86.83
Rutsatz	41.83	95.09	121.86	**85.58**
Kenny/Coal	39.30	81.35	91.12	**77.75**
Big Rock Canyon	7.80	5.72	5.47	6.50
Hatchery	55.24	78.66	99.66	90.35
Farmhouse	38.15	94.46	104.58	98.14
Maple Canyon	4.04	1.80	1.97	2.33
Maple Creek	18.36	22.63	32.38	**16.70**
Mahaffey Canyon	11.52	10.44	12.91	12.65
Below Boulder	13.14	22.09	25.20	27.00
Lone Tree	25.71	31.65	44.87	**28.37**
Wildcat	31.73	37.56	44.94	44.31
Canyon	16.32	16.18	23.99	16.69
Cornell	N/D*	24.58	37.67	27.75
NF Total	*348.8*	*593.3*	*744.1*	*621.0*

*assumes 1933-1998 average area for NF Total

The active channel area, along with the forested island and forest encroachment metrics addresses channel stability in the North Fork. There appears to be less year-to-year variation in the active channel area relative to the forest island area and count indicators, although it does not address the distribution of the channels (i.e. are there multiple smaller active channels separated by forest patches, or is it a wide braided channel) that is captured in the forest island targets. Going forward, with multiple LiDAR flights available, it may be better to define the active channel area based on the vegetation height and density for the bar surfaces, rather than based on aerial photo interpretation. It also may be appropriate to revise the Historic (GLO) Area target for the confined reaches to reflect the narrower channel observed in aerial photographs. The target could be a percentage of the values observed in the aerial photo record, such as 10% above the minimum value.

South Fork Nooksack Restoration Strategy

The South Fork is split into the upper and lower geographic areas at the confluence of Skookum Creek at River Mile 14.5. The Lower South Fork geographic area is from the confluence with the North Fork to Skookum Creek and the Upper South Fork area lies between Skookum Creek and the chinook passage barrier at River Mile 31. The lower South Fork area is described in the WRIA 1 Salmonid Recovery Plan (WRIA 1 Salmon Recovery Board 2005):

> Downstream of Skookum Creek, gradient and valley confinement of the South Fork decreases substantially. The wide floodplain and low gradient make this reach an area of fine sediment deposition, channel migration and wood accumulation. The large amounts of wood described in early accounts would likely have caused frequent avulsions among a series of channel configurations. Channel movement through avulsion, coupled with logjams that functioned as hard points across the floodplain, would likely have yielded a patchwork mosaic of mature forest and immature forest, as has been described in similar reaches that have not been as heavily impacted by land use activities. Land use in the lower South Fork valley is predominantly zoned for agriculture, although rural and rural forest zoning is also present. Riprap, which is prevalent from Acme downstream, has confined the channel to a single thread and greatly reduced the amount of slough and side-channel habitat.
>
> The lower South Fork represents 36% of the spawning distribution and 19% of the freshwater habitat for SF Nooksack early chinook. Restoration of the lower South Fork is expected to have a very significant impact on recovery of SF Nooksack early chinook abundance and productivity; diversity would also be improved. Indeed, accounting for differences in reach length, it is the most important geographic area for restoration and the 3rd most important geographic area for protection, after the estuary and upper South Fork. High temperatures and lack of habitat diversity are the most significant limiting factors, followed by high fine sediment load, lack of key habitats, low flows, and human disturbance. Productivity of pre-spawn migrants, fry, egg incubation, and pre-spawn holding life stages are the most limited.

The Upper South Fork Geographic Area was described as:

> The lower reaches of the upper South Fork are relatively low gradient and unconfined, except for Dyes Canyon; gradient and confinement increase steadily in the upper half of the area. Stream-adjacent roads are minimal, although bridges constrain the channel at RM 20.6 and 30. There are multiple stream-adjacent landslides along the upper South Fork from ~RM 16.5 to RM 36 that are delivering or have the potential to deliver substantial amounts of fine sediment directly to the South Fork. Most are deep-seated rotational features (e.g. earth slumps), although secondary shallow features occur within the larger deep-seated landslides. All of these slides are associated with unconsolidated glacial sediments, most notably glacial outwash and glacial lacustrine sediments. Land use adjacent to the upper South Fork is predominantly commercial forestry.
>
> The upper South Fork represents 44% of the spawning distribution and 24% of the freshwater habitat for South Fork Nooksack early chinook. Restoration of the upper South Fork is expected to have a significant impact on SF Nooksack chinook abundance and productivity. Accounting for differences in reach length, the upper South Fork is the 2nd most important geographic area for both restoration and protection for the SF Nooksack early chinook population. High

temperatures and lack of habitat diversity are the most significant limiting factors, followed by high fine sediment load and lack of key habitats. Productivity of egg incubation, fry, pre-spawn holding and migration, spawning, and overwinter rearing life stages is most limited.

The causal mechanisms and monitoring metrics that are tied to the limiting factors for the South Fork geographic area are shown in Table 15. Several of the targets for the monitoring indicators were developed as a part of developing the WRIA 1 Monitoring and Adaptive Management Plan (WRIA 1 Watershed Management Board 2017). Generally, the monitoring targets were based on a comparison to two conditions: an estimate of properly functioning conditions, which was considered “Good” and an estimate of early historic conditions, which was considered “Very Good”. Monitoring indicators that are not included as viability indicators in the monitoring and adaptive management plan have targets developed for this report relative to change in the historic conditions. For consistency with the WRIA 1 monitoring plan, “Good” was based on a percentage of the historic conditions, while “Very Good” reflects the early historic conditions or the maximum measured value, depending on the metric. Temperature is a habitat viability indicator that is expected to respond to instream habitat restoration (Environmental Protection Agency 2016). Temperature monitoring has been done at the project scale, so it will be summarized there and not be included as a habitat indicator. Turbidity and low flow were not monitored for this report, so they will not be included as project effectiveness indicators. For the key habitat indicators in the South Fork the “Good” and “Very Good” conditions are shown in Table 16.

Based on the limiting factors and causal mechanisms, habitat restoration strategies were identified and prioritized to guide project development in the planning reaches of the two South Fork Geographic Areas (Table 17). Tier 1 represents the highest priority action in the highest priority geographic area, while Tier 2 represents that the action is considered a lower priority in the reach. The strategies and reach designations were a result three reaches assessments that were done in the South Fork Nooksack (Maudlin et al. 2002, Soicher et al. 2006, and Brown and Maudlin 2007). For this report, the South Fork Nooksack used the fifteen reaches for project planning that are included in the WRIA 1 Habitat Restoration Strategy (Figure 14).

Table 15: High and moderate importance limiting factors, primary causal mechanisms and monitoring metrics for the Lower South Fork Geographic Area (WRIA 1 Salmon Recovery Board 2005).

Limiting Factor (Importance)	**Causal Mechanism**	**Monitoring Indicator**
Temperature (High)	Degraded riparian function leads to a loss of stream shade; disconnection of the floodplain has reduced groundwater discharge.	*Cold water refuge areas- monitored at the project scale*
		Continuous temperature- monitored at the project scale
Habitat Diversity (Moderate)	Bank protection limits channel migration and wood recruitment; degraded riparian conditions has reduced the supply of wood to the channel; wood removal.	Pool quality/ quantity
		Habitat unit diversity
		Edge type
Key Habitat Quantity (Moderate)	Loss of in-channel wood has limited pool formation; increased sediment has filled pools; floodplain disconnection has reduced side channel formation; low flow reduces total habitat area and volume.	Pool quantity/ quality
		Sediment/ bed changes- no monitoring indicator
		Side channel length- monitored at the project scale
		Low flow minimum discharge and duration- unmonitored
Sediment (Moderate)	Elevated mass wasting from land use practices.	*Turbidity- unmonitored*

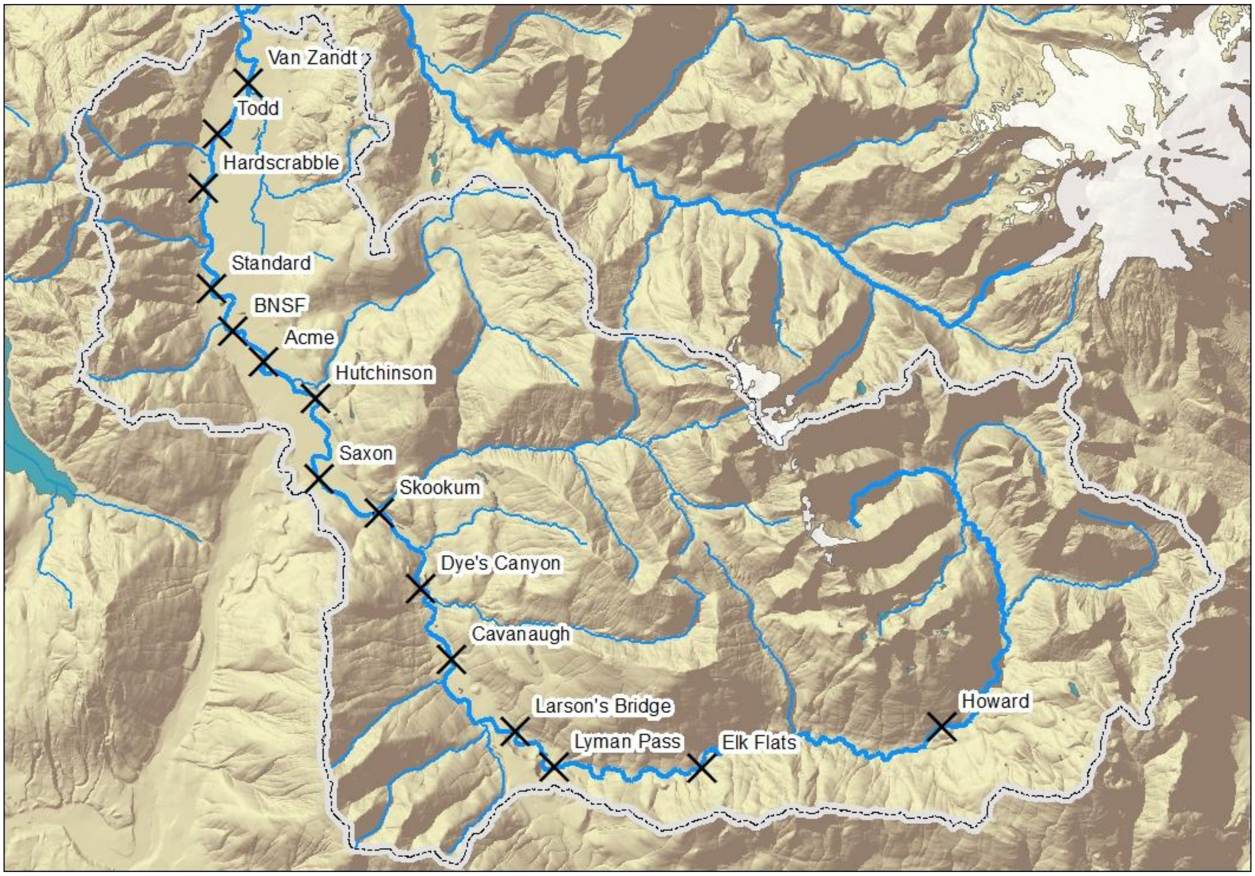
Table 16: WRIA 1 habitat indicators and targets relevant to the South Fork Geographic Areas (adaptive management viability indicators are shown with an asterisk). Condition targets in italics are suggestions for indicators that lack tiered targets that are based on project-level effectiveness targets.

Monitoring Indicator	**"Good" Condition**	**"Very Good" Condition**
Habitat unit diversity (# of units per km)	Increase *(15units per km)*	*20 units per km*
Pool quantity/quality*	<1.4 channel widths per pool, >70% formed by wood	<1 channel widths per pool
Length of complex edge habitat*	Increase (*90% length of natural conditions*)	*Natural bank conditions*

Table 17: The five restoration strategies that have been identified as Tier 1 (highest priority) for the South Fork Nooksack River (WRIA 1 Watershed Management Board 2019) and their importance by planning reach. Italics: Upper South Fork planning area.

Reach	Upstream RM	Restoration Strategies				
		Log jams to form deep complex pools: cool-water influence areas	Log jams to form deep complex pools: other areas	Set back or remove riprap embankments	Lower artificial levees to native bank elevations	Relocate river-adjacent infrastructure outside the 100-year erosion hazard area
Van Zandt	1.8	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2
Todd	3.7	Tier 1	Tier 1	Tier 1		Tier 2
Hardscrabble	5.1	Tier 1	Tier 1	Tier 1		Tier 2
Standard	7.2	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2
BNSF	8.6	Tier 1	Tier 1	Tier 1	Tier 1	Tier 1
Acme	9.6	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2
Hutchinson	10.9	Tier 1	Tier 1	Tier 1	Tier 1	Tier 2
Saxon	12.8	Tier 1	Tier 1	Tier 1		Tier 2
Skookum	14.3	Tier 1	Tier 1	Tier 1		Tier 2
Dye's Canyon	*16.1*		*Tier 1*			
Cavanaugh	*18.0*	*Tier 1*	*Tier 1*			
Larson's Bridge	*20.6*	*Tier 1*	*Tier 1*			
Lyman Pass	*22.0*	*Tier 2*	*Tier 2*			
Elk Flats	*25.4*	*Tier 2*	*Tier 2*			
Howard	*31.0*	*Tier 2*	*Tier 2*			

Figure 14: The project planning reaches for the South Fork Nooksack River (WRIA 1 Watershed Management Board 2019).



The planning reaches and the project reaches are not coincident in the lower South Fork, in many cases project extents are based on landowner willingness rather than the planning reach boundaries (Table 18). For the discussion of the South Fork Habitat Indicators, the indicators will be summarized by both the planning reach and as a roll-up of project and non-project extents.

Table 18: Planning reaches and project reach extents in the South Fork geographic areas. Upper South Fork projects were monitored as a part of the 2019 Upper South Fork Effectiveness Monitoring report (NSD 2019 Draft) and will be summarized separately.

<table>
<tr><th>Salmon Recovery Planning Reach</th><th>Upstream River Mile</th><th>Project/ Untreated Reaches</th><th>Upstream River Mile</th></tr>
<tr><td rowspan="3">Van Zandt</td><td rowspan="3">1.8</td><td>Not Monitored</td><td>0.95</td></tr>
<tr><td>Van Zandt Project</td><td>1.35</td></tr>
<tr><td rowspan="2">Todd to Van Zandt</td><td rowspan="2">3.70</td></tr>
<tr><td>Todd</td><td>3.7</td></tr>
<tr><td rowspan="3">Hardscrabble</td><td rowspan="3">5.1</td><td>Todd/Sygitowicz Project</td><td>4.00</td></tr>
<tr><td>Hardscrabble to Todd</td><td>5.05</td></tr>
<tr><td>Hardscrabble Project</td><td>5.10</td></tr>
<tr><td rowspan="4">Standard</td><td rowspan="4">7.2</td><td>River Farm to Hardscrabble</td><td>5.35</td></tr>
<tr><td>River Farm Project</td><td>5.50</td></tr>
<tr><td>Kalsbeek to River Farm</td><td>6.35</td></tr>
<tr><td>Kalsbeek Project</td><td>6.75</td></tr>
<tr><td>BNSF</td><td>8.6</td><td rowspan="2">Acme to Kalsbeek</td><td rowspan="2">8.85</td></tr>
<tr><td rowspan="3">Acme</td><td rowspan="3">9.6</td></tr>
<tr><td>Acme Project</td><td>9.00</td></tr>
<tr><td>Acme to Hutchinson</td><td>9.60</td></tr>
<tr><td rowspan="3">Hutchinson</td><td rowspan="3">10.9</td><td>Downstream of Hutchinson Project</td><td>10.15</td></tr>
<tr><td>Lower Hutchison Project</td><td>10.30</td></tr>
<tr><td rowspan="2">Nesset’s to Hutchinson</td><td rowspan="2">11.40</td></tr>
<tr><td rowspan="3">Saxon</td><td rowspan="3">12.8</td></tr>
<tr><td>Nesset’s Project</td><td>12.10</td></tr>
<tr><td>Saxon Project</td><td>12.65</td></tr>
</table>

South Fork Habitat Indicators

Habitat Diversity

Habitat Diversity is represented by the number of primary habitat units per kilometer. Primary habitat units are those that span the majority of the channel. Field mapping usually included secondary units, but these were mapped in different ways depending on the survey and were not included in the habitat diversity metric for the South Fork. Where there is data available at the project reach, it is included in the project effectiveness section. Baseline conditions were field mapped in 2000 or 2003 (representing the 2005 Recovery Plan conditions) for the lower South Fork Nooksack and in 2005 for the upper South Fork. Mapping date of the current (2016 in Table 19) conditions varied between project reaches but relied on mapping from 2016, 2017, 2018, or 2019. An exception was the Van Zandt, where the most recent mapping was from 2013.

Habitat Diversity was summarized at both the project reach and planning reach scales. Since the project extents often cross planning reach boundaries, the project reach mapping was compared to non-project reaches for both the pre-project and post-project periods to assess effectiveness. For the planning reaches, the habitat diversity indicator at the time of the adoption of the recovery plan is compared to habitat targets for "Good" and "Very Good" habitat conditions. The original habitat goal for habitat diversity was an increase over baseline conditions for the reach. Targets were then developed to better assess habitat change compared to values measured in least impacted reaches of the lower South Fork that are located upstream of Hutchison Creek. Different targets may be appropriate in the more confined reaches in the upper South Fork geographic area.

At the project scale, there was a slight increase in habitat diversity in the non-project reaches during the monitoring period, from 9.0 primary units per km to 10.4 units per km (a 15.6% increase) when the project reach lengths are summed together (Figure 15). This change represents the background variation in habitat diversity in the absence of habitat restoration projects. Increases in diversity in the untreated Todd to Van Zandt, Acme to Kalsbeek, Acme to Hutchinson and Nesset's to Hutchinson reaches slightly outweighed the losses observed in the other three untreated reaches.

Project reaches saw an even greater increase in habitat unit diversity from 10.8 units per km to 15.5 units per km (a 43.1% increase). Nearly all of the project reaches saw an increase in habitat diversity when compared to the baseline monitoring, with the exception of the Saxon Project Reach, which was the most diverse reach of the river when the baseline mapping was done. The Acme and Hardscrabble projects showed no change in habitat diversity. Five of the project reaches had approximately 18 primary units per km or more: Saxon, Nesset's, Lower Hutchinson, Downstream of Hutchinson, and Hardscrabble. In the case of Hardscrabble and Lower Hutchinson this was driven by the relatively short project reaches, while the Saxon, Nesset's, and Downstream of Hutchinson reaches the diversity was largely driven by the unconfined channel and the aggressive scope of the restoration projects.

Several projects didn't meet the habitat indicator target of 15 units per kilometer. These included the Acme, Kalsbeek, River Farm, Sygitowicz/Todd and Van Zandt projects. The reasons for this vary by project and include structures with limited interaction with the low flow channel, wide structure spacing, and structures that are designed to provide functions that are not related to habitat diversity. These functions can include increasing wood cover in existing pools, or providing bank protection.

At the planning reach level, the habitat diversity targets for "Good" conditions were met in two of the reaches, but the target for "Very Good" conditions was not met (Table 19). All reaches where current data is available showed an increase in habitat diversity from the conditions at the time of plan adoption, which meets the original reach-scale habitat target for diversity. While no comparable data was available for the reaches upstream of the Saxon Reach, project monitoring of the River Mile 30, Larson's Bridge, Fobes, Cavanaugh and Saxon projects concluded that many of the structures were increasing the habitat diversity in the project extents and possibly increasing the project reach-scale diversity (NSD 2019 Draft). A comparison to the project-scale mapping shows that it is clear that the substantial increase in diversity associated with the projects is driving the overall increase in diversity in the reaches that are meeting the target. The failure of many of the planning reaches to meet the diversity targets likely has to do with the modest extent of the restoration projects relative to the planning reach length, design constraints, or project objectives constraints that do not focus on habitat diversity.

Figure 15: Habitat diversity (primary habitat units per mile) in project reaches (blue) and untreated reaches (red) in the Lower South Fork Nooksack River (RM 1-12.6). Data collected in 2016-2018 (NNR). Orange bars show unlabeled pre-project baseline habitat diversity of the river for comparison. Data collected in 2000 (NSEA) and 2003 (NNR).

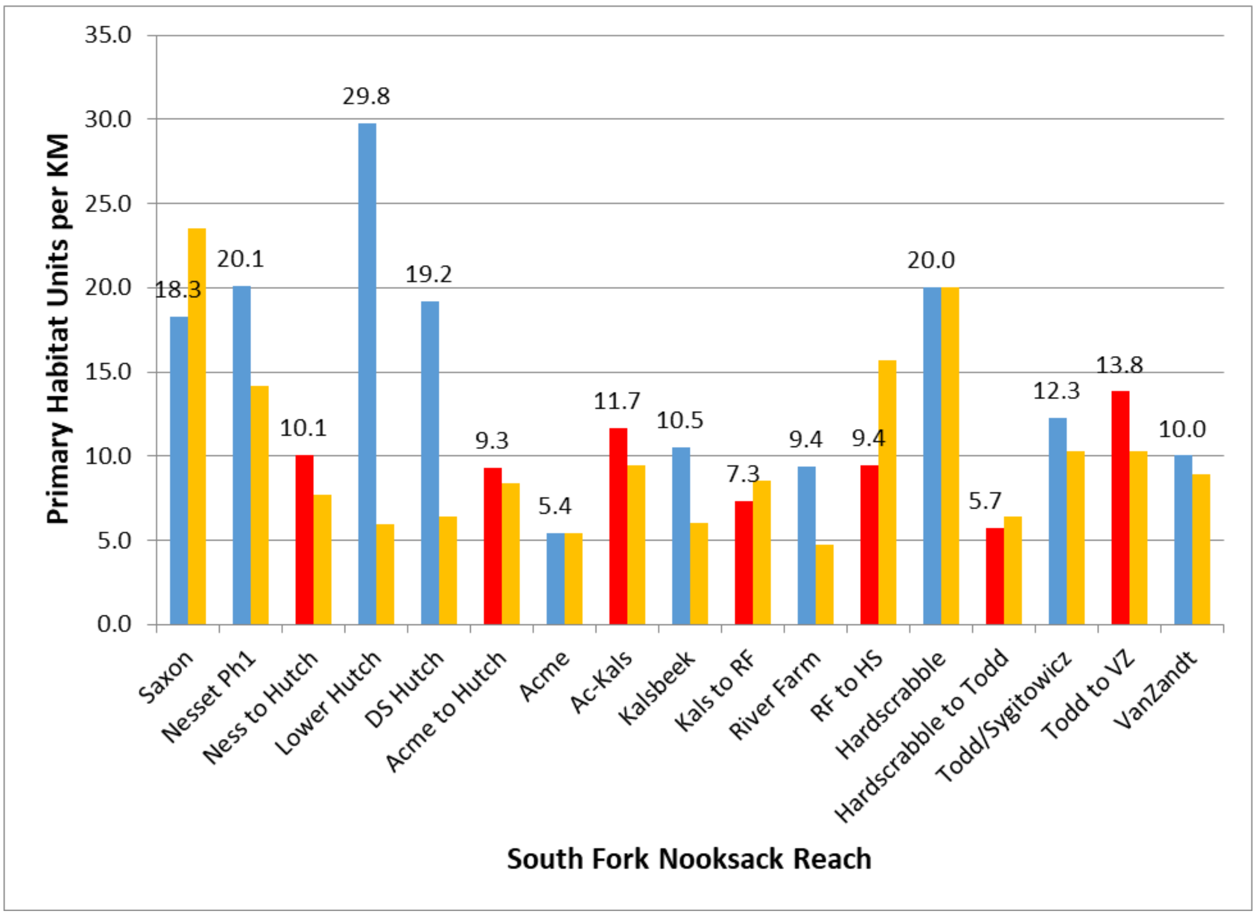


Table 19: Habitat diversity (units per km) relative to planning targets for the South Fork Nooksack. Comparable habitat data was not available for current conditions in the river upstream of the Saxon Reach. Green boxes show reaches that meet habitat targets (light green/ black text= "Good"; dark green/ white text= "Very Good").

Reach	Targets		Conditions	
	20 units per km ("Very Good")	15 units per km ("Good")	2005 Recovery Plan	2016 Conditions^
Van Zandt*	64	48	21	35
Todd	42	32	24	28
Hardscrabble	40	30	15	16
Standard	80	60	29	40
BNSF	44	33	18	26
Acme	34	26	16	18
Hutchinson	46	35	23	**44**
Saxon	56	41	36	**41**
Skookum	48	36	21	25
Dye's Canyon*	62	47	28	N/D
Dye's Canyon (RKM 24.88-22.86)	41	30	17	26
Cavanaugh*	62	47	30	N/D
Cavanaugh* (RKM27.43-26.02)	28	21	13	24
Larson's Bridge	80	60	42	64
Lyman Pass	48	36	22	33
Elk Flats*	114	86	55	N/D
Elk Flats* (RKM 37-35.27	34	26	19	19
Howard	206	155	125	N/D
Howard* (RKM 48.28-48.12)	3.2	2.4	6	10
SF Total				

*based on partial mapping of the reach with assumed no change in density in unmapped areas.
^ = 2019 conditions

The habitat diversity monitoring will be an important indictor to determine project success and salmon recovery. It may be appropriate to revise the target values to reflect the channel gradient and confinement in different reaches or sub-reaches. While all of the project reaches have shown an increase in habitat diversity, there has also been an increase in untreated reaches. Monitoring these trends and comparing the project response to the natural range of variation in the river will help set goals for future restoration projects, to ensure that we are meeting the targets within the treated reaches.

Considering the differences in habitat mapping when surveyors identify smaller units and more habitat classes, it is likely best to keep a simplified monitoring approach and focus just on primary habitat units that span the majority of the channel for the metric. The baseline mapping was conducted by four different agencies all using slightly different methods, which could be summarized at the primary unit level. This does miss secondary units, such as backwaters and smaller scour pools around wood, which provide important habitat for chinook and reflect changes in habitat diversity from instream restoration projects. It may be that habitat diversity in the South Fork is better reflected in monitoring the pool spacing and quality rather than primary units per kilometer, since the major limiting factors are associated with pool habitat rather than riffle or glide spacing.

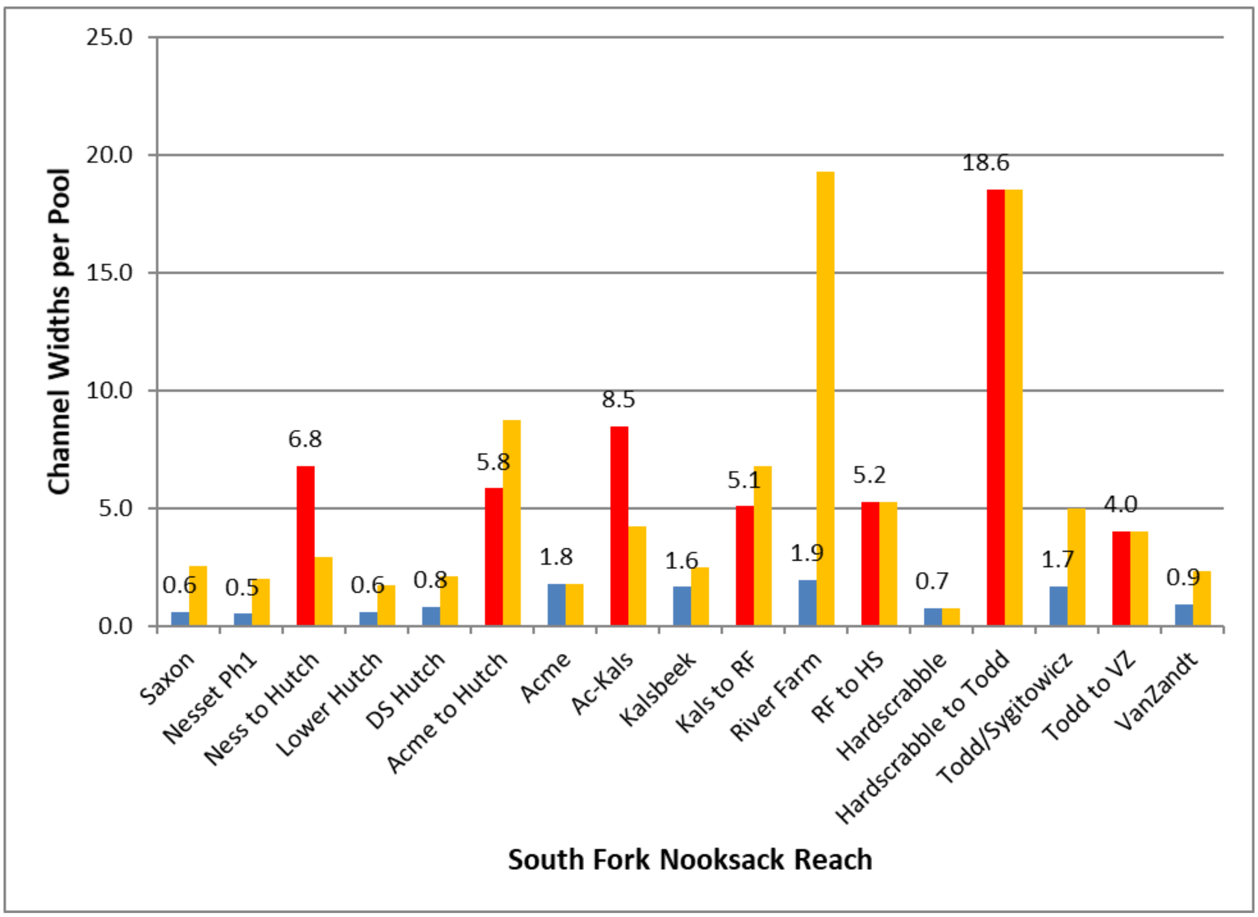
Pool Quantity and Quality

Pool Quantity and Quality is measured as the spacing between pools and the forming feature of pools. Pools were limited to those that had a residual depth greater than 1 meter in main channels, side channels and braids. Secondary pools adjacent to primary habitat units were also included if they met the residual pool depth criteria. The residual depth is the maximum depth of the pool subtract the tail-out depth at the downstream end of the pool and is used to compensate for the difference in flow and water depth of the river between surveys. The pool spacing is relative to the channel size and is expressed as the number of channel widths between pools. Therefore, if the unvegetated channel width averages 100 m for the reach, then the target spacing for “Very Good” conditions would be having pools within 100 m of each other (<1.0 channel widths per pool) (Collins et al. 2002). A “Good” spacing in this case would be having pools located with 140 m of each other (<1.4 channel widths per pool). Pool-forming feature reflects how the pool is formed, which affects the habitat quality (capacity and productivity) of the pool. The target is to have pools formed by wood because the complex wood cover increases the density of fish that can find hiding cover in the pool. The baseline conditions for pool mapping occurred in 2000, 2003, or 2005 when the three reach plans were developed for the South Fork Nooksack and current conditions were evaluated between 2016 and 2019. An exception was the Van Zandt, where the most recent mapping was from 2013.

Pool spacing was calculated at both the **project reach** scale to assess the impact of restoration on the indicator and the **planning reach** scale to assess status and trends across the watershed. Pool spacing was summarized for project and non-project reaches to compare pre- and post- project results for treated and untreated reaches. For the planning reaches, the pool spacing and percent wood-formed pools are compared to the “Good” and “Very Good” habitat targets for the reach. The conditions at the time of the plan adoption in 2005 is compared the current conditions (approximately 2016) to show the direction of change in the reach.

The number of pools >1 meter residual depth in the Lower South Fork Geographic Area increased from 53 to 79 between 2000-2003 and 2016-18. Within non-project reaches the number of pools decreased in that period from 34 to 27 pools, while pool count increased in project reaches from 19 to 52 pools. Comparing pre- and post- project pool spacing for project and non-project reaches showed that there was decrease in the distance between pools in all project reaches, with the exception of the Hardscrabble and Acme projects, which were projects that focused on improving quality of existing pools rather than creating new pools. Six of the ten project reaches reduced the pool spacing to meet the "Very Good" target of <1.0 channel widths between pools (Figure 16). The greatest decrease in pool spacing occurred in the River Farm project reach. This was a short (~220 m) project reach where the number of pools increased from zero in 2003 to one in 2018. For the untreated reaches, the pool spacing varied, with decreases in spacing occurring in the Acme-Hutchinson and Kalsbeek-River Farm reaches. The untreated Nesset's-Hutchinson and Acme-Kalsbeek reaches saw increases in the distance between pools that outweighed the decreases seen in the other untreated reaches. There was no change in the Todd to Van Zandt reach.

Figure 16: Spacing of pools greater than 1m residual depth in project reaches (blue) and untreated reaches (red) in the Lower South Fork Nooksack Geographic Area (RM 1-12.6). Data collected in 2016-2018 (NNR). Orange bars show unlabeled pre-project baseline pool spacing of the river for comparison. Data collected in 2000 (NSEA) and 2003 (NNR).



The percent of the pools formed by wood was given a "Good" target value of 70%. It is assumed that the "Very Good" conditions will exceed 70% of pools formed by wood as well. Prior to project implementation, 17 of the 53 pools (32%) in the lower South Fork geographic area were formed by wood, mostly natural logjams (Table 20). In an assessment of the current conditions, 56 of the 79 (71%) pools that were mapped were formed by wood- mostly engineered logjams. When the current conditions are summarized by project versus non-project reach, the positive impact of the engineered logjams on pool-forming feature is pronounced. Within project reaches, 85% of the pools were formed by wood, while outside of the project reaches less than half (44%) were formed by wood. Prior to project implementation in the upper South Fork project area, 5% of the 21 pools mapped in the project reaches were wood-formed. In 2019 surveys, 49% of the 33 pools were wood formed in upper South Fork project reaches (Table 21).

Table 20: Number of pools and percent that had wood as a pool-forming feature in the Lower South Fork Geographic Area for the pre-project and post-project monitoring. Project reaches are shown in italics. Mapping in 2000 conducted by the Nooksack Salmon Enhancement Association, all other years by the Nooksack Tribe.

Reach	Year	Number of Pools	% LWD-formed	Year	Number of Pools	% LWD-formed
Saxon	*2000*	*2*	*100*	*2017*	*9*	*89*
Nesset's	*2000*	*2*	*0*	*2017*	*8*	*88*
Nesset's to Hutch	2000	7	14	2018	3	33
Lower Hutch	*2000*	*1*	*0*	*2016*	*3*	*100*
DS Hutch	*2000*	*5*	*60*	*2016*	*13*	*92*
Acme to Hutch	2000	2	0	2016	3	33
Acme	*2000*	*1*	*0*	*2016*	*1*	*100*
Acme to Kalsbeek	2003	10	30	2018	5	20
Kalsbeek	*2003*	*2*	*50*	*2017*	*3*	*100*
Kals to River Farm	2003	3	0	2018	4	75
River Farm	*2003*	*0*	*0*	*2018*	*1*	*100*
River Farm to Hardscrabble	2003	1	0	2017	1	0
Hardscrabble	*2003*	*1*	*0*	*2017*	*1*	*100*
Hardscrabble to Todd	2003	1	0	2017	1	0
Todd/ Syggy	*2003*	*1*	*0*	*2017*	*3*	*33*
Todd to Van Zandt	2003	10	60	2018	10	60
Van Zandt	*2003*	*4*	*25*	*2013*	*10*	*70*
TOTAL:		**53**	**32%**		**79**	**71%**

Table 21: Count and pool-forming feature of pools in the Upper South Fork project areas for the pre-project (2005) and post-project (2019) monitoring.

Reach	Year	Number of Pools	% LWD-formed	Year	Number of Pools	% LWD-formed
River Mile 30	*2005*	*2*	*0*	*2019*	*1*	*100*
Camp 18 Phase 1	*2005*	*0*	*0*	*2019*	*3*	*100*
Larson's Phase 1	*2000*	*2*	*0*	*2019*	*10*	*100*
Larson's Phase 2	*2005*	*8*	*50*	*2019*	*16*	*75*
Fobes Phase 1	*2005*	*4*	*50*	*2019*	*5*	*20*
Cavanaugh Island	*2005*	*6*	*0*	*2019*	*5*	*0*
Skookum Edfro Phase 2	*2005*	*3*	*0*	*2019*	*4*	*50*
Skookum Edfro Phase 1	*2005*	*0*	*0*	*2019*	*0*	*0*
TOTAL:		**25**	**20%**		**44**	**66%**

The engineered logjams were also preferentially used by adult early spring chinook (Figure 17). Snorkel surveys conducted though the reach between RM 5 and 13 found a strong association between migrating and holding spring chinook and engineered logjam-formed pools. Only a handful of the fish counted in the survey were in habitats that were not wood-formed pools. Looking at the number of fish holding in the pools by pool type shows that engineered logjam-formed pools also provided a higher density of fish in the pools (Figure 18). This likely reflects the pool size, depth and complex woody cover associated with the structures.

Figure 17: Adult chinook distribution and pool-forming feature of holding habitat (July 15-Sept 1, 2017) in the Lower Nooksack River.

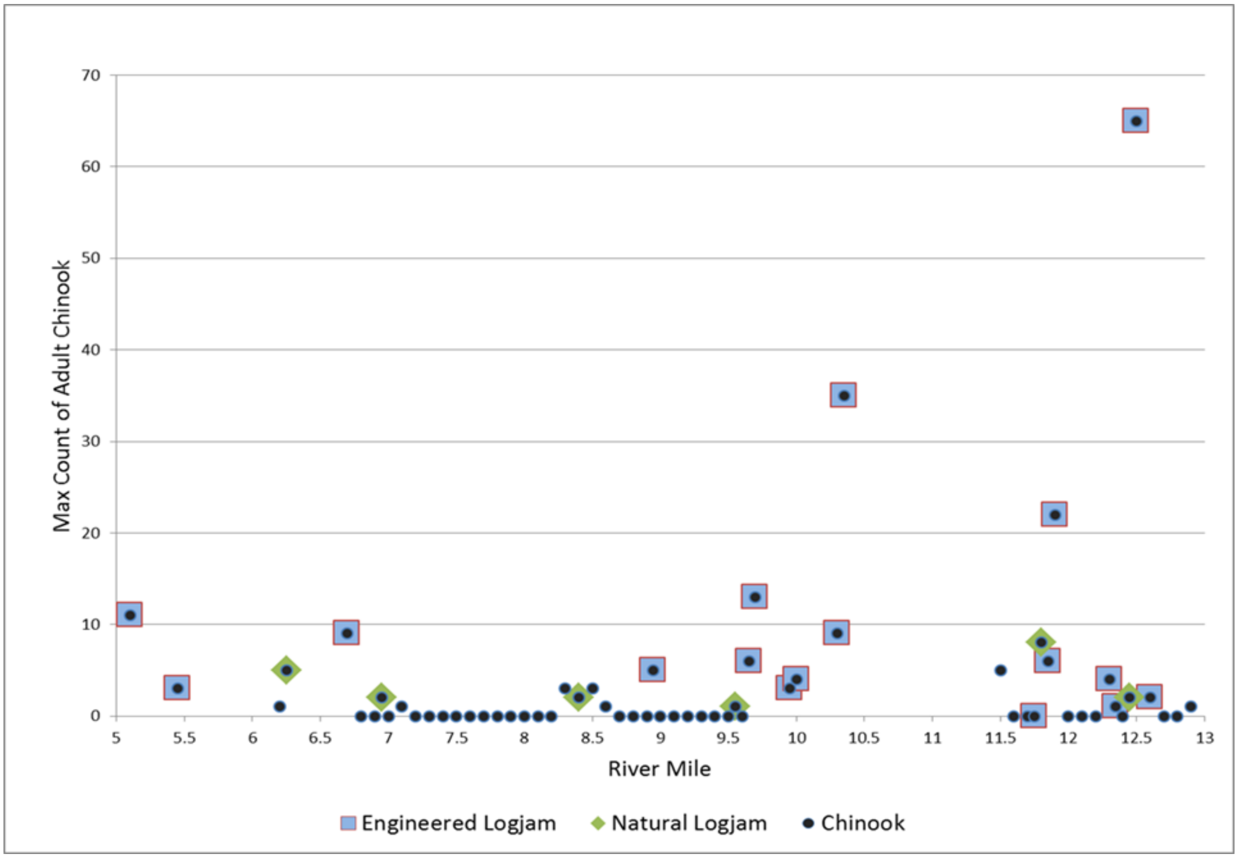
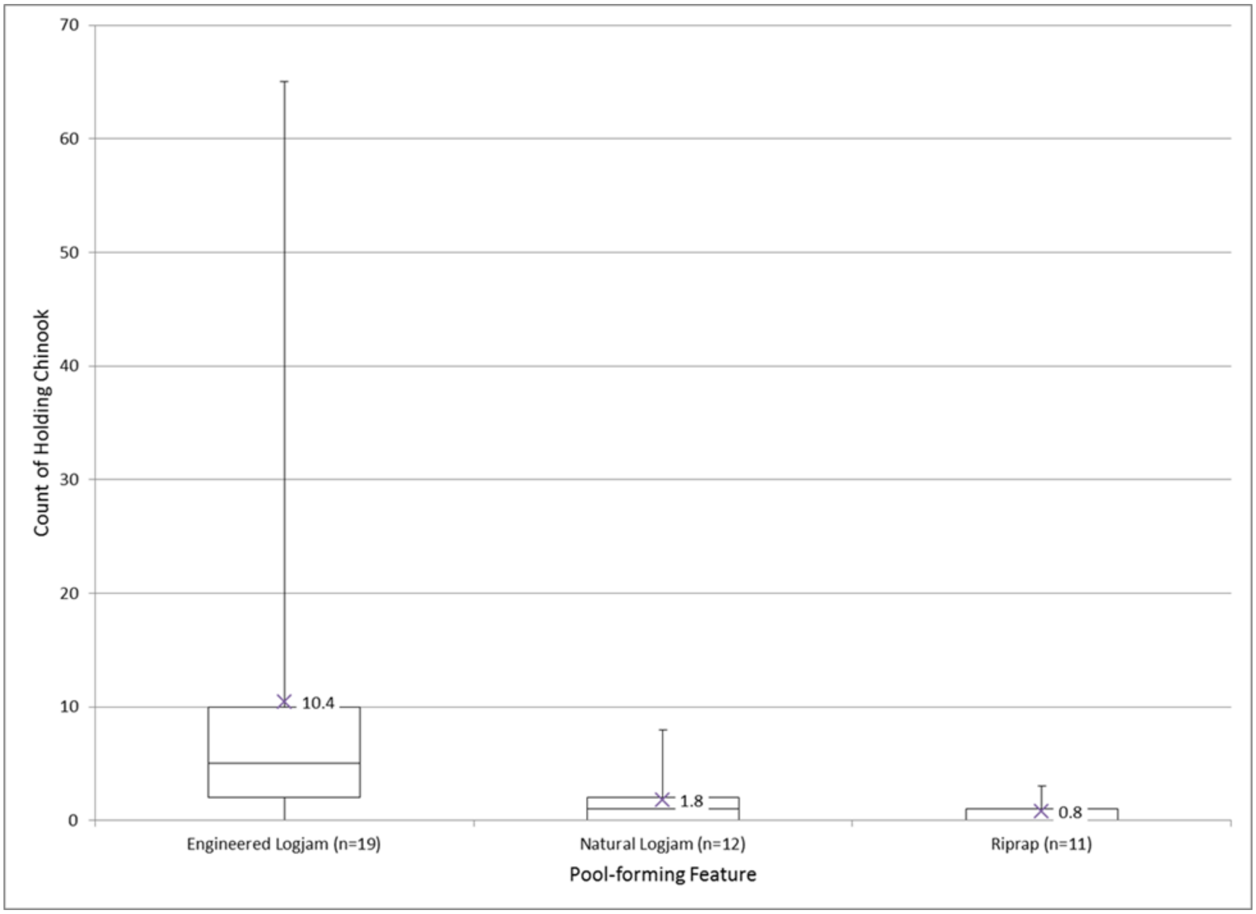


Figure 18: Adult holding chinook in pools by pool-forming feature (2017 data).



While several of the Lower South Fork project reaches met the pool spacing target, none of the planning reaches met the target for “Good”. The “Good” target for pool spacing was approached for pool spacing and met for the percent wood-formed pools in the Saxon and Hutchinson reaches, reflecting the effects of the Saxon, Nesset’s Reach, Lower Hutchinson and Downstream of Hutchinson logjam projects that were constructed in those planning reaches (Table 22). Gaps between the project areas that have low pool counts are responsible for the planning reaches not meeting the target level, since all four projects exceeded the threshold for “Very Good” within their project extents.

In the upper South Fork the mapped areas had a total pool spacing of 5.9 channel widths per pool in 2019 habitat surveys, an improvement from 10.4 in 2005 conditions (Table 22). This decrease in pool spacing in the project reaches was driven by large decreases in the Skookum, Lyman Pass, Dye’s Canyon and Larson’s Bridge reaches. Lyman Pass had the lowest pool spacing in the upper South Fork at 3.9, followed by Larson’s Bridge at 4.8. The Howard Reach had the lowest pool spacing, but the mapping covered less than 0.2 km of the 10.3 km reach. Project monitoring of the River Mile 30, Larson’s Bridge, Fobes, Cavanaugh and Saxon projects concluded that many of the structures were forming deeper pools and likely reducing the pool spacing and increasing the percent of pools formed by wood in the project extents (NSD 2019 Draft). Even though none of the project reaches meet the spacing target, the reduction in pool spacing by nearly half suggests that upper South Fork projects have been successful in lowering pool spacing (Table 23).

Table 22: Pool spacing and pool-forming feature relative to planning targets for the South Fork Nooksack. Mapping in the Upper South Fork focused on past and proposed project areas, rather than planning reaches. Where this is less than the planning reach the extent is shown in parentheses. Green boxes show reaches that meet habitat targets (light green/ black text= "Good"; dark green/ white text= "Very Good").

<table>
<tr><th rowspan="2">Geographic Area</th><th rowspan="2">Reach</th><th colspan="2">Pool Spacing
(Targets: "Very Good" <1.0; "Good" 1.0-1.4)</th><th rowspan="2">2016 Pool-forming Feature (Target: 70% wood)^</th></tr>
<tr><th>2005 Recovery Plan Conditions</th><th>2016 Conditions^</th></tr>
<tr><td rowspan="8">Lower South Fork</td><td>Van Zandt</td><td>5.8</td><td>3.4</td><td>50.0</td></tr>
<tr><td>Todd</td><td>2.5</td><td>3.1</td><td>62.5</td></tr>
<tr><td>Hardscrabble</td><td>8.4</td><td>6.3</td><td>50.0</td></tr>
<tr><td>Standard</td><td>6.2</td><td>3.1</td><td>56.3</td></tr>
<tr><td>BNSF</td><td>6.1</td><td>4.4</td><td>28.6</td></tr>
<tr><td>Acme</td><td>4.6</td><td>4.6</td><td>33.3</td></tr>
<tr><td>Hutchinson</td><td>2.9</td><td>1.6</td><td>**87.5**</td></tr>
<tr><td>Saxon</td><td>2.0</td><td>1.5</td><td>**78.6**</td></tr>
<tr><td rowspan="7">Upper South Fork</td><td>Skookum</td><td>43.7</td><td>12.5</td><td>33</td></tr>
<tr><td>Dye's Canyon
(RKM 24.9 - 22.9)</td><td>13</td><td>8.1</td><td>25</td></tr>
<tr><td>Cavanaugh*
(RKM 27.4 - 26.0)</td><td>3.9</td><td>4.9</td><td>0</td></tr>
<tr><td>Larson's Bridge</td><td>10</td><td>4.8</td><td>**73**</td></tr>
<tr><td>Lyman Pass</td><td>16.2</td><td>3.9</td><td>50</td></tr>
<tr><td>Elk Flats
(RKM 37.0 - 35.3)</td><td>8.7</td><td>8.9</td><td>25</td></tr>
<tr><td>Howard*
(RKM 48.3 - 48.1)</td><td>2.4</td><td>2.8</td><td>N/D</td></tr>
<tr><td colspan="2">Lower SF Total</td><td>*4.0*</td><td>*2.8*</td><td>*71%*</td></tr>
<tr><td colspan="2">Upper SF Total</td><td>*10.4*</td><td>*5.9*</td><td>*42%*</td></tr>
</table>

^ = 2013 for Van Zandt; 2019 for upper SF reaches

Table 23: Pool spacing relative to planning targets for the Upper South Fork Nooksack project areas. Green boxes show reaches that meet habitat targets (light green/ black text= "Good"; dark green/ white text= "Very Good").

Project Reach	Pool Spacing (Targets: "Very Good" <1.0; "Good" <1.4)	
	2005 Recovery Plan Conditions	2019 Conditions
River Mile 30	*2.4*	*2.8*
Camp 18 Phase 1	*No pools*	*1.9*
Larson's Phase 1	*9.5*	*1.6*
Larson's Phase 2	*5.8*	*2.4*
Fobes Phase 1	*10.8*	*8.0*
Cavanaugh Island	2.2	2.5
Skookum Edfro Phase 2	*6.0*	*4.4*
Skookum Edfro Phase 1	*No pools*	*7.9*

Monitoring pool spacing directly addresses one of the most common restoration objectives for the South Fork Nooksack. The targets for pool spacing are based on literature (Collins et al. 2002), although it may be appropriate to revise the targets for various reaches depending on the channel confinement. In the upper South Fork reaches (Howard and Elk Flats), the active channel is relatively narrow and yields a closer pool spacing target than the less confined, wider active channel areas in the lower reaches of the river. This may indicate the need for a higher target in these areas. Similar to the limitations of the Habitat Diversity indicator, it is important that habitat surveyors are consistent in how they define pools and measure depth.

Nearly all of the reaches where data is available showed a decrease in pool spacing since the adoption of the salmon recovery plan in 2005. The exception is the Todd Reach, where pool spacing increased by 0.6 channel widths (~40 m) between pools. This was one of two planning reaches in the lower South Fork where no restoration projects have been implemented (Table 18). The other reach where no projects have been constructed is the BNSF reach, which saw an increase of two pools in the reach as the channel migrated along the railroad grade and eroded a forested patch of floodplain.

Length of Complex Edge Habitat

Edge habitat represents the slow water area at the edge of the channel. Edge habitat type (gravel or sand bar, bank (generally steeper and vegetated), riprap, logjam) has a direct impact on the width of slow water at the channel margin, the habitat diversity and the rearing capacity of the river. Vegetated banks and wood banks have been found to support a higher density of rearing juvenile salmonids than bar edges or riprapped banks. The target for monitoring edge type is to have the summer low flow channel edges reflect the historic conditions. It is expected that under high flow conditions, the length of riprap and bank edges would increase and the length of gravel bar edges would be reduced, as the river inundates the shallow gravel bar edges. Historically in the lower South Fork, edges would likely have been dominated by natural banks and bars with intermittent areas of bedrock or boulder banks. In the more confined areas of the upper South Fork, bedrock and boulder would have likely been more prevalent. Targets for edge type are 100% natural bank types (bars, banks and logjams) for “Very Good” and 90% natural edge types for “Good”. Edge types were not classified in the field in 2003, so the habitat mapping was compared to aerial photos to estimate the lengths of the different edges. For the 2016-2018, edges were classified in the field for the lower South Fork area and from aerial photos for the upper South Fork area and engineered logjams were included as a natural bank type.

Edge types were classified for project and non-project reaches to evaluate the impact of the project on the distribution of edges. For project reaches, an evaluation of the 2016-2018 period with and without the project was done to show how the changes relate to the project relative to the natural change in edge type distribution from channel migration. These are then compared to the targets. For the planning reaches, the extent of natural banks is summarized for the reach and compared to the targets for the period around the Salmon Recovery Plan adoption in 2005 and the current conditions (approximately 2016) to show the direction and magnitude of change.

Edge types for the lower South Fork were interpreted from aerial photos based on the field mapped low flow wetted channel. In 2003, 62.8% of the wetted edge was classified as bar (Figure 19). Natural banks accounted for 22.7% of the edge habitat and armored bank was 14.6% of the wetted edge. Reflecting the habitat restoration that has occurred in the lower watershed between 2003 and 2018, the engineered logjam (ELJ) edge type makes up 2.1% of the total edge length mapped between 2016 and 2018 (Figure 20). The greatest increase in ELJ edge habitat occurred in the Downstream of Hutchinson project reach. Similar to mapping in 2003, bar edges are the dominant edge type in the lower South Fork, representing 66% of the wetted channel edge. Natural banks account for 19.6% and armored banks have decreased in length to 12.3% of the wetted edge. In the Upper South Fork, there was little change in the edge types through time. Riprap accounted for less than 0.1% of the edge habitat in both years, with bars (44%) and natural banks (56%) fairly evenly split in both years. The total length of riprap edge in 2003-2005 mapping period was 6.7 kilometers in the lower South Fork and 0.9 kilometers in the upper South Fork. In spite of riprap removal and replacement with wood, the total length of riprap in 2016 increased slightly to 6.8 kilometers in the lower South Fork, largely due to channel migration encountering more existing riprap. The length in the upper South Fork decreased to 0.6 kilometers due to riprap removal as a part of the Skookum Reach projects.

Figure 19: Length of edge types in the lower South Fork reaches (interpreted from field mapping from 2003).

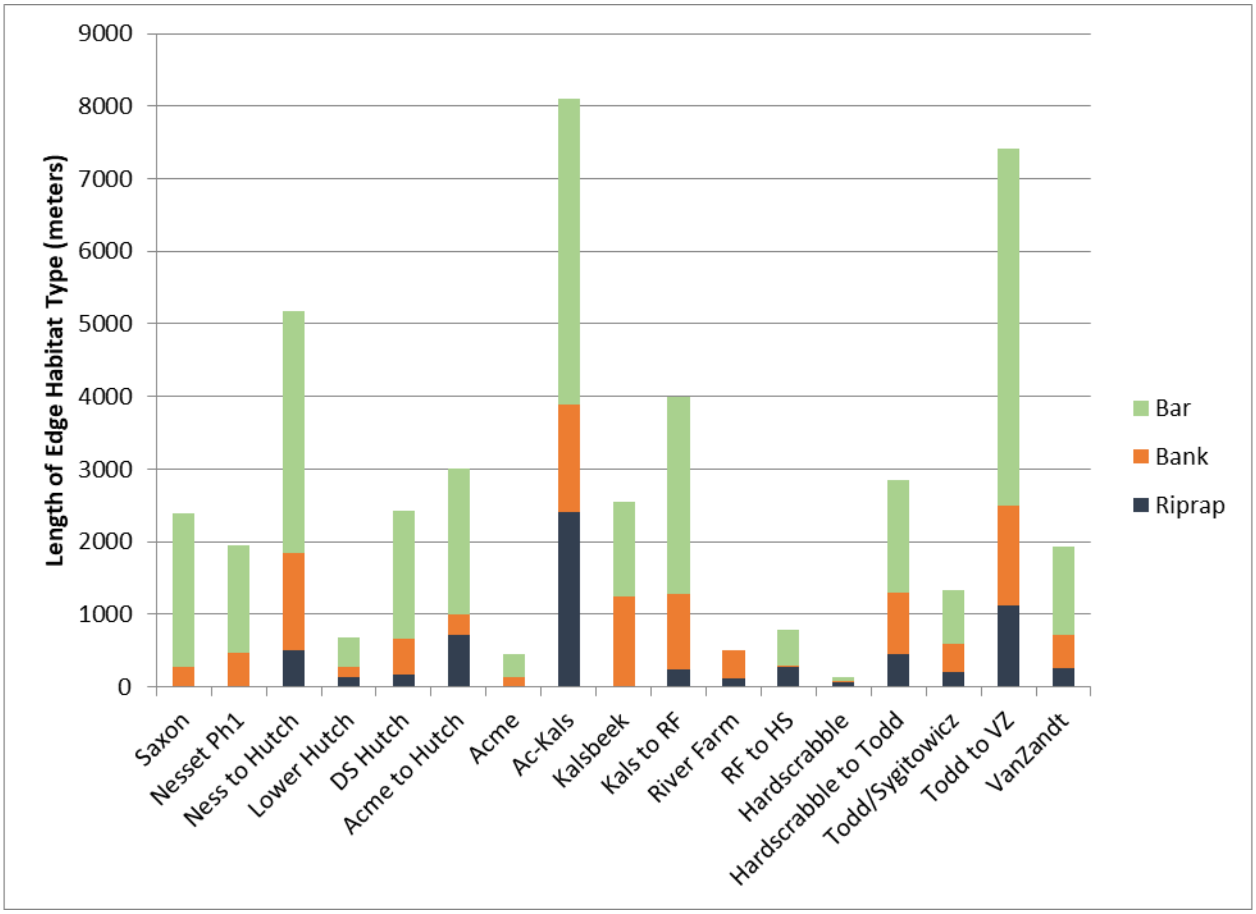
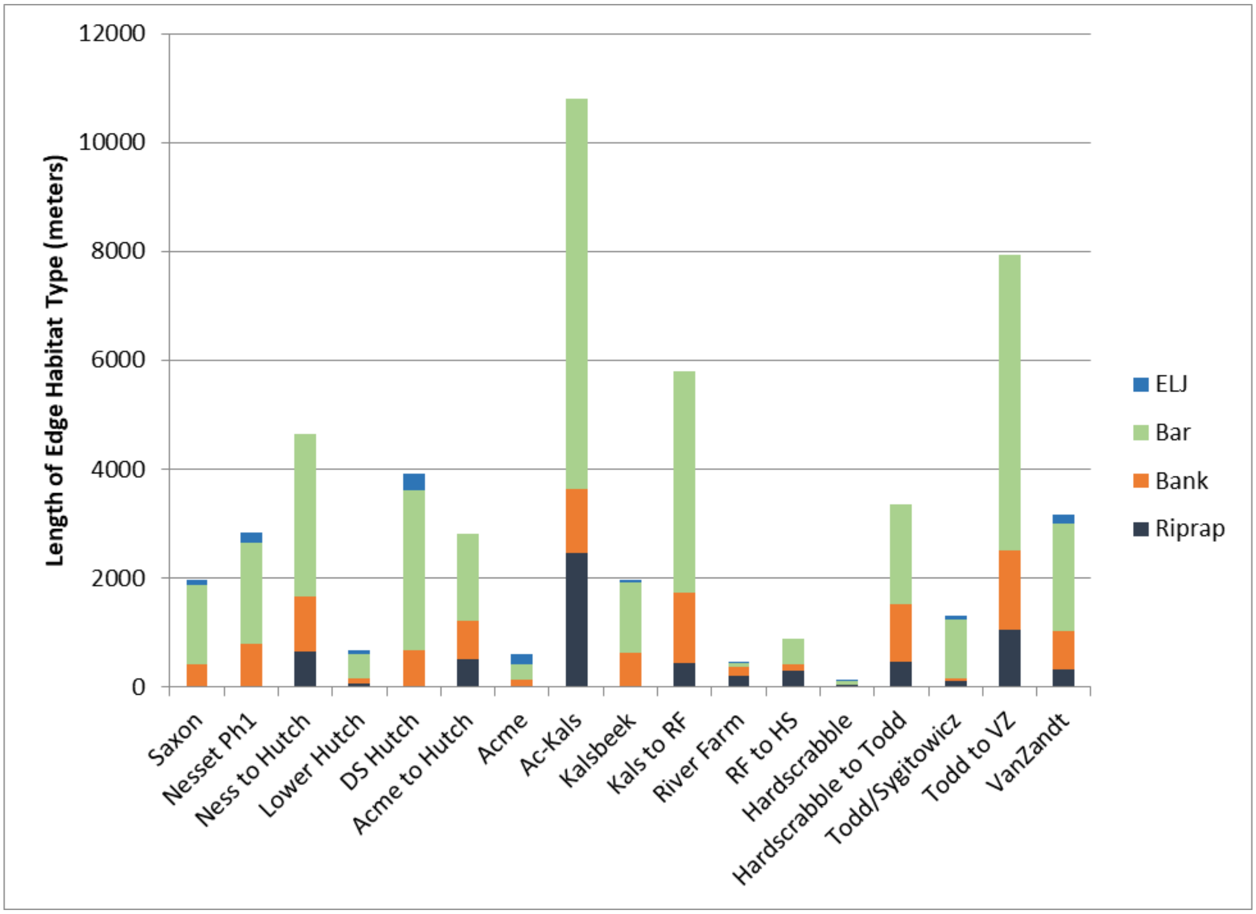


Figure 20: Length of edge types in the lower South Fork reaches (interpreted from field mapping from 2016-2018).



Comparing the percent of natural bank at the project scale shows that all of the project reaches, except the River Farm reach, showed an increase in the percent natural edges between 2003 and 2016-18 (Table 24). To try to separate the effects of restoration from the natural variability in edge types related to channel migration (i.e. the river migrates away from a riprap bank and the riprap edge type decreases without actually removing riprap), the project reaches were measured in 2016-18 with and without the restoration elements (engineered logjams and riprap removal) that took place as a part of the project. All of the project reaches that contained some length of riprap banks in 2003 showed an increase in natural edges in 2016-18 relative to the amount of that would have been present without the project. The most extreme change in the percent natural bank occurred in the Hardscrabble project reach, which was a relatively short project reach that saw the replacement of a riprap bank protection project with two engineered logjams. In the Saxon Reach, the restoration project included the construction of a long woody revetment along an eroding bank that was threatening several houses. This reach would likely have seen a large increase in artificial bank if the project was not implemented and a riprap project was built instead.

Table 24: Percent natural edges (including logjams) in the project reaches in 2003 and 2016-2018. The 2016-2018 length is shown as the measured length and an estimate of the measured length as if the riprap had not been altered as a part of the project. Data is not available for the Upper South Fork Projects, which generally occur in reaches not impacted by bank armoring.

Project	2003	2016-2018	
	% Natural Edges	% Natural Edges	% Natural Edges (w/o Project)
Saxon	100	100	100
Nesset's	100	100	100
Lower Hutchinson	81.6	90.2	81.0
Downstream of Hutchinson	92.9	100	97.0
Acme	100	100	100
Kalsbeek	100	100	100
River Farm	75.9	58.4	56.1
Hardscrabble	49.6	68.9	49.2
Todd/ Sygitowicz	84.3	91.5	88.6
Van Zandt	86.9	90.3	88.8

At the salmon recovery planning reach scale, there is a distinct break in the percent of natural banks upstream of the Skookum Reach in the Upper South Fork Geographic Area (Table 25). With the exception of a short section of bank protection to protect the forest road crossing at Larson's Bridge in the Lyman Pass Reach, the banks are unmodified. The only real changes that have occurred in these areas is an increase in engineered logjam-formed edges due to the habitat restoration projects at River Mile 30, Larson's Bridge, Fobes, and Cavanaugh.

In the lower South Fork Nooksack geographic area, the impact of artificial bank hardening on edge habitat quality is more prevalent. Aside from the Saxon Reach, all of the lower South Fork reaches have been impacted by bank hardening to some degree, with the changes between the two time periods reflecting bank protection installation, removal and channel migration toward or away from existing bank armor. In the Van Zandt Reach, there has been an expansion in riprap along the railroad, as channel migration has threatened the tracks. This is the only section of new riprap placed in the lower South Fork since the adoption of the salmon recovery plan in 2005. The increase in riprap was enough to lower the percentage to just below the threshold for "Good" conditions. Riprap removal and replacement with wood structures has occurred in several of the project reaches and are reflected in the improvement in natural edge length in the Hardscrabble (Sygitowicz and Hardscrabble projects), Acme (Acme Project) and Hutchinson (Lower Hutchinson and Downstream of Hutchinson projects) reaches. The changes in the Todd and Standard reaches are the result of channel migration that has changed the amount of existing riprap that interacts with the low flow channel. Over the entire extent of the South

Fork, the percent of natural edge exceeds 94% of the low flow channel edges, although over the lower South Fork the value is 88.5%.

The targets for edge types are based on extent of bank armoring present in the reach. A 90% natural bank length was selected based on observations of higher quality reaches relative to lower quality reaches in the South Fork. Considering the difference between the upper and lower South Fork geographic areas, it is likely more important to monitor this habitat indicator in the lower reaches of the river, where bank armoring is prevalent.

Table 25: Percent natural bank edges relative to planning targets for the South Fork Nooksack. Green boxes show reaches that meet habitat targets (light green/ black text= "Good"; dark green/ white text= "Very Good").

Reach	**2005 Edge Type (Targets: Good: >90% Natural, Very Good: 100% Natural)**	**2016 Edge Type (Targets: Good: >90% Natural, Very Good: 100% Natural)**
Van Zandt	**91.4**	89.8
Todd	84.9	**90.2**
Hardscrabble	82.9	87.4
Standard	**91.8**	89.7
BNSF	64.2	74.3
Acme	75.1	80.4
Hutchinson	86.6	**90.4**
Saxon	**100**	**100**
Skookum	85.4	89.6
Dye's Canyon	**100**	**100**
Cavanaugh	**100**	**100**
Larson's Bridge	**100**	**100**
Lyman Pass	**98.4**	**98.9**
Elk Flats	**100**	**100**
Howard	**100**	**100**
*SF Total**	*93.8*	*94.4*

Nearly all of the project reaches saw an increase in natural bank types between 2005 and 2016. The only exception is the River Farm project, where channel migration led to an increase in riprap bank type that was greater than the amount of riprap that was removed as a part of the project. For the planning reaches, all but two showed an increase in natural bank percentage between 2005 and 2016. The two reaches that were the exception, Van Zandt and Standard, saw decreases of 1.6% and 2.1% respectively. Since different edge types provide different fish capacity and productivity, targets could be set for the reaches based on salmon population and life stage needs and limitations, rather than extent of different edge types. Historic estimates of habitat capacity in the South Fork could further help with setting goals for habitat restoration projects.

Middle Fork Nooksack Restoration Strategy

The Middle Fork Nooksack shares an early chinook population with the North Fork Nooksack. In the WRIA 1 Salmonid Recovery Plan, the Middle Fork Nooksack is split into upper and lower geographic areas at the Mosquito Lake Bridge at approximately River Mile 5. The upper Middle Fork is considered to be relatively well protected under current forest practices rules and federal management plans, and is not considered a priority for instream habitat restoration. Because of this, it is not covered in the review of habitat indictors for the watershed. The upper Middle Fork does include the highest priority restoration action- restoring fish passage at the City of Bellingham's water diversion dam. The lower Middle Fork area is similar to the unconfined reaches of the North Fork, switching between braided and island-braided channels, and shares many of the same habitat limitations with the North Fork reaches. The lower Middle Fork geographic area is described as (WRIA 1 Salmon Recovery Board 2005):

> The lower Middle Fork is an unconfined, highly braided system. Like the lower North Fork, the channel pattern was historically anastomosing, with multiple channels, sloughs, and forested islands; a simpler, more frequently shifting braided pattern with fewer forested islands characterizes current conditions. The historic channel migration zone of the lower Middle Fork nearly fills its floodplain, occupying about 70% of floodplain width. The lower Middle Fork valley is largely zoned rural and rural forestry, while hillslopes are zoned commercial forestry. Stream-adjacent roads include Rutsatz Rd. and the Mosquito Lake Rd.; bank hardening is not extensive but is present at the edges of some meander bends.
>
> The lower Middle Fork represents 19% of the spawning distribution and 12% of the freshwater habitat for NF/MF Nooksack early chinook. Restoration of the lower Middle Fork is expected to have a significant impact on recovery of NF/MF Nooksack early chinook abundance and productivity. Indeed, accounting for differences in reach length, it is the 3rd most important geographic area for restoration, after the Middle Fork diversion dam and the lower North Fork, and the 2nd most important geographic area for protection, after the lower North Fork. High temperatures, high fine sediment load, and lack of key habitats are the most significant limiting factors. Low flows have the potential for significant impact to the population, depending upon withdrawals at the Middle Fork diversion dam. Egg incubation is the most limiting life stage, followed by spawning, pre-spawning holding, and fry life stages.

The causal mechanisms and monitoring metrics that are tied to the limiting factors for the lower Middle Fork geographic area are shown in Table 26. Targets for the monitoring indicators were developed as a part of developing the WRIA 1Monitoring and Adaptive Management Plan (WRIA 1 Watershed Management Board 2017). The monitoring targets were based on a comparison to two conditions: an estimate of properly functioning conditions, which was considered "Good" and an estimate of early historic conditions, which was considered "Very Good". Monitoring indicators that are not included as viability indicators in the monitoring and adaptive management plan have a target relative to change in the historic conditions of the North Fork Nooksack. For consistency with the WRIA 1 monitoring plan, "Good" was based on a percentage of the historic conditions, while "Very Good" reflects the early historic conditions or the maximum measured value, depending on the metric. Turbidity, temperature and flow have not been monitored in the lower Middle Fork relative to salmon life history needs, so it will not be included as a project effectiveness indicator. For the key habitat indicators in the lower Middle Fork the "Good" and "Very Good" conditions are shown in Table 27. Other than side channel length, key habitat indicators have not been monitored throughout the analysis reaches, so changes will be assessed only at the project scale, where the project had an objective of increase key habitat quantity.

Table 26: High and moderate importance limiting factors, primary causal mechanisms and monitoring metrics for the Lower Middle Fork Geographic Area (WRIA 1 Salmon Recovery Board 2005).

Limiting Factor (Importance)	**Causal Mechanism**	**Monitoring Indicator**
Key Habitat Quantity (Moderate)	Degraded riparian function leads to loss of stable instream wood accumulations that provide complex cover and form pools	Pool Count by Type
		Wood Function
		Side Channel Length
Sediment (Moderate)	Elevated mass wasting from land use practices	*Turbidity- Unmonitored*
Temperature (Moderate some years)	Increased summer water temperatures are a result of channel widening and riparian forest loss.	Active Channel Width
		Floodplain Forest Encroachment
		Temperature- Unmonitored
Flow (Moderate potential)	Diversion of flow for the City of Bellingham reduces downstream instream flows.	*Streamflow- Unmonitored*

Table 27: WRIA 1 habitat indicators and targets relevant to the Lower Middle Fork Geographic Area (adaptive management viability indicators are shown with an asterisk). Condition targets in italics are suggestions for indicators that lack tiered targets that are based on project-level effectiveness targets.

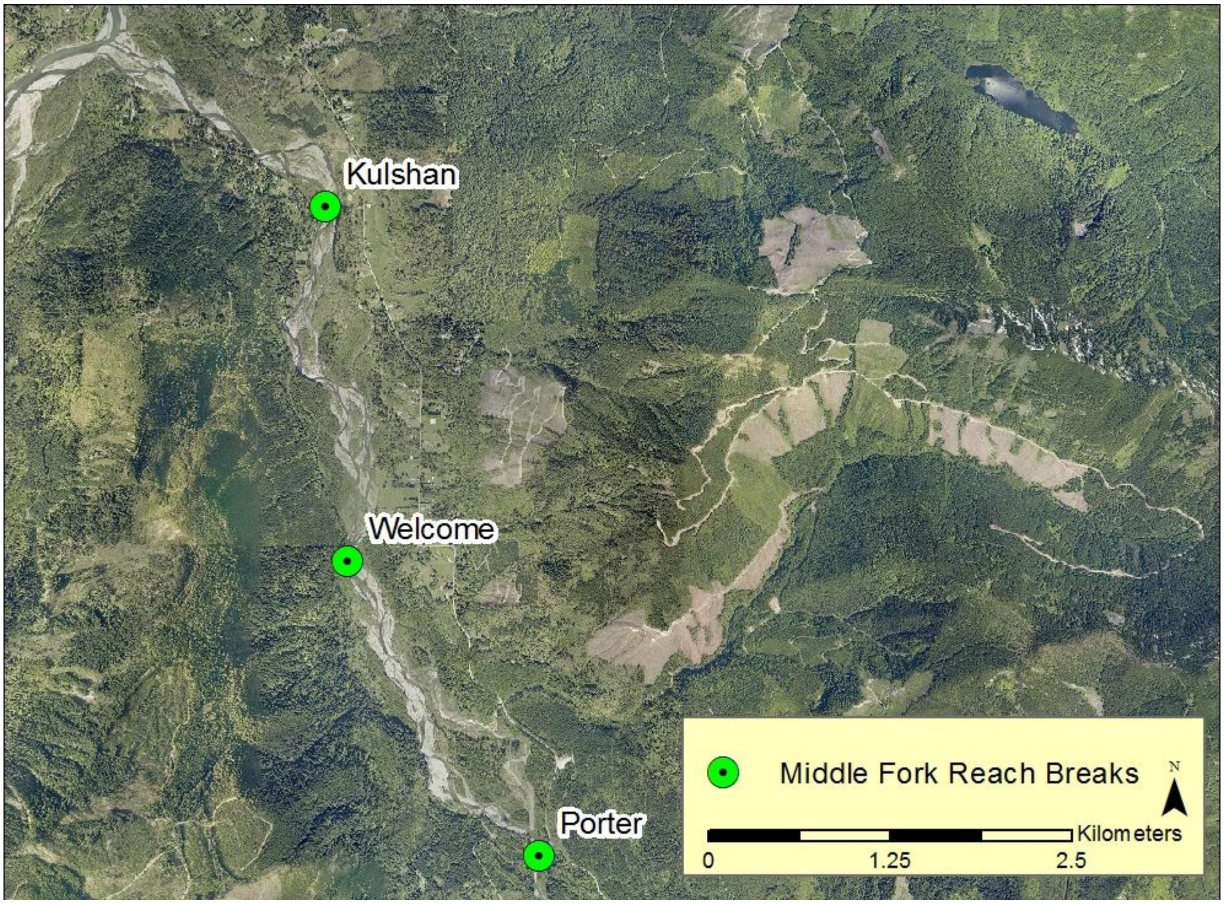
Monitoring Indicator	**"Good" Condition**	**"Very Good" Condition**
Floodplain Forest Encroachment*	Stand age >80% of natural condition	Stand age characteristic of natural condition (>40% older than 25 yrs., >10% older than 75 yrs.)
Active Channel Area	*>Recent historic mean (1933-1998)*	Early Historic Conditions
Pool Count by Type*	<1.4 channel widths per pool;	<1.0 channel width per pool
Wood Function*	>70% of pools formed by wood	>70% of pools formed by wood
Side Channel Length	*30% of the main channel length (where less than historic)*	Early Historic Conditions

Based on the limiting factors and causal mechanisms, habitat restoration strategies were identified and prioritized to guide project development in the planning reaches of the Lower Middle Fork Geographic Area (Table 28). Tier 1 represents the highest priority action in the highest priority geographic area, while Tier 2 represents that the action is considered a lower priority in the reach. For this report, the Lower Middle Fork Nooksack was divided into three project planning reaches. These reaches were identified in *Middle Fork Nooksack River Habitat Assessment* (Lummi Natural Resources 2011), which underpins the habitat restoration planning for this section of the river (Figure 21).

Table 28: The three restoration strategies that have been identified as Tier 1 (highest priority) for the Lower Middle Fork Nooksack River (WRIA 1 Watershed Management Board 2019).

Reach	**Upstream RM**	**Restoration Strategies**		
		Install logjams to increase the stability of forested islands and their associated side-channel habitats.	**Install logjams to reconnect side channels (provide for flows during spawning/ incubation)**	**Install logjams to increase pool depth and frequency**
Kulshan	1.5	**Tier 1**	**Tier 1**	**Tier 1**
Welcome	3.1	**Tier 1**	**Tier 1**	**Tier 1**
Porter	5.2	**Tier 1**	**Tier 1**	**Tier 2**

Figure 21: Lower Middle Fork planning reaches (LNR 2011).



Middle Fork Habitat Indicators

Side Channel Connectivity

For assessing side channel connectivity in the Middle Fork reaches, we will use a similar approach to the North Fork reaches. The habitat mapping that is used for monitoring and adaptive management in the Nooksack Watershed is broadly based on four channel types: main channel, braid, side channel, and slough (Coe 2013). The main channel is the channel or channels that contain the dominant flow of the river. For the historic channel mapping, this determination is based on the mapped channel width. Braided channels are those secondary channels that are split from the main channel by gravel bars or sparse, young vegetation, shown as "high flow" channel or "gravel bar" in the historic mapping (Collins and Sheikh 2004). Slough channels are disconnected at the upstream end by sediment deposition or organic debris and are often groundwater-sourced. Side channels are defined as smaller (contains less than half of the river discharge) perennial channels that are connected to the main channel of the river at both the upstream and downstream ends and separated from the main channel area by patches of persistent woody vegetation (Beechie et al. 2017). These areas are labeled "forest island" in the historic mapping (Collins and Sheikh 2004). For the purposes of this monitoring report, historic (pre-2005) side channel length is taken from habitat mapping of high flow, low flow, and forested islands done by Collins and Sheikh (2004) (see Figure 7 for an example). These channels were mapped from spatially referenced aerial photos taken at various flow conditions, so seasonal changes in high flow channel area and side channel connectivity is not captured. For this analysis, side channels that span analysis reaches are segmented and measured by project reach. Side channels that include multi thread braided sections are classified as braids, rather than additional side channel length. In this case, the dominant (widest) channel is considered for the side channel length measurement, or if the braids appear to carry approximately equal flow, then the longest flow path is measured as the side channel, with the other channels considered braids.

Side channel length has varied considerably by reach through time in the Middle Fork Nooksack (Table 29). Channel migration and seasonal changes in flow has a strong influence on the side channel length, causing the length of side channels to increase or drop drastically between photo years within a reach. Each of the three reaches has seen zero side channel length at points in time.

In a pattern that mimics the unconfined reaches of the North Fork, the length of side channel increased to the mid-1960s, dropped and then steadily grew until a rapid drop at the time of the adoption of the Salmon Recovery Plan in 2005. Cumulative side channel length through time in the Middle Fork rose from the historic minimum length (~650 m) in 1943 until it reached approximately 4,450 m in 1966, which was slightly more than double the average side channel length of the Middle Fork through the historic photo record. By 1975, the length had dropped to approximately 30% this length before increasing to its historic maximum in 1994. Side channel length then fell precipitously to 770 m by 1998 and was near the historic low by 2005, when the salmon recovery plan was adopted and the focus of restoration became restoring the length of side channel areas. By 2016, the length had again increased to twice the historic average, with 2 of the 3 reaches showing an increase in length. This increase was driven by the Welcome Reach, which greatly exceed the historic maximum in 2016. The Kulshan Reach has continued to see a decrease in side channel length since reaching its historic maximum in 1994. In the Porter Reach, where restoration projects have occurred since the adoption of the salmon recovery plan in 2005, there was an increase in side channel length in 2016 with 260 meters of the 660 meters associated with the instream project.

Table 29: Side channel length (meters) for each of the analysis reaches through time. Bolded areas are reaches that include habitat restoration projects designed to increase side channel length.

Reach	Aerial Photo Year								Mean
	1943	1961	1966	1976	1986	1994	2005	2016	
Kulshan	0	450	1,263	0	513	1,818	712	359	471
Welcome	0	1,477	1,426	855	1,832	2,703	0	3,595	1,322
Porter	644	683	1,767	487	0	1,791	0	660	603
MF TOTAL:	*644*	*2,610*	*4,456*	*1,342*	*2,345*	*6,312*	*712*	*4,614*	*2,186*

Comparing the changes in side channel length to the targets for “Good” and “Very Good” conditions, the Welcome Reach is currently above the historic maximum length for side channels (Table 30). Overall the Lower Middle Fork Geographic Area met the “Good” condition in 2016, with a side channel length that exceeded 30% of the mainstem length, although the majority of this length occurred in the Welcome Reach. The Porter Reach, which has the focus for habitat restoration has not met the criteria for “Good” conditions, but there has been an increase in side channel length since the adoption of the plan.

Table 30: Side channel length (meters) relative to planning targets for the Middle Fork Nooksack. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects.

Reach	Targets		Conditions	
	Pre-2005 Historic Maximum Length ("Very Good")	30% of Mainstem Length ("Good") 2005/2016	2005 Recovery Plan	2016 Conditions
Kulshan	1,818	605/621	**712**	359
Welcome	2,703	852/900	0	**3,595**
Porter	1,791	891/835	0	660
MF Total	*6,312*	2,348/2,355	*712*	***4,614***

Similar to the results for the North Fork side channel length assessment, continued monitoring of the side channel length through time will be important to determine if the restoration projects have been effective in increasing and maintaining side channel length relative to reaches without projects. While the project reach has seen an increase in side channel length since 2005, this has apparently occurred during a period when there has been a very large increase in length in the Welcome Reach and a continued loss in the Kulshan Reach. These differences are also likely affected by a difference in the river stage between the 2005 and 2016 conditions. To improve the estimate, field observations of channel connectivity at a similar discharge can help.

In spite of the difficulty of controlling for differences in the river stage and the limitations of the historic photos to document the target conditions, side channel length is an important direct measurement of habitat diversity. Since side channel habitat has been tied to incubation success and channel stability as a limiting factor, it will be more important to assess seasonal side channel connectivity and habitat quality at the project scale, while understanding the broader seasonal and climate context presented in the historic record.

Floodplain Forest Encroachment

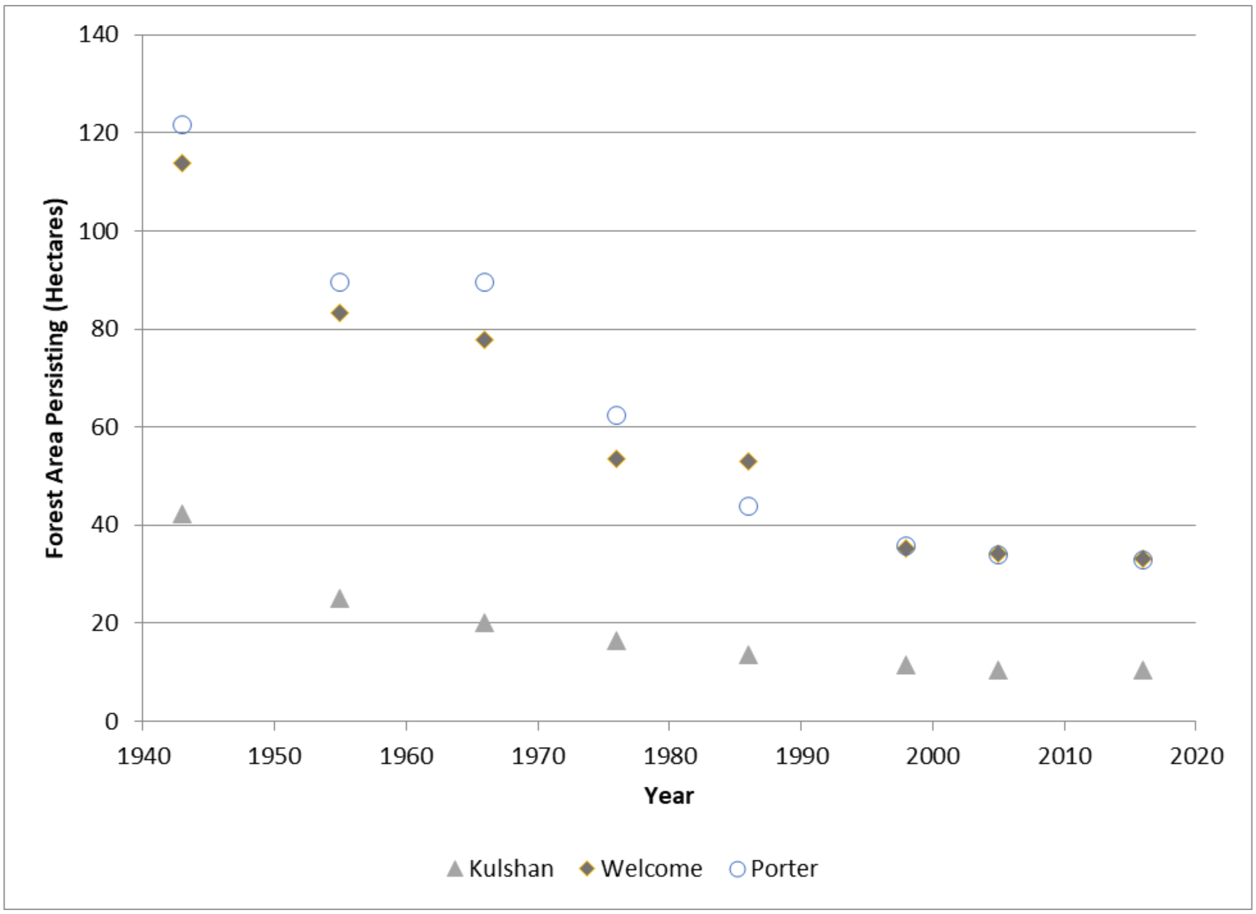
The floodplain forest viability indicator and targets are the same for the Middle Fork reaches as it was for the North Fork Reaches- floodplain vegetation age classes that are greater than 25 years old (>40%) and greater than 75 years old (>10%). Similar to the North Fork, mapping data from Collins and Sheikh (2004) of the forest cover from the earliest complete aerial photo flight (1943, in this case) was compared to subsequent photo years to determine the amount of erosion or land clearing that affected those forest patches. If the forest patch still appears to be forested in the subsequent photo year, it will be counted as the same stand. Patches that were not reset by channel migration or cleared for land use by the 2016 aerial photo year are considered >75 years old. To evaluate the stands older than 25 years, habitat mapping based on the 1998 aerial photos was used and the metric adjusted to reflect 20 years of stability. To compensate for changes in the riparian area through time due to changes in the active channel width, the channel area from the 1890s Government Land Office surveys was subtracted from the floodplain area to come up with the remaining “potential vegetated area” for each reach. This is consistent with the “Very Good” target for Active Channel width. To define the riparian area for this indicator a combination of the historical floodplain habitat mapping from 1938 and 1998 by Collins and Sheikh (2004) and the draft Erosion Hazard Zone (Whatcom County 2007) was used to define the boundaries (see Figure 8 for an example).

In the lower Middle Fork geographic area, the entire floodplain was mapped as forested at the time of the GLO surveys in approximately the late 1880s. By the earliest photos in 1943, the amount of forest had been greatly reduced by channel migration and land clearing for agriculture. It is unclear how much of the forest in the 1943 map was a remnant of the 1880s, but it is likely that settlers cleared the great majority of the floodplain forest and that it had regrown in the ~50-year period between the mapping and the first aerial photos. Starting with the forest that is present in the 1943 photo and then tracking the erosion and clearing of those stands shows that the bulk of the forest removal in the last 75 years occurred in the early part of that period (Table 31, Figure 22). The Kulshan reach has the smallest amount of forest area greater than 75 years old, with only 10.5 hectares remaining. The Porter reach lost nearly 90 hectares of the forest that was mapped in 1943- a loss of 73% of the forest patches.

Table 31: Area (hectares) of forest mapped in 1943 (Collins and Sheikh 2004) and the change in area of those forest patches through time.

Reach	Year							
	1943	1955	1966	1976	1986	1998	2005	2016
Kulshan	42.2	25.0	20.0	16.5	13.6	11.5	10.5	10.5
Welcome	113.7	83.2	77.6	53.6	53.0	35.1	34.2	33.0
Porter	121.6	89.5	89.5	62.3	43.9	35.9	33.9	32.8
MF Total	*277.5*	*197.7*	*187.3*	*132.4*	*110.5*	*82.5*	*78.6*	*76.3*

Figure 22: Erosion and clearing of patches mapped as forest in the 1943 aerial photos through time.



The percent of the forest that is older than 75 years shows that the Kulshan reach has the lowest percentage of older forest, while the other two reaches are nearly double that amount (Table 32). The stands that are older than 20 years are fairly well distributed among the three reaches, with all three reaches exceeding 50% of the potential vegetated area. Comparing the floodplain forest age and area to the targets for “Good” and “Very Good” conditions, all of the reaches show that they are currently above the target values (Table 33). When the whole lower Middle Fork Geographic area is summed, it exceeds the "Very Good" targets. The Porter project reach currently meets the targets for floodplain forest encroachment.

Table 32: All reaches have retained at least 10% of the vegetated area in forest patches that are older than 75 years and more than 40% of the forested patches mapped in 1998 (Collins and Sheikh 2004).

Reach	1890s GLO Vegetated Area (hectares)	Percent of GLO Vegetated Area Forested in 1943	Percent Older than 75 years (2016)	Percent of GLO Vegetated Area Forested in 1998	Percent Older than 20 years (2016)
Kulshan	86.18	48.9	12.2	68.6	56.6
Welcome	164.68	69.1	20.1	77.7	65.0
Porter	158.00	76.9	20.8	62.0	54.0
MF Total	*408.86*	*67.9*	*18.7*	*69.7*	*59.0*

Table 33: Forest area (hectares) relative to planning targets for the Middle Fork Nooksack. The planning target is a combination of the two stand age classes. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects.

Reach	Targets				2016 Conditions	
	100% of stands meet criteria (10% >75 years old) ("Very Good")	80% of stands meet criteria (10% >75 years old) ("Good")	100% of stands meet criteria (40% >20 years old) ("Very Good")	80% of stands meet criteria (40% >20 years old) ("Good")	Area older than 75 years	Area older than 20 years
Kulshan	8.6	6.9	34.5	27.6	**10.5**	**48.8**
Welcome	16.4	13.1	65.9	52.7	**33.0**	**107.0**
Porter	15.8	12.6	63.2	50.6	**32.8**	**85.3**
MF Total	*40.8*	*32.6*	*163.6*	*130.9*	***76.3***	***241.1***

Stand age and area measurements for the analysis reaches show that all of the reaches met the threshold for "Very Good" conditions for stands older than 75 years and older than 20 years. This analysis included portions of the Erosion Hazard Area that were beyond man-made barriers to channel migration, such as roads and structures, that will likely provide little near-term benefit for instream habitat for the mainstem channel. Isolating the extent to the portion of the floodplain that is currently accessible to migration with an associated riparian buffer might provide a better estimate of the forest conditions that can provide wood to the channel.

Using the interpretation of multiple LiDAR datasets, as was done for the North Fork, would provide a more detailed look at the growth and erosion of the floodplain forest and would likely be a better method for evaluating forest encroachment.

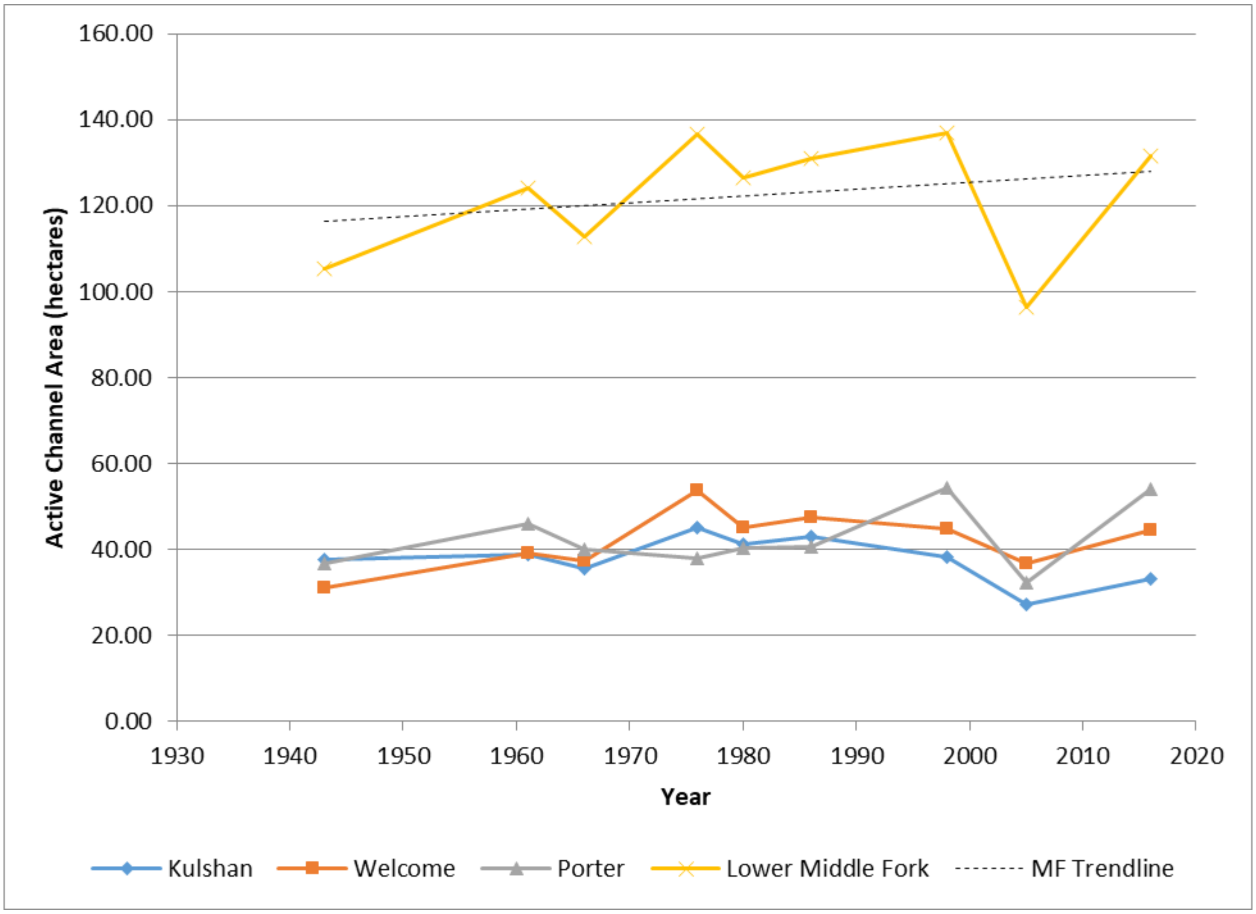
Active Channel Area

The active channel area is the largely unvegetated area of the channel that reflects frequent flow and recent migration. Changes in the active channel width reflect both watershed-scale changes in sediment and flow from weather and climate variation and site-specific conditions such as bank materials and floodplain vegetation characteristics. Increases in channel stability will likely be reflected in a narrowing of the active channel area through time as floodplain vegetation encroaches and increases the bank resistance to erosion. The goal is to reverse the trend of increasing active channel width through time, although short-term fluctuation in width in response to flood events is anticipated (Figure 23).

The target active channel area is based on the historic conditions of the high flow channel area of the river. The high flow and low flow channel areas from the record before 1998 were determined from aerial photo and map-based habitat mapping by Collins and Sheikh (2004). Active channel area for 2005 and 2016 were mapped from aerial photos. The target for a "Good" condition was based on the aerial photo record that was available at the time of their assessment (1933-1998). The area for each reach was measured by photo year and the mean was compared to the conditions at the time of the Salmon Recovery Plan adoption in 2005 and the current conditions (2016 aerial photo year). The "Very Good" target was based on the high flow channel area from the Government Land Office surveys in the 1890s, as interpreted by Collins and Sheikh. Through the photo record, none of the reaches have approached the narrow active channel area that is shown in the early historic mapping. The change from the sinuous, mostly single thread channel that is shown in the GLO maps to the braided channel seen in the early aerial photos led to nearly doubling the active channel width in the Middle Fork.

Both the Kulshan and Welcome reaches have maximum active channel areas in the mid-1970s. The Porter reach was at its widest in 1998 following a major channel avulsion that left a large area of recently disturbed floodplain. A second avulsion in the reach back into the original channel occurred before the 2016 photos, yielding a similarly wide active channel area. All three reaches were at their minimum width in 2005 at the time of the Salmon Recovery Plan adoption. The trend of rapidly increasing channel area at the expense of floodplain forest up until 2005 drove the restoration strategy to focus on forest encroachment and island formation (Hyatt 2007), and the 2016 photo showed the trend of increasing active channel area continued after the anomalously low width measured in 2005.

Figure 23: Active channel (high flow and low flow) area through time for the Lower Middle Fork Nooksack summed and each of the three reaches.



The channel avulsions in the Porter reach have masked the potential influence of the habitat restoration projects on the active channel width. The reach is currently near its historic maximum, but will likely narrow as vegetation encroaches on the recently abandoned channel area. There is a several year lag between project implementation and when vegetation would be mature enough to be considered forested instead of high flow channel. The Porter Reach projects were only recently completed, so it is expected that these projects will continue to narrow in response to the project as the stable floodplain areas begin to revegetate.

The active channel area targets for “Good” conditions were met in all of the reaches of the Lower Middle Fork in 2005, when two of the reaches, Porter and Kulshan, were at their historic minimum area (Table 34). In 2016, all of the reaches are wider than the 2005 conditions, leaving only the Kulshan reach meeting the target for “Good” conditions. As mentioned above, it is expected that the Porter reach will continue to narrow due to the natural recovery of the floodplain, as was seen between 2005 and the first avulsion in the mid-1980s. The restoration projects will likely encourage this process by providing stable patches of floodplain associate with the engineered logjams, similar to the channel response we have seen in the unconfined project reaches in the North Fork. The change in channel type from a sinuous single thread channel to a braided channel in response to floodplain development between the GLO mapping and the first aerial photos may make the “Very Good” target very difficult to achieve given the current level of watershed development.

Table 34: Active channel area (hectares) relative to planning targets for the Middle Fork Nooksack. Green boxes show reaches that meet habitat targets (light green= "Good"; dark green= "Very Good"). Reaches shown in bold include restoration projects.

Reach	Targets		Conditions	
	Historic (GLO) Area ("Very Good")	Mean 1933-1998 ("Good")	2005 Recovery Plan	2016 Conditions
Kulshan	21.9	39.9	**27.1**	**33.2**
Welcome	18.5	42.6	**36.8**	44.5
Porter	17.5	42.3	**32.4**	54.0
MF Total	*57.9*	124.8	***96.3***	*131.7*

NOOKSACK INSTREAM PROJECT EFFECTIVENESS

North Fork Instream Projects

This section evaluates the stated objectives for each of the instream habitat restoration projects that have been constructed in the North Fork Nooksack Watershed (Figure 24, Table 35). Objectives were identified from grant proposals where they are available, or from subsequent monitoring reports. In some cases, the project objectives may have changed from the grant proposal stage, through scoping and design. This can be the result of the evaluation of potential negative impacts, or new opportunities that are discovered during the design and permitting process. The goal is to present the project effectiveness relative to how the project was presented to funders and reviewers. The stated objectives were then generalized into objective groups for comparison across the watershed and linked to the habitat limiting factors from the WRIA 1 Salmonid Recovery Plan (WRIA Salmon Recovery Board 2005). Project location and general description are provided for reference.

Project-scale monitoring generally followed methods presented in the *Quality Assurance Project Plan* (QAPP) *for Implementation and Effectiveness Monitoring of Nooksack River Watershed Habitat Restoration Projects* (Coe 2013). For projects that predate the QAPP, habitat data was collected using a variety of methods, so in some cases analysis is constrained by the scope of the baseline data. Effectiveness monitoring data was collected at both the project reach scale and the individual structure scale. For most projects, baseline information was collected along with as-built conditions and subsequent years. The goal was to visit each project at 1, 2, 5, and 10 years after construction (Coe 2013). Due to the number of projects that are present in the Nooksack Watershed and the limited availability of resources, this schedule was often not met and projects were mapped opportunistically.

For each of the projects below, the project objectives will be presented and evaluated for success. We will provide an opinion on whether the objective was **met**, **partially met**, or **not met**. In some cases, it will be **uncertain**. Data that informs the reach-scale habitat indicators will also be presented by project reach. In many cases the project reaches do not conform to the analysis reaches, so projects will be evaluated within the extent of the project, rather than the extent of the analysis reach. Following the evaluation of the project objectives and the habitat indicators, recommendations will be provided.

Figure 24: North Fork Nooksack project locations.

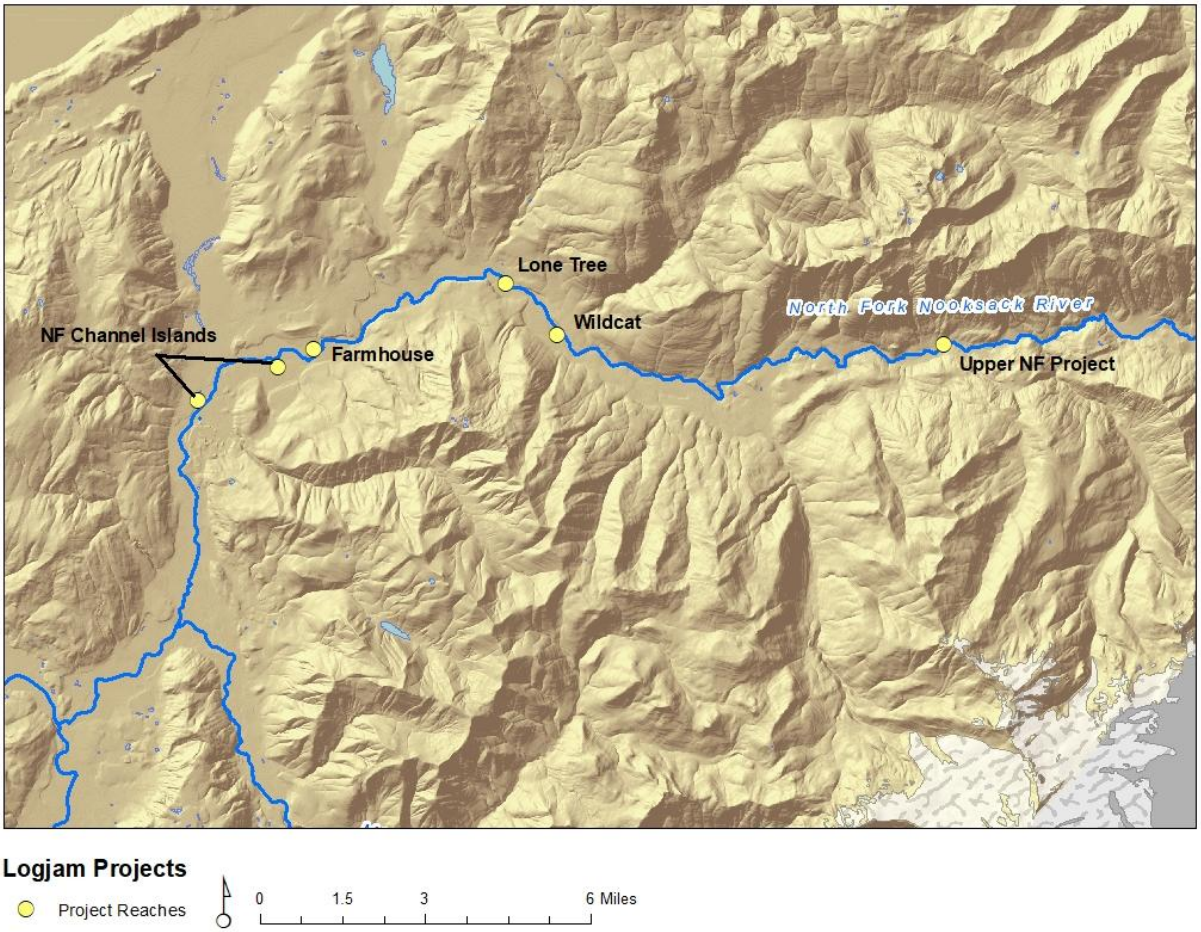


Table 35: North Fork Restoration Projects

Project	Lead Sponsor	Year
Upper North Fork	U.S. Forest Service	2003
Wildcat	Nooksack Tribe	2011-13
Lone Tree	Nooksack Tribe	2008-10
Farmhouse	Nooksack Tribe	2015-20
North Fork Channel Islands	Nooksack Salmon Enhancement Association (NSEA)	2010

Upper North Fork Project

Project Description

The Upper North Fork Project reach is located in the Deadhorse planning reach between RM 61.4 and 64.4 of the North Fork Nooksack River, upstream of the Lower North Fork planning area assessed in the North Fork Habitat Indicators section (Figure 26). The Tier 1 strategies for this reach are similar to other unconfined reaches of the North Fork Nooksack and are given in Table 3.The North Fork Nooksack In-stream Project was developed cooperatively between the U.S. Forest Service (USFS) and the Nooksack Salmon Enhancement Association (NSEA) with the goal of decreasing the loss of native chinook, coho, cutthroat, pink, sockeye, steelhead and char between the egg-to-fry life stages due to main-stem scour and dewatering of side-channels (Table 36). The North Fork In-stream project was completed in three phases during the summers of 2003, 2004 and 2005, and consists of 40 rock-ballasted log structures (9 small and 31 larger structures) through a 3-mile reach (Figure 25).

Project monitoring occurred in 2001 (baseline), 2004, and 2006. A portion of the reach was remapped in 2017 to support development of the Boyd Reach project. In the 2006 mapping and the 2018 mapping, it was evident that many of the structures had moved downstream and formed several larger accumulations in different spots. It appears that other structures were washed downstream out of the project reach. The lack of stability of the structures probably had a strong influence on the ability of the project to meet the habitat objectives, which were related to creating stable patches of forest and their associated side channels.

Figure 25: Ballasted log structures in the Upper North Fork Project reach.

Figure 26: USFS Upper North Fork Project logjam locations at the time of construction.

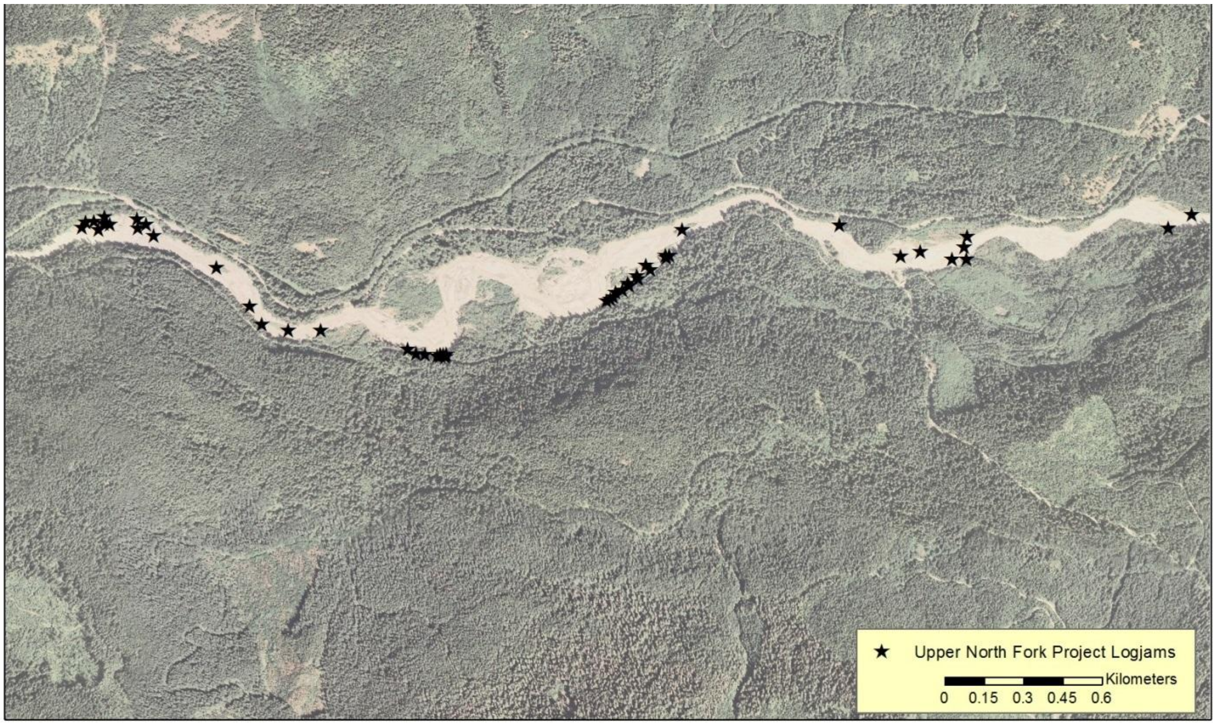


Table 36: Upper North Fork project objectives (cited from LNR 2004 monitoring report).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Decrease egg-to-fry loss of native chinook, coho, cutthroat, pink, sockeye, steelhead, and char due to redd scour.	Redd scour	Channel stability
Decrease frequency of dewatering of side-channels, which are areas containing valuable spawning and rearing habitat.	Secondary channel length	Low habitat diversity

Project Objectives

Redd Scour

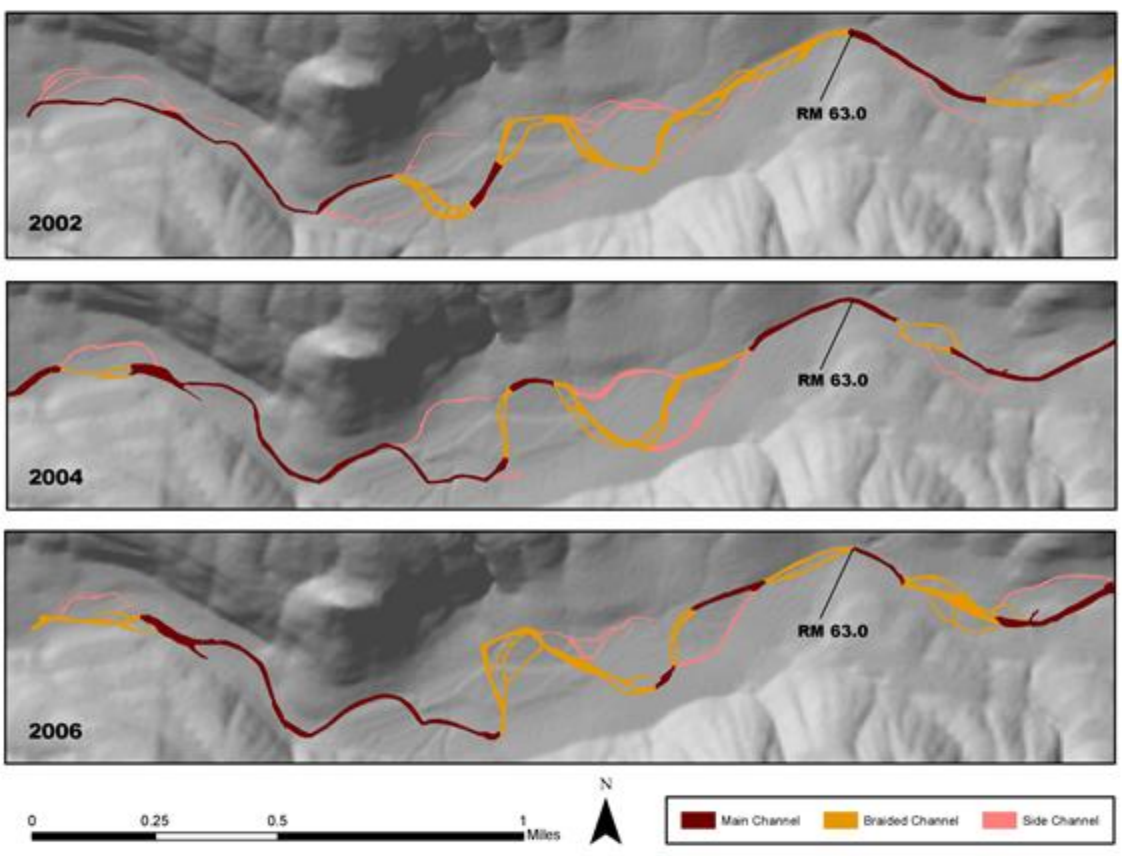
The objective of decreasing egg-to-fry loss due to redd scour was assessed in the 2006 monitoring report (Lummi Natural Resources 2006). At that time, it was uncertain whether the project was meeting the objective due to the influence of a large flood event in 2003. It was concluded that the channel response to the 2003 flood was still likely overwhelming the channel response to the project. The rapid increase in secondary channel types between 2004 and 2006 would likely have resulted in little improvement in egg-to-fry survival because the majority of this length was in braided channels and not stable side channels. Also, much of this secondary channel length occurred in sections of the reach that were not treated and would probably have occurred regardless of the project. Based on scour chain studies, braided channel types were found to have similar redd losses to main channel habitat types, while side-channels saw much better incubation success (Hyatt and Rabang 2003). It does appear from cross-section monitoring that occurred in 2002 and 2006 that the main-channel was deepening and that the bars between the braids were beginning to grow and revegetate. In several instances, this is directly related to the engineered structures located on the bars trapping woody debris and protecting establishing vegetation.

Monitoring that was conducted in 2018 showed a continue decrease in side channel length through the portion of the reach that was mapped. In 2001, there was more than 1960 meters of side channel mapped in the Boyd Project Reach. This declined to approximately 1360 m by 2004 and then steeply declined to 380 m in 2006 (Figure 27). Mapping in 2018 showed 330 m of side channel and that the length has not recovered to the conditions in observed the early 2000s. This new monitoring data would indicate that the recovery from the 2003 flood has not led to an increase in side channel length.

Secondary Channel Length

As mentioned above, the wetted side channel length has decreased though the project reach from pre-project conditions. Monitoring of the change in wetted side-channel area through the year was not done to determine if wetted areas were becoming seasonally dewatered with less frequency. Looking at successive habitat maps, it appears that there has been a decrease through time of secondary channels (braids and side channels) (Figure 27). This decrease also directly affects the amount of lower velocity channel edge habitat available for rearing during the winter low flow period when the mapping was done.

Figure 27: Channel types (main, braided and side-channels) in the Upper North Fork Project reach 2001-2006 (LNR 2006).



Pool Formation

Pool-formation and woody cover area are habitat indicators for all of the Nooksack geographic areas. While not a primary project objective of the project, pool-formation and wood cover have been monitored through time in the project reach. The entire project reach was mapped in 2001, 2004 and 2006. In 2018, a two-kilometer reach was remapped to provide the baseline conditions for the Boyd Project, which is still in the design stage. This reach is the least confined section of the project reach has seen the greatest channel change through time. Pool location, pool-forming feature and wood cover were mapped for each of the four years. While the count and pool-forming features changed through time, the ballasted structures were not noted as forming a primary pool in any of the surveys. In 2004, three pools in secondary channels (braids or side channels) were associated with ballasted structures. These three pools contained ~190 m^2 of wood cover. In 2006, one secondary pool in a main channel riffle was associated with a structure. This pool contained ~15 m^2 of wood cover. None of these pools occurred within the Boyd Project extent that was remapped in 2018, when no pools were associated with the wood structures. Where pools were formed by wood, it tended to be either large trees that were recently recruited to the channel, or accumulations of natural wood.

Conclusions and Recommendations

The Upper North Fork project does not appear to have met either of the two stated objectives (Table 37). The project objectives (redd scour and changes in seasonal inundation of side channels) were not directly monitored as a part of the project. It would be difficult to determine project success because there is a lack of pre-project monitoring data. The best available metric was the length of lower scour habitats (side-channels) during the low flow period. The project did not appear to lead to an increase in side channel habitat during the low flow period. This is likely tied to the lack of stability of the structures, which is important when the goal is increasing channel stability, reflected in the length and persistence of side channels. The channel did appear to respond the structures in other ways that were not directly tied to the project objectives. The 2006 monitoring report noted several changes in the reach, although it appeared that many of the changes were related to the flood in 2003 and it was difficult to attribute many of the changes to the project (LNR 2006):

- Side channel length had decreased continuously between 2002 and 2006, losing over half of the side channel length in the reach.
- Pool habitat in braided channel areas increased significantly between 2002 and 2004, but dropped back down by 2006.
- There were considerable changes in dominant pool-forming features during the monitoring period, from bedrock (2002) to wood (2004) in main channel reaches, and back to bedrock (2006).
- While pool area has remained relatively constant, the number of pools has increased in the reach from 6 to 9 in 2004 and 14 in 2006, yielding smaller pool sizes and closer pool spacing.
- Residual depth has gotten shallower steadily between 2002 (5.2 feet) and 2006 (3.4 feet) and rock-formed pools continue to be the deepest pools in the reach.
- Wood was a common dominant cover type in habitat units in 2002 (31%) and 2004 (36%), but was reduced to only 10% of units in 2006.

Table 37: Upper North Fork Project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
Decrease egg-to-fry loss of native chinook, coho, cutthroat, pink, sockeye, steelhead, and char due to redd scour.	Redd scour	**Uncertain**- no direct measure of redd scour, but a decrease in targeted lower scour habitats.
Decrease frequency of dewatering of side-channels, which are areas containing valuable spawning and rearing habitat.	Secondary channel length	**Uncertain**- no seasonal monitoring of side channel dewatering, but a decrease in low flow side channel length.

Because the Deadhorse Reach is still considered a Tier 1 project area, the Boyd project is being designed to better meet the objectives that were not met by the Upper North Fork Project. This design will include engineered logjams that have been designed to meet the 100-year flow conditions and focus more directly on the unconfined portion of the reach that has the highest potential to form side channels. The project also includes relocating the forest road on the south side of the channel that currently limits wood recruitment to the channel- better addressing the longer-term process of large wood delivery to the channel.

Wildcat Project

Project Description

The North Fork Nooksack Wildcat Reach (RM 53-55) was identified as a priority for habitat restoration in *Lower North Fork Nooksack River: Reach Assessment and Restoration Recommendations* (Hyatt 2007). The primary limiting factor identified was a lack of channel stability during the winter incubation and early rearing period. The lack of stability was attributed to changes in wood recruitment to the channel and more frequent large floods. These landscape-scale changes due to timber harvest and floodplain encroachment have resulted in a reduction in the number of large trees that can be recruited to the channel during floods, and therefore fewer logjams to form and stabilize forested channel islands, more transient river bars, and smaller suitable areas for vegetation to become established (Hyatt 2007).

The Wildcat Project was completed in 3 phases in 2011, 2012 and 2013. The project consists of 83 individual woody structures, although 47 of these structures were incorporated into 19 groups to form floodplain roughness and protect emerging floodplain forest. The project is located between river mile 53.8 and 54.8 on the North Fork Nooksack River. The general goal of the project was to increase side channel connectivity by protecting emerging forest islands in the active channel and encourage floodplain forest encroachment on the active channel (Table 38). The project was monitored in 2010, 2013, 2015 and 2018, focusing on side channel length, habitat diversity and persistence through the incubation period.

Table 38: Wildcat project objectives (cited from NNR SRFB grant proposals for the three phases).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Encourage channel stability in active channel	Redd scour	Channel stability
Roughen the channel and encourage backwatering and flow toward side channels	Secondary channel length	Low habitat diversity
Protect the maturing forested island separating Wildcat side channel from the North Fork	Riparian habitat	Channel stability
Increase side channel habitat diversity	Habitat unit diversity	Low habitat diversity
Increase low-flow connectivity of the side channels- Wildcat, Warnick, Canyon and McDonald Creek	Secondary channel length	Low habitat diversity

In the 2005 habitat assessment, the mainstem in the Wildcat Reach was found to be a relatively steep, homogenous channel of riffles and braids, with few stable side channels, little LWD, few well-established forested islands, and generally little habitat heterogeneity or structure (Hyatt 2007). Based on historic survey records, little chinook spawning occurs in the mainstem along this reach, despite extensive spawning both upstream and downstream (Hyatt 2007). The North Fork through the Wildcat Reach is characterized by active channel migration with the mainstem channels shifting location multiple times per year across the active channel area. The habitat mapping in the reach reflects the rapid channel migration and lack of stable hard points, such as logjams, across the active channel area that could create local scour pools. The mainstem habitat type area in the reach, mapped in 2005, are dominated by fast water habitat with riffles (48%), glides (21%) and braided riffles (17%) making up the bulk of the habitat types (Hyatt 2007). Off-channel habitat area (11%), mostly floodplain habitat and portions of McDonald Creek, comprises the remaining habitat (Figure 28). There were no forested islands and no side channels mapped in the reach in 2005.

Habitat mapping in the reach also showed a considerable difference in the habitat diversity between the mainstem channel and the secondary channels. Within the 2.4-kilometer Wildcat Reach, there were 13 mainstem and braided habitat units, compared to 122 secondary channel units. This is also reflected in the pool counts by channel type: 1 mainstem pool and 40 secondary pool units. The lack of main channel pools was typical of the North Fork Nooksack River, which averaged 1.1 pools per mile (0.7 pools per km) over the 20.9 (33.5 km) miles surveyed for the North Fork habitat assessment (Figure 29). The increase in habitat diversity associated with the increase in secondary channel types appears critical to addressing the limiting factors identified for North Fork early Chinook.

The low pool counts in the mainstem likely reflect the reduced availability through time of pool-forming large wood. The only mainstem pool in the reach is a backwater formed by local scour along a resistant stream bank. In 2004, the Lummi Nation found that the reach contained a limited supply of large wood pieces (Lummi Natural Resources 2007a). Surveyors found only 4.8 key-sized (>9m^3) pieces of LWD per mile (3 pieces per km) of channel. This is in spite of a local source of large wood from the relatively large stands of mature conifer occupying the left bank floodplain. More recent surveys found the count of pieces increased to 7.4 pieces per km (Maudlin 2011), although this is still likely much less than historic conditions described for the Nooksack watershed (Collins and Sheikh 2004).

Figure 28: Wildcat Reach main-stem habitat mapping (NNR 2005). Floodplain habitat mapping from 2010 to show the difference in habitat diversity.

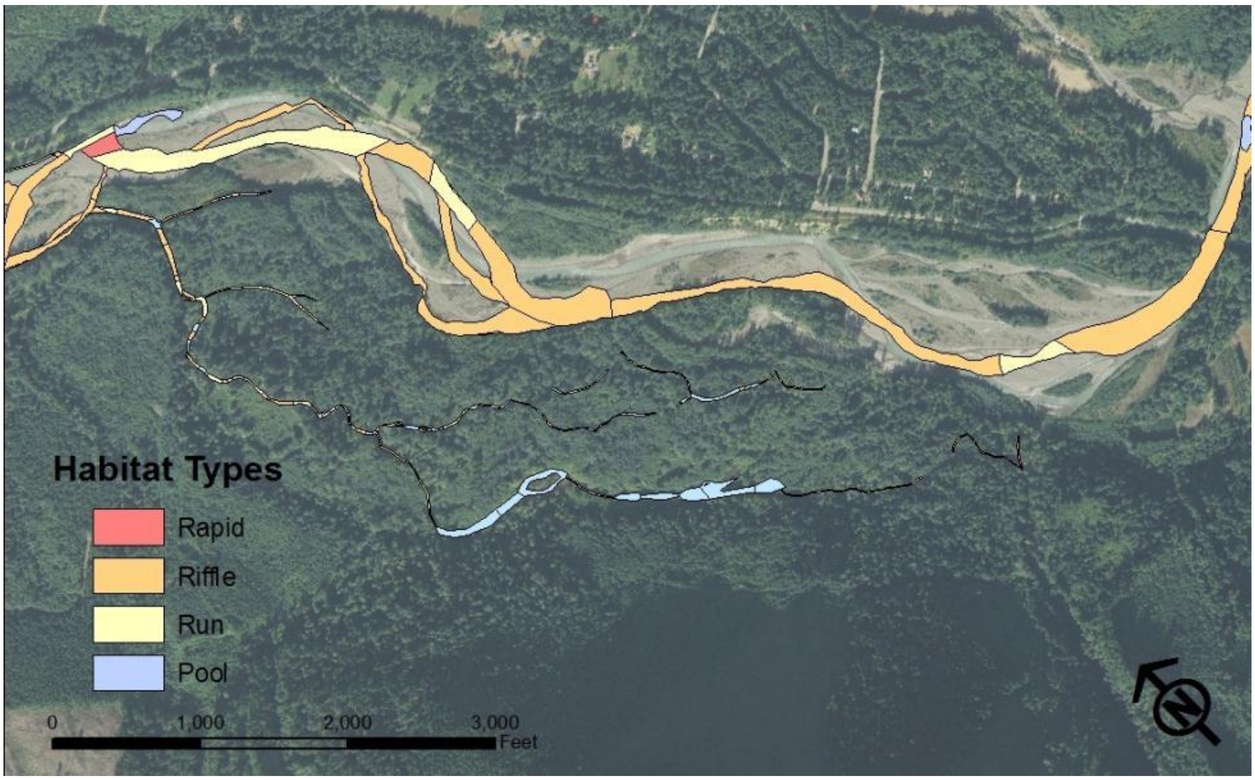
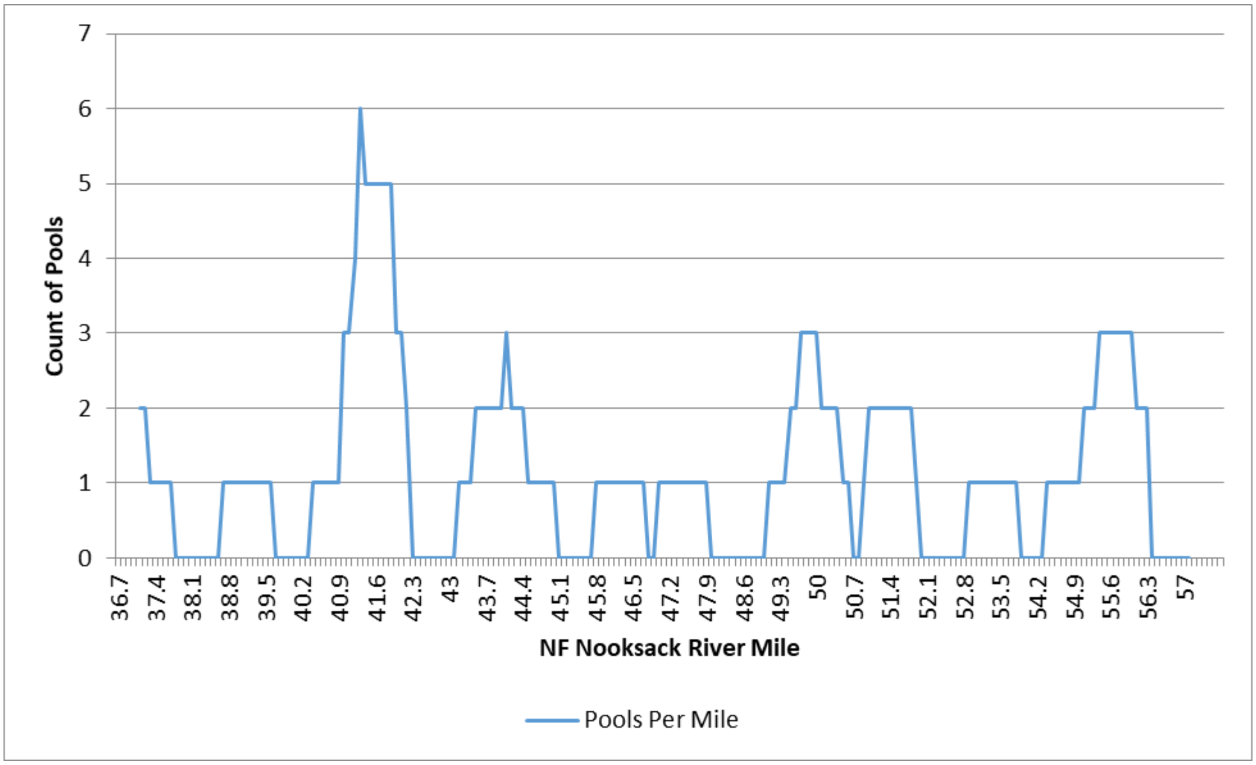


Figure 29: Rolling pools per mile in the North Fork Nooksack River (Maudlin 2011).



Project Objectives

Redd Scour

The redd scour objective for the Wildcat Project focused on increasing the stability of the active channel area. The active channel (wetted channel and gravel bars) in the Wildcat Reach has ranged between approximately 100 and 190 meters in average width through the historic period (Table 39). The minimum active channel width occurred in 1976 and then nearly doubled by 1994, although there was little loss of forested islands during this period. This follows the greater trend of increasing active channel width at the expense of adjacent floodplain forest that was seen throughout the unconfined reaches of the lower North Fork. Since 1994, the channel has been consistently wider than its historic average. This corresponds to large debris floods in 1989 and 1990 on Canyon Creek, and may be a response to increased sediment deposition downstream of Warnick Bridge (GeoEngineers 2011). While there was no target width presented in the grant documents, the feasibility and alternatives analysis for the project set a target of reducing the mean active channel width to the 1933-1986 mean (135 m) (Maudlin 2011).

Following the project construction, the active channel area has decreased slightly from the 2010 average width, but has not reached the project target. There is a lag expected in the response of the active channel width to the project because it takes some time for vegetation to colonize the bars and grow to the point where it is identified as forested on the aerial photos. As the vegetation continues to encroach on the areas stabilized by the engineered logjams, it is expected that the active channel width will narrow substantially.

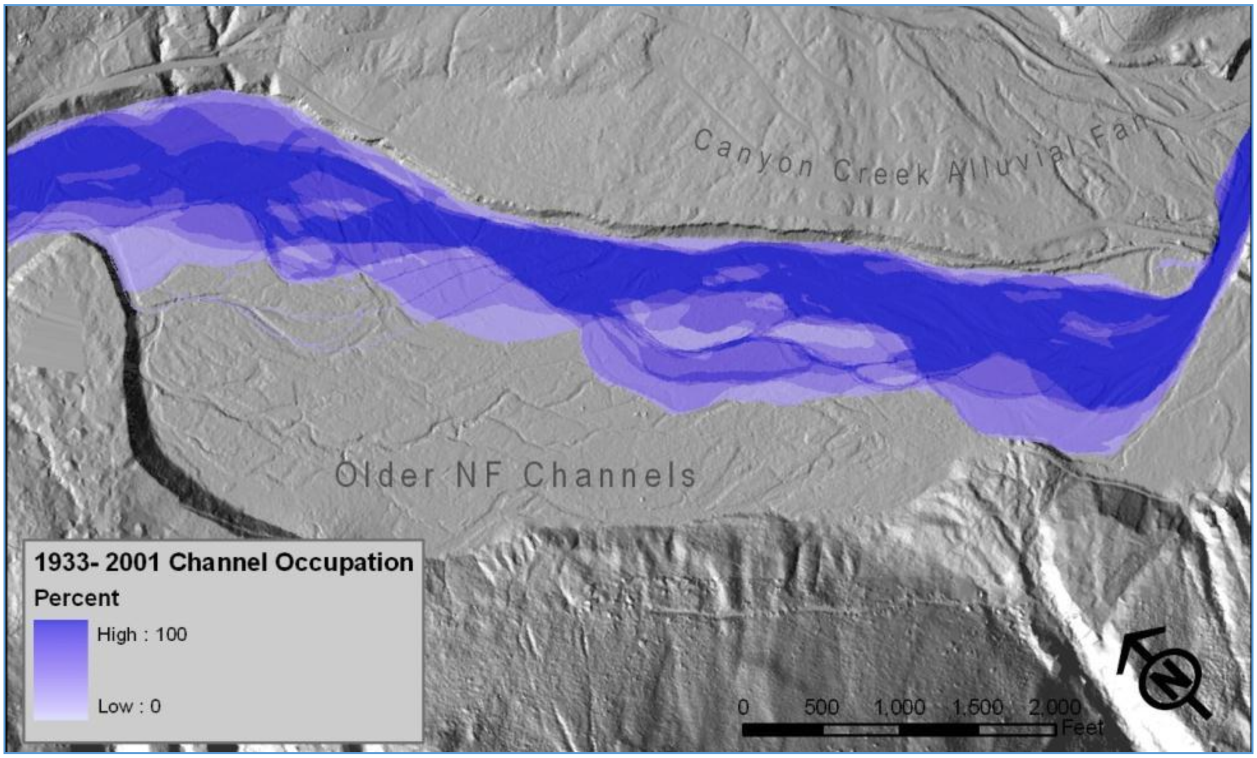
Table 39: Active channel width changes through time, compared to the target of the 1933-1986 mean (135 m).

Photo Year	Active Channel	
	Average Width (m)	Difference from 135m Target Width (m)
1938	152	+17
1955	146	+11
1967	140	+5
1976	104	-31
1986	125	-10
1994	192	+57
1998	146	+11
2005	172	+37
2010	174	+39
2016	169	+34

Riparian Habitat

The wide active channel area likely reflects periods of rapid channel migration in the reach, often associated with floods and sediment deposition (GeoEngineers 2011). The annual channel migration rate for the reach averaged nearly 6 meters per year from 1933-2005, although this has occurred in a relatively narrow portion of the floodplain (Hyatt 2007). Despite the evidence of North Fork-sized channel scars across the floodplain to the south of the channel, this area has not been occupied by the active channel in the last 80 years (Figure 30). The channel occupation figure further indicates that there was no floodplain within the historic migration area that was not occupied by the channel over the last 70 years. This means that any forest that has established within the active channel area has been eroded.

Figure 30: Channel occupancy in the Wildcat Reach (Collins 2004).



The area of forested islands (patches of forest within the unvegetated channel area) has changed considerably in the reach through the aerial photo record. The earliest mapping of the reach occurred as a part of the General Land Office Surveys in 1894. This map showed the channel split by a large island that was stable enough for the McDonald homestead and a county road, implying that a substantial portion of the North Fork was flowing through the older floodplain channels at that time (Figure 31). Beginning with the first aerial photos in 1938, the large island was incorporated into the adjacent floodplain and the reach had no islands in active channel area (Collins and Sheikh 2004). Over the next 40 years, the area of forested islands steadily increased to its maximum value of 10.5 hectares in 1976 (Table 40). Island area reached a second peak in 1994 of 8.8 hectares before dropping to zero only four years later, reflecting a drastic decrease in forested islands throughout the lower North Fork Nooksack at the time of the adoption of the salmon recovery plan (WRIA 1 Salmon Recovery Board 2005). The change in side channel length (channel separated from the main channel by a forested island) through time did not show a strong linear relationship to island area in the reach through time. This implies that most of the forested island area that was identified in the active channel area was marginal to the main channel and served only to split high flow, rather than low flow. In spite of the poor relationship between island areas and side channel length, there are no years with forested islands that do not also have side channels associated with them.

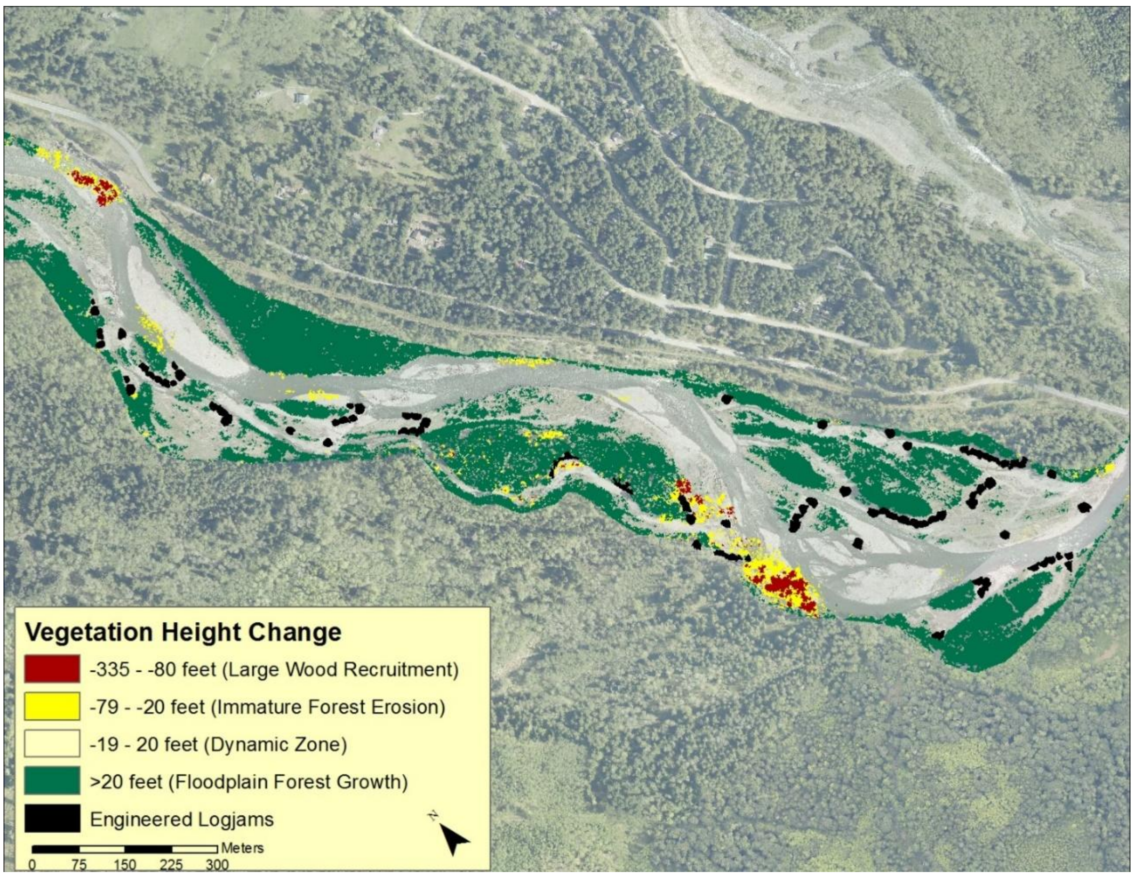
Figure 31: General Land Office survey map of the Wildcat Project Reach (1894). Note large islands in the Wildcat Slough area.

Table 40: Changes in forested island area and count through time (Collins and Sheikh 2004).

Year	Total Island Area (hectares)	Count	Maximum Single Island Area (hectares)
1938	0	0	0
1955	4.9	8	1.4
1966	6.9	7	2.1
1976	10.5	8	3.3
1986	4.1	5	1.8
1994	8.8	7	2.8
1998	0	0	0
2005	0	0	0
2010	3.6	5	2.6
2016	3.5	6	2.6

The mean area between 1955 and 1994 (7.1 hectares) was selected as the target for restoration in the Wildcat Reach feasibility and alternatives analysis, with the additional goal of increasing the persistence to 50 years to allow for mature conifer stands to establish (Maudlin 2011). Mapping in subsequent years showed an increase in forested island area from 0 to 3.6 hectares in 2010. This area mostly occurred in one island area that became a major focus of the Wildcat Project. This island persisted through 2006 and also accounted for the majority of the island area in that photo year. While the island area has increased following the project completion, the reach is still well below the target established for the project. Similar to the active channel area, there is a lag period while vegetation establishes and grows on the bars. When looking at the change in vegetation height in the reach, it is evident that the engineered logjams are associated with young forest patches in the reach that should continue to mature if they are protected from migration (Figure 32). It is anticipated that continued growth of the forested islands will occur in response to the project.

Figure 32: Vegetation height change in the Wildcat Reach between 2005 and 2017, showing the association of young forest islands with the engineered logjams.



Secondary Channel Length

The project had two objectives relate to increased secondary channel length: increase the low-flow connectivity of side channel s and increase roughness to encourage backwatering and flow toward the side channel areas. The feasibility report provided a target value for side channel length of 30% of the main channel length based on the historic conditions in the reach (Maudlin 2011). This is consistent with the “Good” target selected for the North Fork habitat indicators.

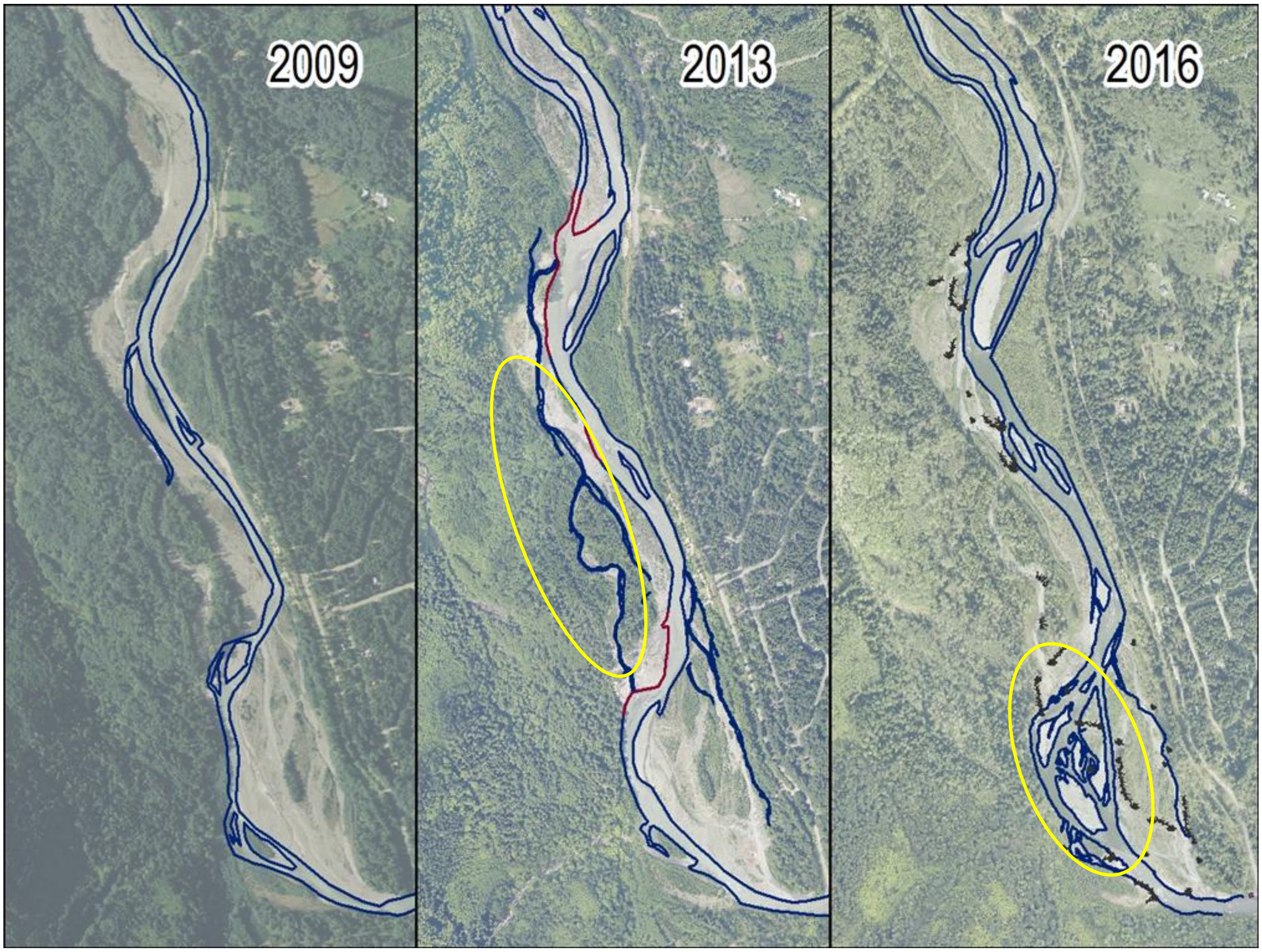
The length of side channels has changed in the reach through the aerial photo record, ranging from zero to nearly 1,400 m of length (Table 41). This is a reduction from the early historic conditions shown in the Government Land Office surveys. In the 1890s, the main channel was ~2,800 m long and the reach had over 2,700 m of side channel length, for a ratio of side channel to main channel length of 0.97, within the range of that found among relatively undisturbed island-braided reaches throughout western Washington (Beechie et al. 2006). By the earliest photos the side channel length had dropped to zero as the large forest island mapped in the 1890s was incorporated into the adjacent floodplain (Collins and Sheikh 2004). The side channel length reached the maximum value in the 1966 photo and then fell back to zero by 1998. At the time of the salmon recovery plan in 2005 the side channel length, along with the forest island area, was zero, which drove the general habitat objectives for the Wildcat Reach. At the time of the project, the reach had ~250 m of side channel length.

Following the construction of the project, side channel length and seasonal persistence were monitored in the Wildcat Reach. Successive surveys of the floodplain channels showed that side channel length increased from 0m in 2005 to 250 m in 2009 to approximately 1,200 m following the project construction in 2013 (Figure 33). This increase occurred in one of the "target" side channels for the first phase of the project. An additional 1,175 m of side channel originated in the reach and flowed downstream in 2013. Subsequent mapping in 2016 showed that the target side channel area was no longer connected, but that side channels had formed upstream as the channel split around engineered logjams. A survey of the side channel length at the onset of chinook spawning in July of 2018 showed a continued increase in side channel length in the upstream portion of the project reach from ~230 m in 2016 to 900 m. Although the upstream connection of this area did not persist through the summer, it indicated that this area is becoming better connected through time. The downstream portion of the project reach had an additional 1,300 m of perennial side channel in 2018.

Table 41: Change in side channel length through time (1938-1998 from Collins and Sheikh 2004).

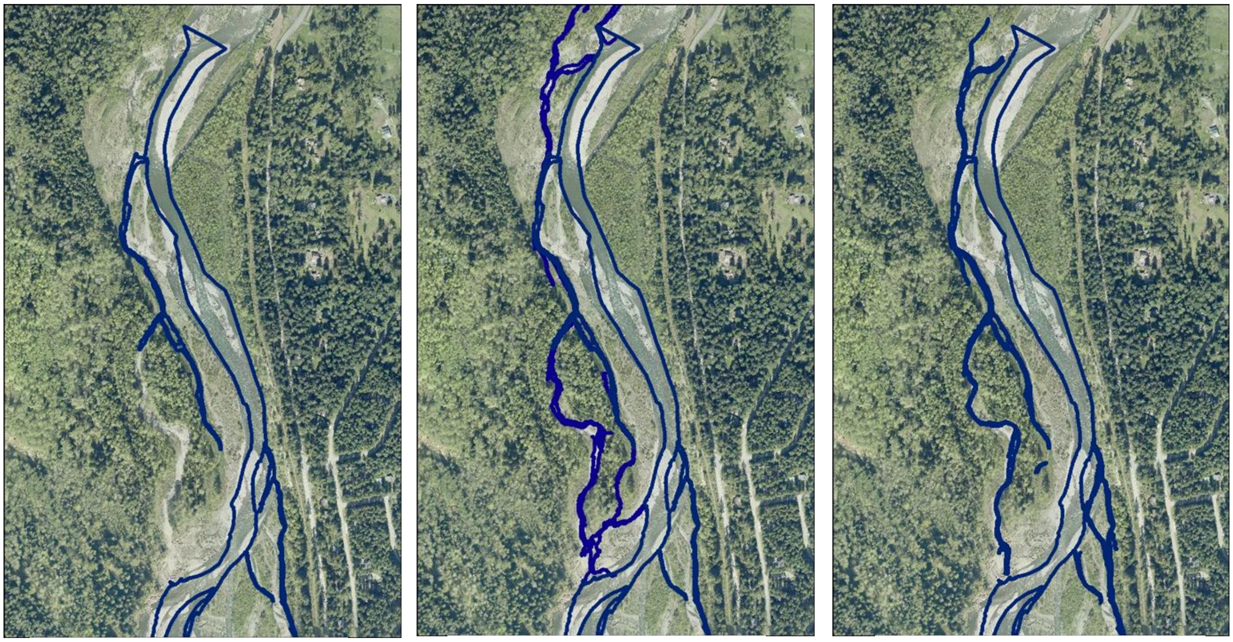
Year	Main channel Length (m)	Side Channel Length (m)	Percent of Main Channel Length
1938	2,579	0	0%
1955	2,534	1,271	49%
1966	2,588	1,384	53%
1976	2,646	343	13%
1986	2,557	416	16%
1994	2,804	616	22%
1998	2,954	0	0%
2005	2,591	0	0%
2009	2,834	250	9%
2013	2,790	1,198	43%
2016	2,768	228	8%
2018	2,684	1,300	48%

Figure 33: Side channel length through time in the Wildcat Reach.



In addition to monitoring the length of side channel through time, the persistence of the side channel was monitored through the spawning and incubation season following the construction of the project. During the 2012-2013 chinook spawning and incubation season the wetted channel area was mapped at the on-set of spawning and during the subsequent winter low flow season to assess the potential for dewatering redds during the incubation season. All of the available spawning area that was present in August of 2012 was still connected and wetted during the winter low flow period (Figure 34). The side channel area remained perennially connected until the summer of 2014, when upstream channel migration away from the inlet of the side channel led to it becoming a groundwater fed slough channel.

Figure 34: Wetted channel area during the 2012-2013 incubation season. This mapping occurred between 200 and 250cfs, which was well below the average flow of 600 cfs at the on-set of spawning in the North Fork.



August 2012 ~250cfs January 2013 ~200cfs February 2013 ~200 cfs

The second goal of increasing roughness and deflecting flow toward the side channel areas reflects the hydraulic modeling for the project and cannot be directly monitored. To address this objective, monitoring focused on the encroachment of vegetation on gravel bars and the potential for structures to deflect the high flow channel.

The reach has seen both an increase in vegetation on gravel bars following construction, which increases the floodplain roughness, and an increase in the area and stability of logjams in the active channel that increases the flow impedance and is likely encouraging the backwatering and flow toward the side channels (Figure 32). In September 2010 existing accumulations of wood were mapped in the reach to assess their distribution and habitat functions. Twenty-nine logjams were identified and their habitat functions described, although many (13) of these were man-made structures similar to the Upper North Fork Project that were cabled to rock ballast and designed to protect the Mt. Baker Highway from erosion. In 2010, five of the 29 logjams were in a position to deflect the flow of the channel. All of these were natural logjams. In 2018 monitoring, 27 of the 55 logjams were in a position to deflect the flow of the high flow of the channel.

Habitat Unit Diversity and Pool Formation

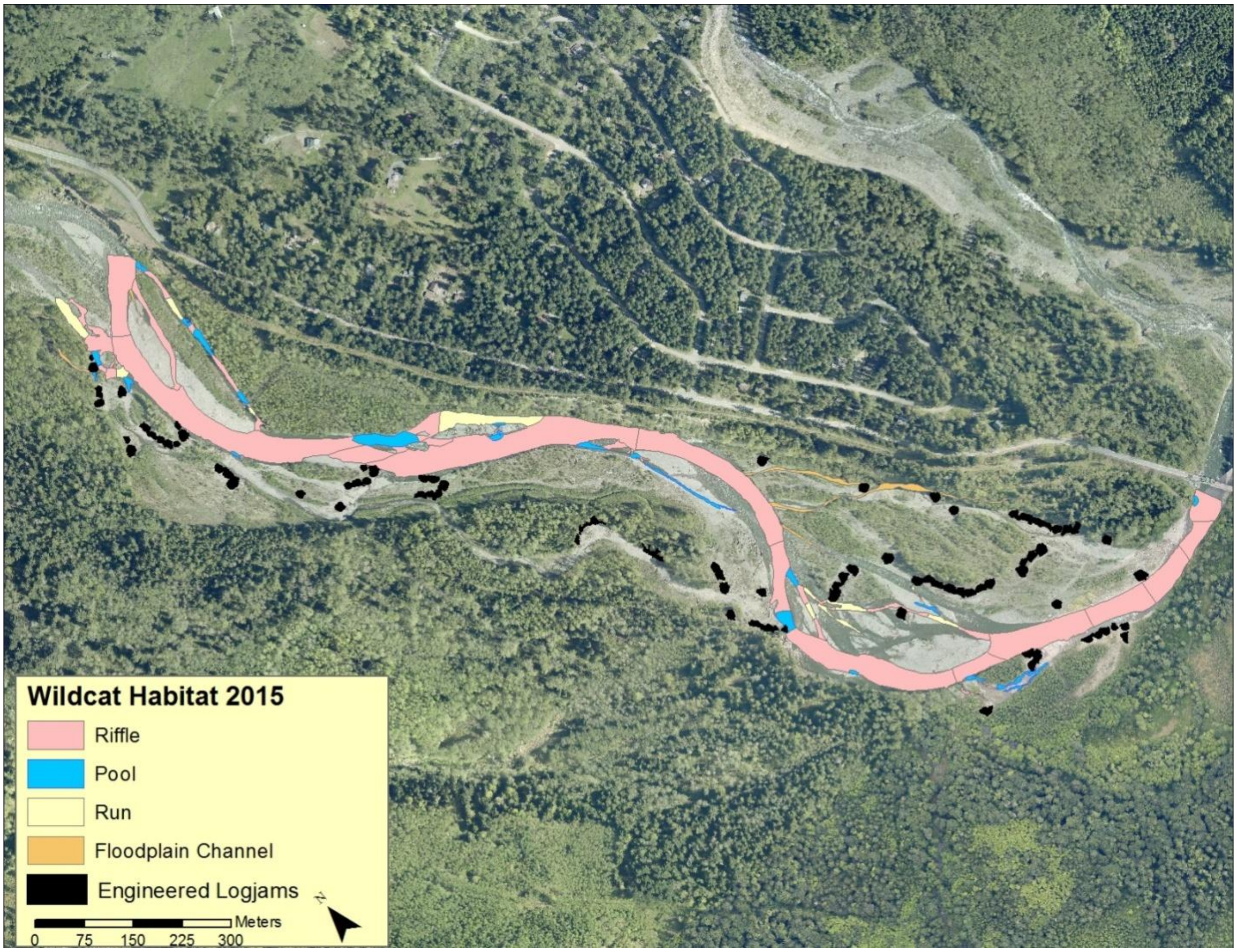
The habitat diversity objective focused on increasing the length of side channels to improve diversity because these features were found to have a much higher number of habitat units per mile than the main channel. The objective focused on three main areas for side channel connection: Wildcat, Warnick and McDonald Creek. The feasibility report also identified main channel pools as an important component of habitat diversity (Maudlin 2011). The target for pools was an increase to 11 primary and backwater pools in the project reach based on the maximum value of 6 pools per mile found (3.8 pools per km) in the 2005 mapping for the lower North Fork. The target also included a dominance of complex wood cover in the pools.

Following construction there has been an increase in habitat diversity through the reach. The project yielded an increase in side channel length compared to the baseline monitoring in 2005. This increase was the greatest in 2013 when a long side channel area (Wildcat side channel) that was the target of the first phase of the project was connected. Mapping in 2016 showed only a slight increase in side channel length from the 2005 conditions because of channel migration and the disconnection of the Wildcat side channel. Mapping in 2018 showed again a large increase in side channel length with the connection of the McDonald Creek side channel in the Phase 2 reach of the project (the downstream-most structures). The project met the habitat diversity target presented in the feasibility report in both 2013 and 2018 when the target side channel areas were perennially connected to the main channel. The design explicitly considered channel migration and the potential for connection and disconnection of side channels in different locations through time.

Main channel habitat diversity has only slightly increased in the 2-kilometer project reach since the 2005 baseline habitat mapping. In 2005, the reach was dominated by riffles, broken only by two runs that accounted for ~300 meters of length. Two braids were also mapped in reach that totaled ~830 meters of secondary channel length. That survey focused on habitat units that represented the majority of the channel width (primary) and found no qualifying pools. The 2015 survey provided a more detailed assessment of habitat units, with the goal of looking at how the engineered structures were affecting the channel. Mapping in 2015 found that the main channel was still dominated by riffles (Figure 35), but that there was an increase in both braided channel and side channel length. Two pools were mapped that likely would have qualified as pools in the 2005 mapping based on their size. Braided secondary channel length increased from 830 m to 920 m and there was approximately 310 m of side channel present in the reach.

Looking more closely at all of the pools mapped in the 2015 survey, it is evident that the engineered structures have formed pools in the reach, but that these tend to be secondary pools located in braided channels, sloughs and side channels. Of the 23 pools mapped in 2015, 7 were associated with engineered logjams in the reach and all three of the pools that were greater than 1.5 m deep were formed by engineered logjams. In 2018, a “structure-scale” survey of each of the Wildcat Project logjams found that 15 of the structures had formed a pool (1 primary pool, 9 secondary pools, and 5 isolated pools that were not connected the low flow channel). The 10 structures that were forming a pool in the low flow channel created 167 m^2 of pool area in the channel. Nineteen of the structures were providing a total of 265 m^2 of wood cover in the channel.

Figure 35: Habitat mapping in the Wildcat Reach (NNR 2015 data, photo from 2016).



Conclusions and Recommendations

The Wildcat Project has generally met the objectives that were presented in the SRFB grant application (Table 42). While the habitat has been improving in the reach, the specific targets for the objectives that were presented in the feasibility report that were developed for evaluating the alternatives have often not been met. Objectives that relate to active channel width and vegetation growth have been affected by the lag between when the project was constructed and the time required to grow trees large enough to be considered stable forest. It is expected that these targets will likely be met within ten years as the forest patches continue to mature. Objectives related to stable side channel length are more uncertain. Channel migration and changes in the bed elevation affect the connectivity of secondary channels, and this reach continues to be relatively dynamic. It is encouraging that the target side channel areas have been periodically connected and that the loss of side channel length in one location has generally been associated with an increase in a different target area. This focus on a variety of side channel locations, rather than just one location, has increased the likelihood of meeting the project objectives. Main channel habitat diversity targets for pools and cover may be more difficult to meet because primary pools are relatively rare in this reach of the North Fork, although recent surveys have indicated that the logjams have been effective at forming pools and providing cover.

Table 42: Wildcat Project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
Encourage channel stability in active channel	Redd scour	**Partially met**- the reach has seen a decrease in the active channel width, but has not met the target provided in the feasibility report.
Roughen the channel and encourage backwatering and flow toward side channels	Secondary channel length	**Uncertain**- flow was not directly measured, but logjams have increased flow deflection through the reach and vegetation has increased floodplain roughness.
Protect the maturing forested island separating Wildcat side channel from the North Fork	Riparian habitat	**Partially met**- the reach has seen an increase in the forest area, but has not met the target provided in the feasibility report.
Increase side channel habitat diversity	Habitat unit diversity	**Partially met-** the reach saw an increase in side channel length and an increase in pool-formation and cover due to the logjams. The feasibility target for primary pools has not been met and the side channel length target was met in two of the three monitoring periods.
Increase low-flow connectivity of the side channels- Wildcat, Warnick, Canyon and McDonald Creek	Secondary channel length	**Partially met**- side channel length has increased following construction, but has varied through time. The target was met in both 2013 and 2018, but not in the 2016 mapping.

Lone Tree Project

Project Description

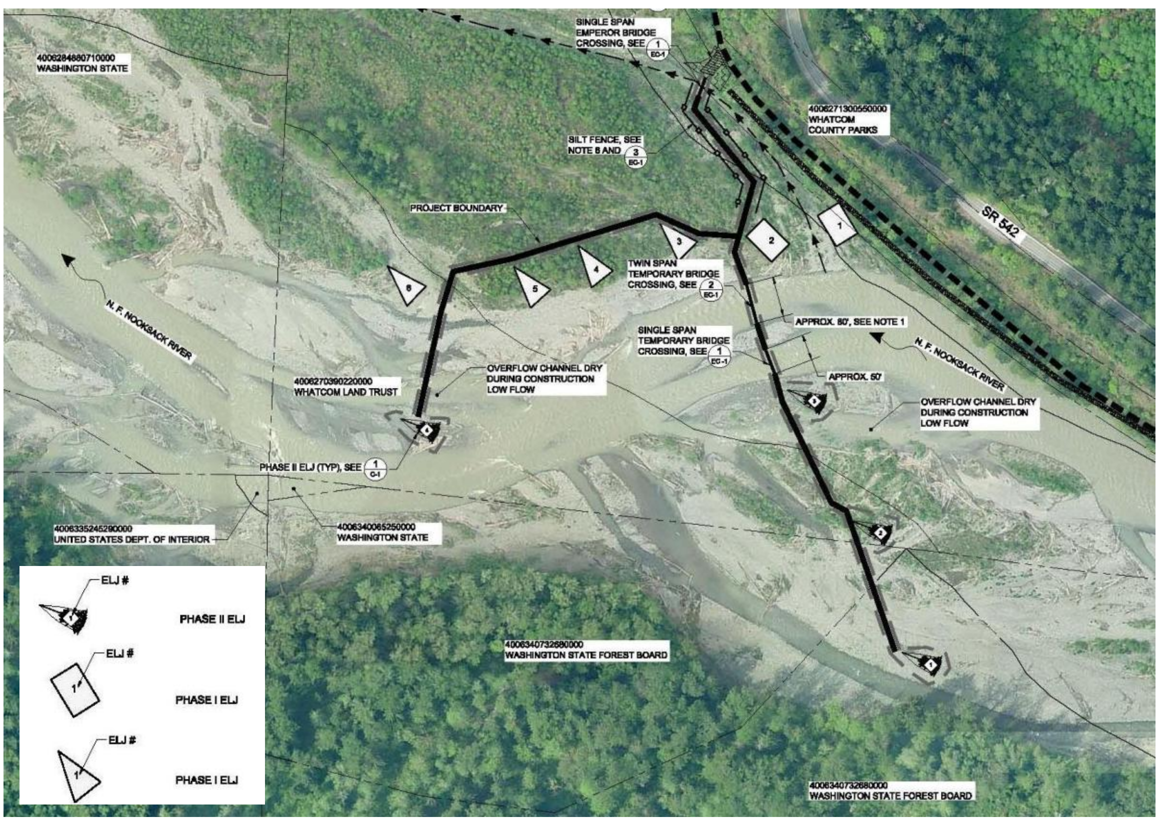
The Lone Tree Project was completed in two phases in the summers of 2008 and 2009 between RM 53.2 and 52.7 of the North Fork Nooksack River. Hyatt (2007) assessed channel changes in the North Fork Nooksack and concluded that past land use activities have resulted in a loss of large trees that can be recruited to the channel and create more stable logjams. The loss of wood is coupled with an increase in flood frequency that speeds wood depletion from the channel. The loss of these stable logjams that would have provided suitable areas for vegetation to become established has led to a loss in forested islands and the associated side channel habitat. The objectives of the Lone Tree Project were to (1) encourage perennial side-channel flow; and (2) protect developing floodplain islands in the project reach with the goal of improving egg-to-fry survival of spring chinook in the reach (Table 43).

Table 43: Lone Tree project objectives (cited from NNR 2010 monitoring report).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Protect developing floodplain islands	Riparian habitat	Channel stability
Encourage perennial side-channel flow	Secondary channel length	Low habitat diversity

To meet this goal, six engineered logjams were constructed along the upstream side of a vegetated bar in 2008 (Figure 36). The structures were spaced to allow smaller channel development between the structures, but to discourage migration of the mainstem across the bar. An existing side-channel located between Logjam #1 and #2 was expected to carry more flow and become a perennial low flow channel. In 2009, a second phase including four more structures was added to help encourage more flood flow toward the target side-channel and create another opportunity to split flow and create a stable side channel. This phase also included three small structures in an active side-channel to form pools and increase habitat diversity in the target side channel. To evaluate the success, the project was monitored in 2009, 2010, 2012, 2014 and 2018.

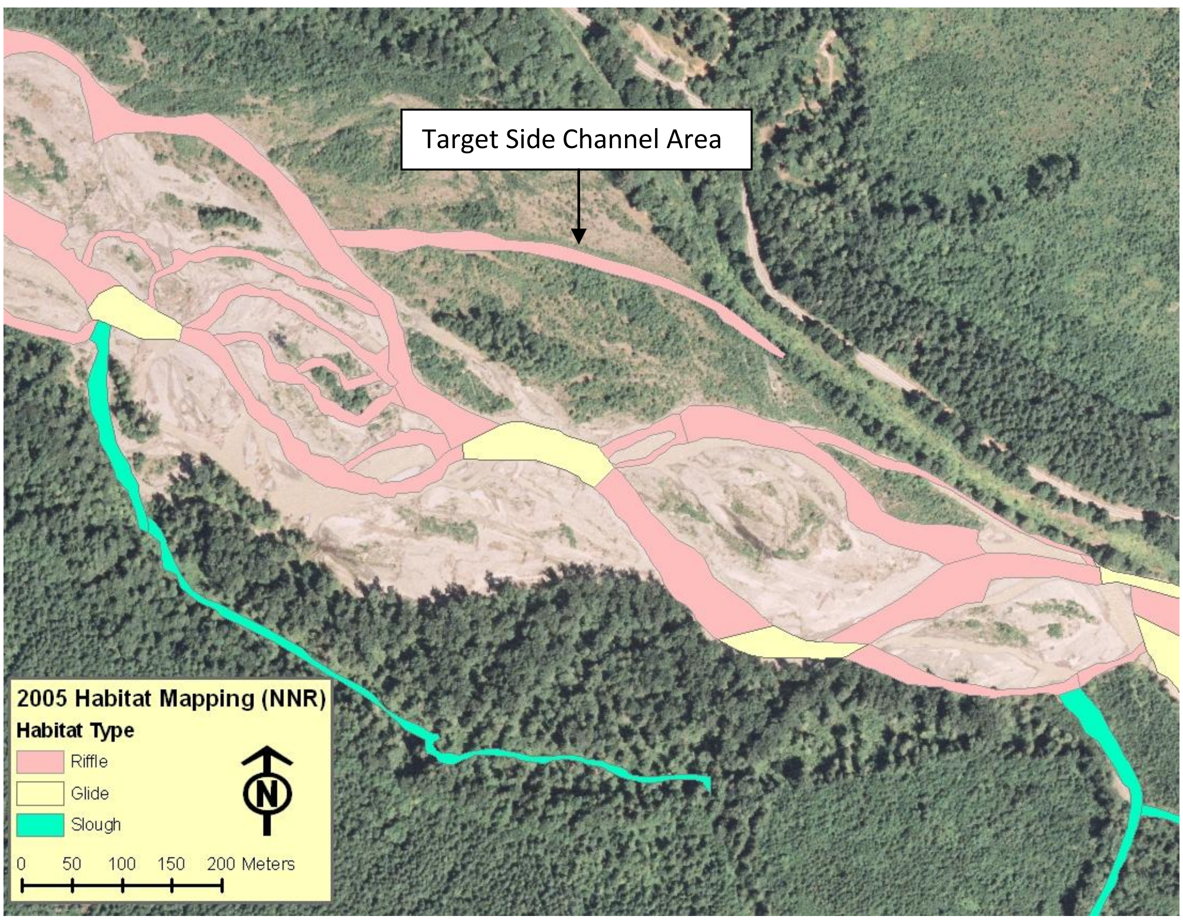
Figure 36: Lone Tree Project- phase 1 (white) and 2 (black).



In the 2005 assessment, the Lone Tree reach was found to have the highest wood loading of all the reaches, the highest proportion of braids, the highest proportion of mature floodplain trees, and was relatively wide (Hyatt 2007). The habitat in the reach was predominantly braid (34%), followed by riffle

(31%), and glide (23%). Off-channel habitat made up 11% of the wetted area, primarily in sloughs (8%). The report noted that channel spanning logjams are common in the vicinity, though they shifted from year to year. While channel shifting in the reach re-arranged the LWD on a nearly annual basis, wood has persisted in the general vicinity over several large floods. The reach was not known for high chinook spawning activity, but is between two sites (Boulder Creek and McDonald Creek) where spring chinook spawning was high in 2005. The annual channel migration rate since 1933 has averaged 7.2 m and ranged between 4.3 and 10.8 m (Hyatt 2007). This active migration has led to an active channel width in 2005 was at a historical maximum of ~275 m, having risen from ~170 m in 1966. Floodplain island area in the reach peaked in 1986. Prior to construction, the side-channel between Logjams #1 and #2 that would be the target for restoration was seasonally connected to the main channel at the upstream end, and wetted by groundwater flow through its lower length (Figure 37). In 2005, the reach was dominated by braided riffles separated by lightly vegetated cobble bars.

Figure 37: Instream habitat mapped in 2005 (Photo 2006).



Project Objectives

Secondary Channel Length

The project objective was to encourage perennial side channel flow. The focus of this was a side channel that split from the main channel between the first two logjams on the right bank (#1 and #2 on the plans). Following construction of Phase 1, the side channel area was connected to the main channel of the river (Figure 38). This was likely due to a combination of migration of the main channel toward the

Phase 1 engineered logjams and scour associated with the logjams at the divergence of the side channel. Together these changes led to the perennial connection of the side channel and an increase in side channel length from none in 2005 to 1,250 m in the summer of 2009 (Figure 39).

Figure 38: North Fork Nooksack channel position after Phase 1 (2009).

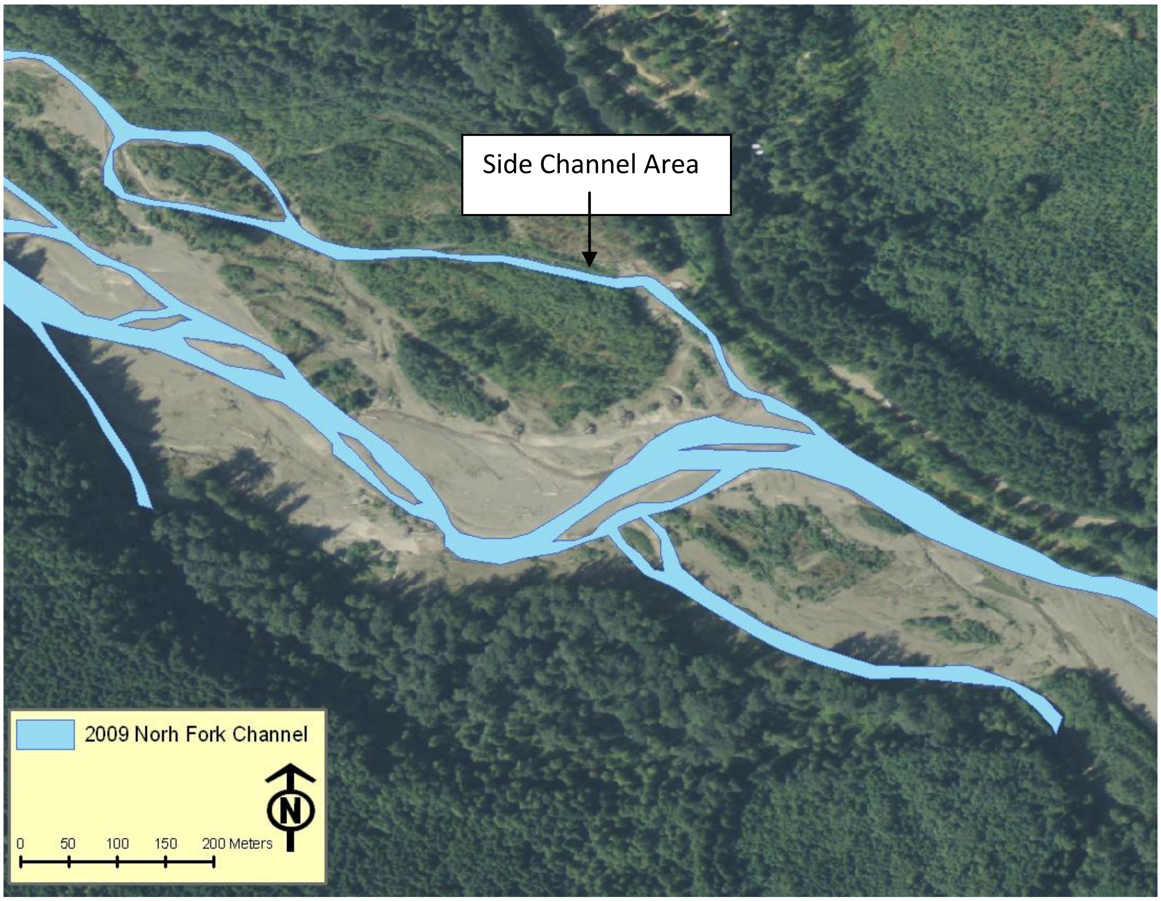


Figure 39: Side channel connection looking upstream (left) and downstream (right) during low flow 2009.

Side channel connectivity continued to increase through the summer of 2010, when it reached the maximum length for the project reach: 1970m (Figure 40). The 2007 reach assessment for the North Fork noted a lack of chinook spawning in this reach of the river (Hyatt 2007). At the time of the 2010 survey, there were 10 redds in the side channel complex and surveyors recorded 24 live chinook despite the turbid viewing conditions (NNR 2010 data). This was the highest level of chinook use in the reach that has been observed. The side channel length had fallen consider ably by 2012, when the main channel migrated northward and captured the downstream end of the side channel (Figure 41). This led to a head-cut in the side channel and abandonment of much of the floodplain channel length. The increased gradient in the side channel led to a coarsening of the bed in the side channel and it was no longer used for chinook spawning.

Figure 40: Lone Tree side channels at the on-set of chinook spawning in late summer 2010 (2010 photo).

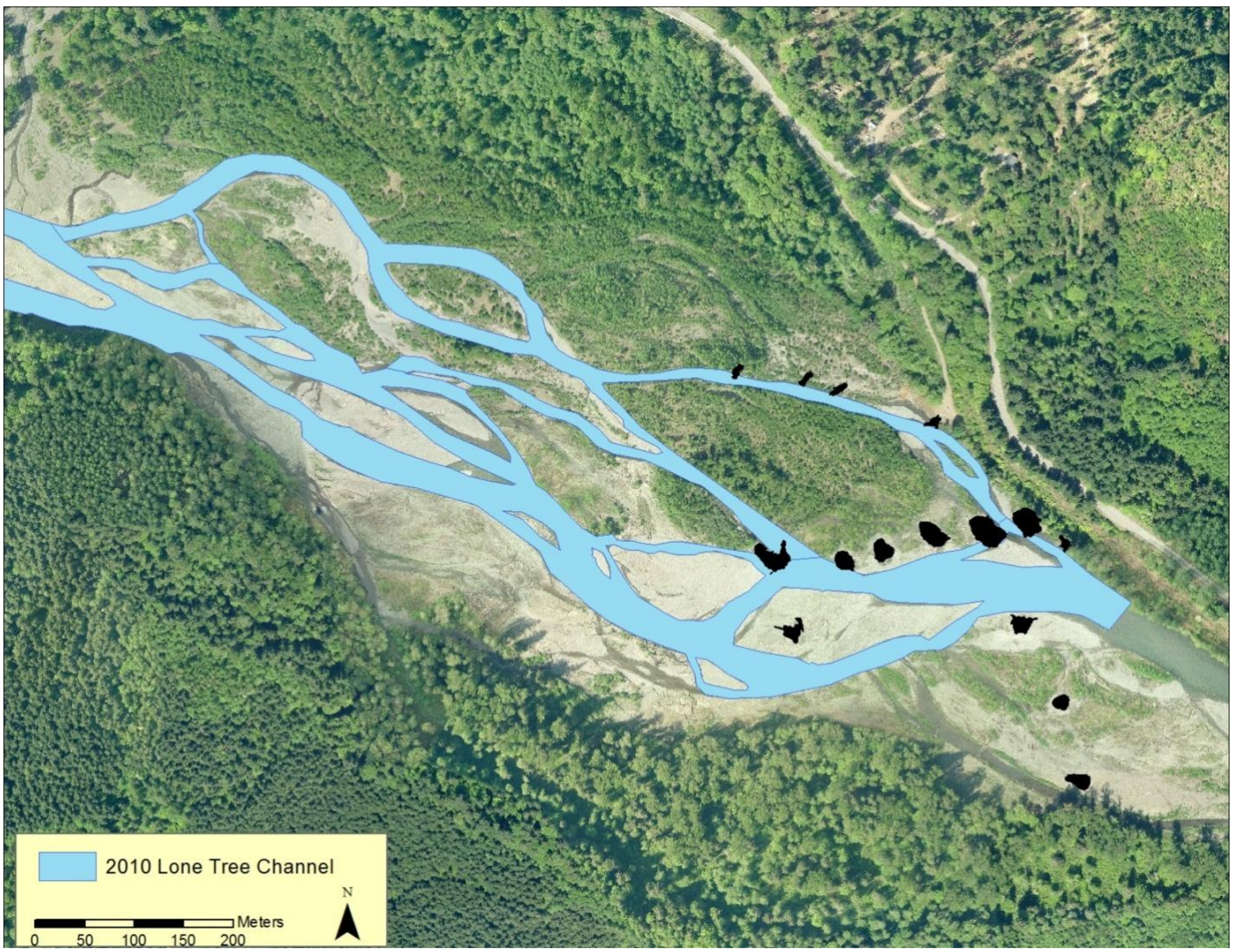


Figure 41: Lone Tree side channel length in summer of 2012 (photo from 2010 to show change).

The main change to the side channel connectivity occurred in the winter of 2015, when a large logjam formed across the head of the side channel and the main channel shifted to the south of the Phase 2 logjams. The side channel maintained a connection through the summer of 2016, but was disconnected during the summer and low flow period in 2017. The main channel has continued to move away from the upstream end of the target side channel since that time. This change reduced the side channel length in the project reach from 670 m to the pre-project level, zero.

The Lone Tree project reach did not have a target value set for side channel length as a part of the objectives- just the focus on the area between logjam #1 and #2. The reach did see an increase in side channel length following the construction from zero in 2005 to a maximum of 1970 m in 2010. The target side channel area remained connected for approximately seven years. Subsequent channel changes within the reach have since reduced the side channel length to the pre-project level. As the channel continues to migrate across the floodplain, it is likely that other side channels will be created associated with logjams.

Figure 42: Channel change at the head of the target side channel between logjam #1 and #2 (left: 2015, center: 2016, right: 2017).

Riparian Habitat

The goal of protecting vegetating cobble bars to allow them to mature into forested islands is a key component of the North Fork Nooksack habitat restoration strategy. Historically, there has been a lot of variability in the island area, although there does appear to be a sharp decrease in area since the late 1980s (Figure 43). A similar decrease occurred previously, as the island area dropped precipitously between the late 1930s and 1955, but then recovered to its highest value in the historic period in the late 1980s. The area reached its minimum value in 2005, when planning for the Lone Tree project began.

So far, the logjams placed as a part of Phase 1 have protected a maturing bar from erosion and halted the downstream migration of the channel into the forest patch behind the logjams. This has led to rapid recovery in forest island area through the reach, exceeding the historic maximum value by 2016. Since the project was constructed, the main channel of the river has been on the south side of the historic channel area, with side channels formed through the northern portion. The recent loss of the side channel length in this area may lead to a future reduction in forest island area as the islands become incorporated into the floodplain forest on the margin of the active channel area (Figure 44). While this will continue to meet the vegetation habitat indicators for the North Fork, it will no longer meet the objectives of the Lone Tree project.

Figure 43: Changes in forested island area through time in the Lone Tree Project Reach.

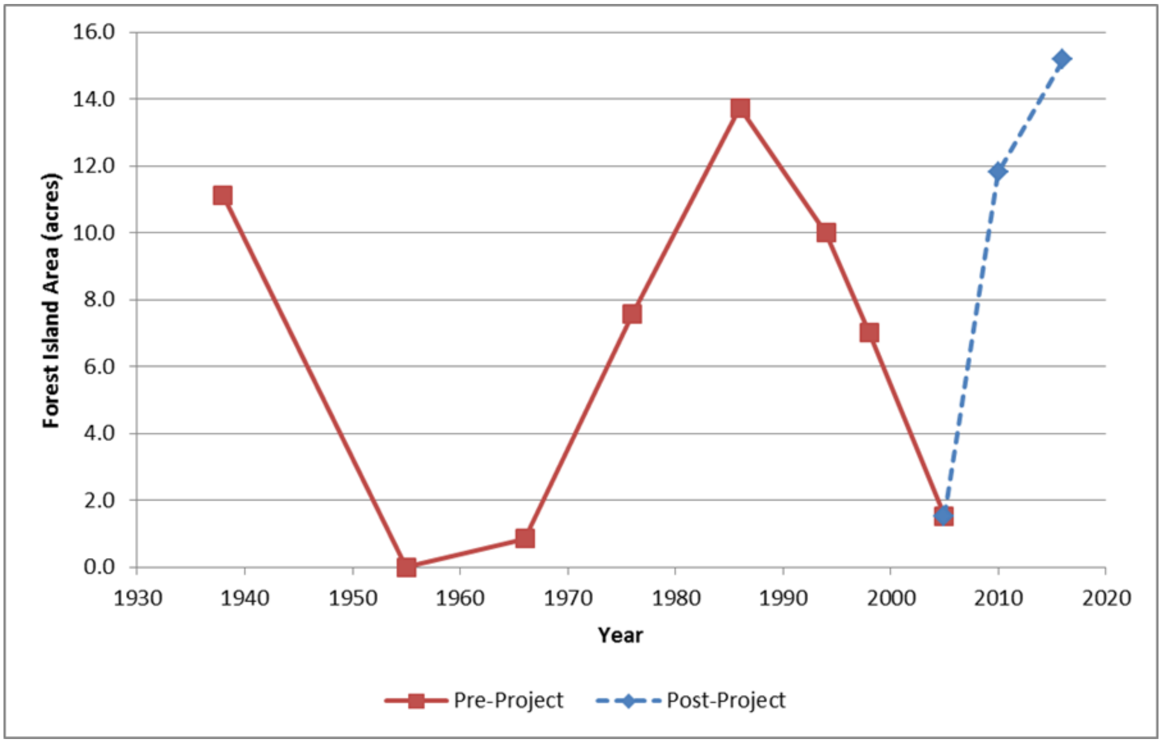
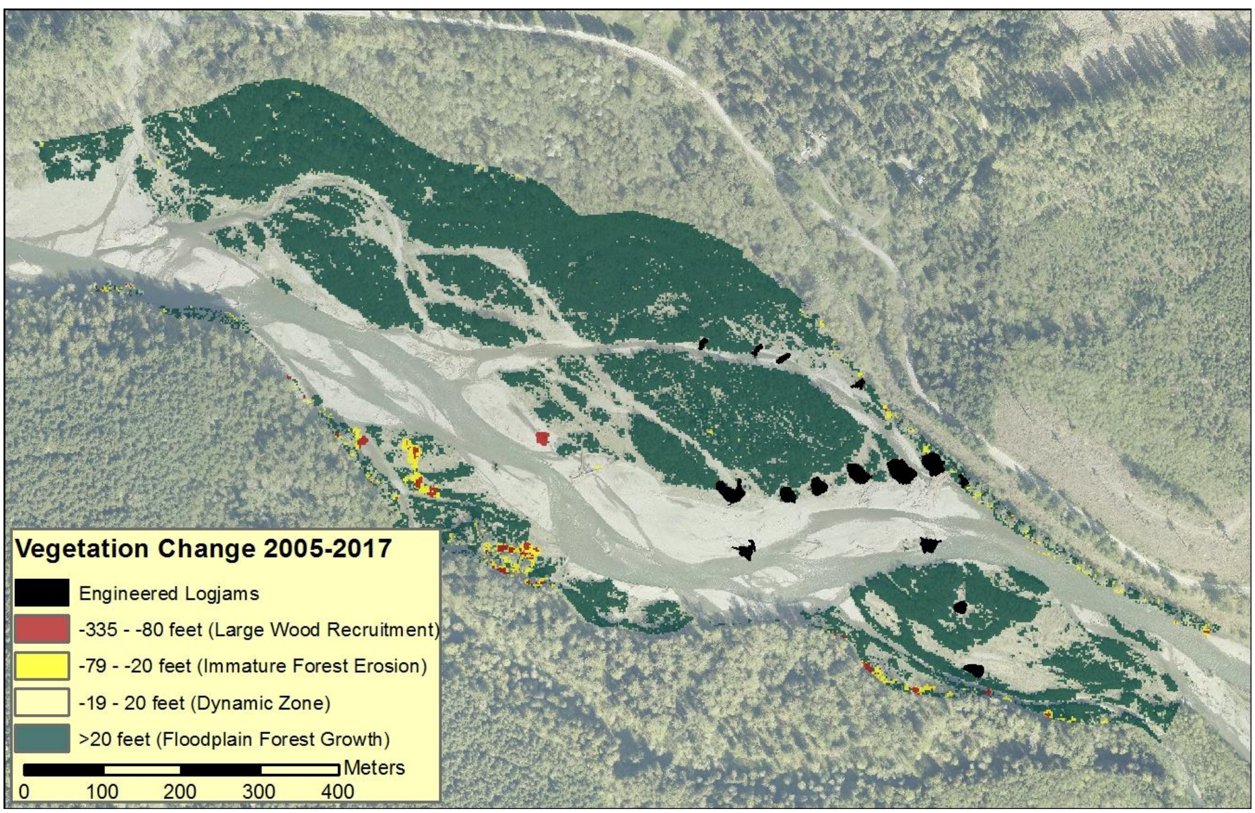


Figure 44: Vegetation change and classification for the Lone Tree Reach 2005-2017.



Pool Formation

Pool-formation and woody cover area are habitat indicators for all of the Nooksack geographic areas. While not a primary project objective of the project, pool-formation and wood cover have been monitored through time in the project reach. Baseline mapping in 2005 found no pools in the project reach. Post construction monitoring in 2012 using different mapping methods identified 12 secondary pools, mostly associated with side channels and braids. These pools likely would not have been mapped in 2005. All of these pools were formed by woody debris or single logs and engineered logjams formed two of the secondary pools. Structure-scale monitoring occurred in 2018. Each of the fourteen structures were assessed for habitat functions and signs of instability. Of the fourteen structures, three were forming pools- two secondary pools and one primary pool. None of these pools exceeded the >1 m residual depth criteria. The logjams provided ~85 m^2 of wood cover cumulatively.

Conclusions and Recommendations

The two project objectives for the Lone Tree project have largely been met (Table 44). The goal of protecting forested floodplain vegetation in the reach has led to an increase in floodplain forest island area to the highest level in the historic period. It is possible that these islands will be incorporated into the adjacent floodplain forest if the logjams prevent side channel development in this area. Side channel length has varied through time in the reach. The target side channel area was a perennial side channel through most of the project's history. The side channel length in the Lone Tree reach was at a historic maximum in 2010, when it reached 1970 m. Subsequent channel movement has disconnected the target side channel and the length has yet to be recovered at another location. The Lone Tree project was heavily focused on reconnection of the target side channel, where subsequent projects have taken the approach of encouraging side channel connectivity in a variety of locations as the channel migrates across the floodplain. The project treated only a small section of the overall planning reach and there is likely the opportunity for more side channel development and forest enhancement in the downstream portion of the project reach near the Boulder Creek fan.

Table 44: Lone Tree Project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
Protect developing floodplain islands	Riparian habitat	**Met-** forest island area has reached a historic maximum in the Lone Tree reach.
Encourage perennial side-channel flow	Secondary channel length	**Partially met**- the reach saw a rapid increase in side channel length following the construction of the project. Subsequent channel movement has reduced the length to pre-project levels (zero).

Farmhouse Project

Project Description

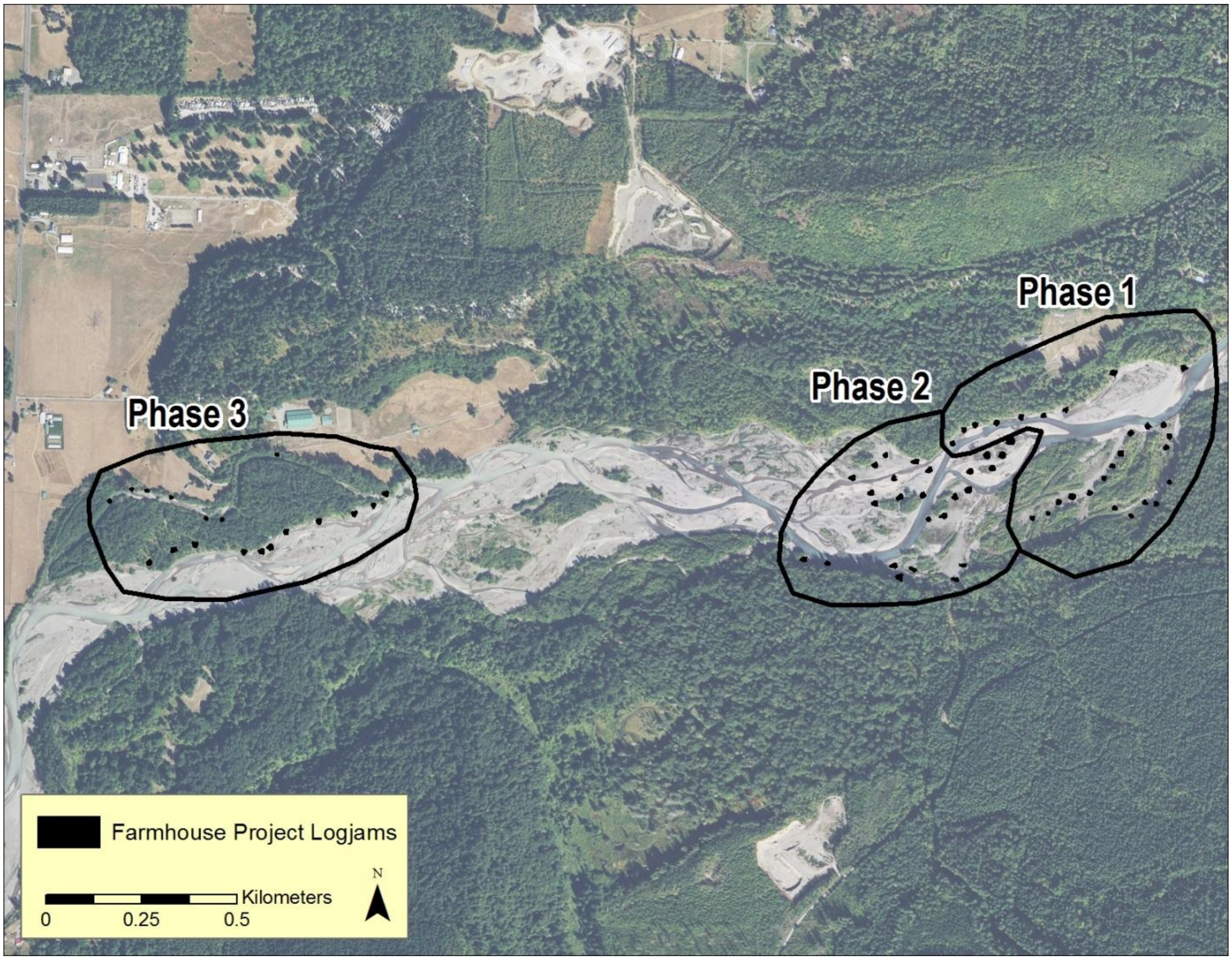
The North Fork Nooksack Farmhouse Reach (RM 46.8 to 49.4) was identified as a priority for habitat restoration in *Lower North Fork Nooksack River: Reach Assessment and Restoration Recommendations* (Hyatt 2007). This report assessed habitat changes in the North Fork Nooksack River (RM 37-58) through time and identified key limiting factors to salmon production in the river. The primary limiting factor identified was a lack of channel stability during the winter incubation and early rearing period. The lack of stability was attributed to changes in wood recruitment to the channel and more frequent large floods. These landscape-scale changes due to timber harvest and floodplain encroachment have resulted in a reduction in the number of large trees that can be recruited to the channel during floods, and therefore fewer logjams to form and stabilize forested channel islands and floodplain areas, leading to more transient river bars and smaller suitable areas for vegetation to become established (Hyatt 2007). The goal of restoration in the North fork Nooksack is to restore the channel stability and improve incubation success, through the placement of wood structures that will improve flow impedance and bank resistance to allow stable floodplain and island formation.

The Farmhouse Project is currently under construction, with three phases complete and one remaining to be built. The project was built over four summers: 2014, 2015, 2016 and 2018. The first three phases have been constructed between RM 46.5 and RM 48.8 of the North Fork Nooksack. Seventy-one engineered logjams have been constructed in the reach to date with the goal of increasing egg-to-fry survival by creating side-channel habitats that are subjected to lower levels of scour during flood events. The three phases shared similar project objectives (Table 45). Monitoring of the Farmhouse Reach has been done for the first and second phases of the project in 2014, 2015 and 2017, with only the as-built mapping completed for Phase 3 (Figure 45).

Table 45: Farmhouse project objectives (cited from NNR SRFB grant proposals).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase key habitat quantity (defined as primary and backwater pools, complex edges and tail outs), especially in side channel areas by placing LWD structures that cause local scour and provide complex edge habitat.	Pool formation	Lack of Key Habitat
Improve low flow connectivity of key marginal side channel areas – Bear Creek Slough, Wicks Slough, Levitt's Slough and Falls Creek Side Channel by separating and encouraging flow toward marginal channel areas	Secondary channel length	Low habitat diversity
Narrow the active channel area by encouraging vegetation establishment and succession on existing exposed gravel bars.	Riparian habitat	Channel stability
Increase longevity of forest islands for riparian habitat by increasing the bank resistance along existing and emerging forest islands.	Riparian habitat	Channel stability

Figure 45: Farmhouse Project phases 1, 2a/2b and 3 (2017 photo).

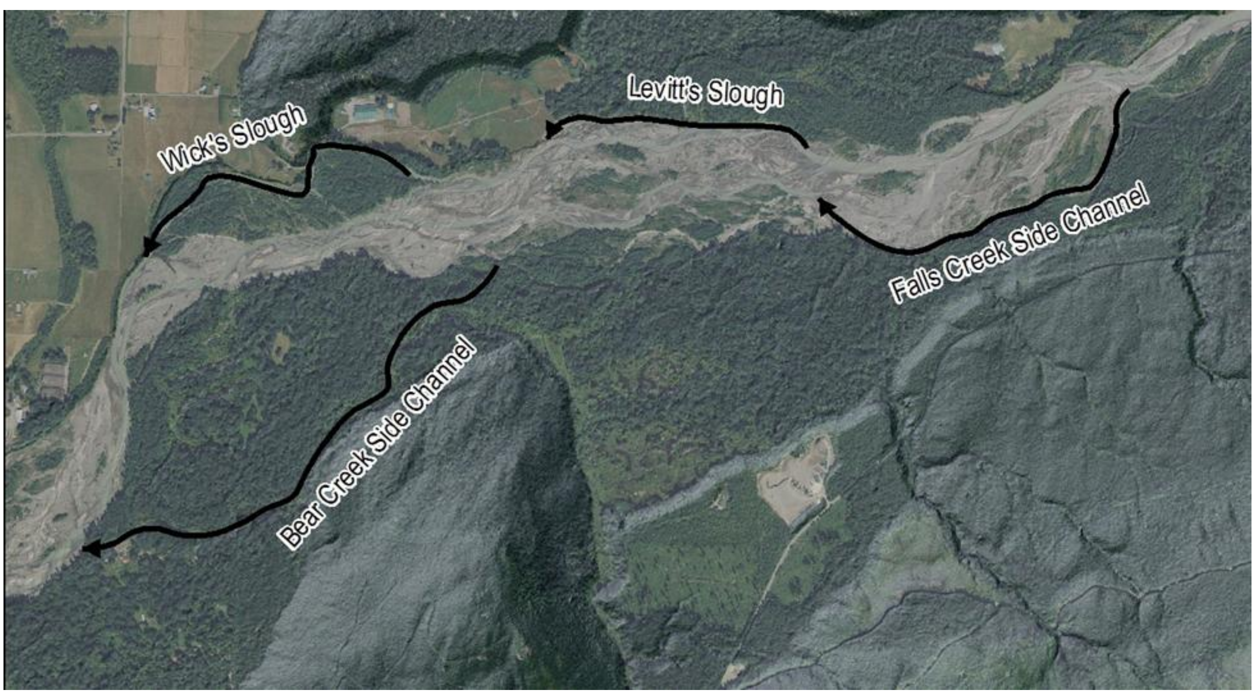


Hyatt (2007) characterized the Farmhouse Reach in the North Fork Nooksack habitat assessment. The Farmhouse reach is one of the widest on the North Fork (above the Middle Fork), averaging 278 m over the entire reach and varying between 135 m at the upstream end near Phase 1 and more than 300 m between the Phase 2 and 3 reaches. Overall gradient is 0.006, steeper than any of the reaches downstream, and varies locally (by 100 m segments) up to 0.02 but with most segments less than 0.01 (Hyatt 2007). Channel migration rates in the most active areas of the reach average 17 m/year and ranges between 11.7 and 29.0 m/year. The assessment found that the mainstem habitat in the Farmhouse reach was predominantly riffle (56%), followed by braid (15%), glide (6%), and pools (<1%). The one large convergence pool in 2005 occurred where three channel braids were joined, but had disappeared the following year. The lack of main channel pools was typical of the North Fork Nooksack River, which averaged 1.1 pools per mile over the 20.9 miles surveyed. Off-channel habitat, primarily in the form of back channels, made up 21% of the wetted habitat in the reach. In the braided section, the channels shift inter-annually, with little in the way of forested islands or logjams to anchor the channel (Hyatt 2007). Spring chinook spawning in 2005 was moderate (14 redds), but historically this reach was one of the more active chinook spawning areas in the North Fork (Schuett-Hames et al. 1988).

Spawning in the reach is tied strongly the edge of the historic migration area. In places where secondary channels are present along the edge of the higher terrace, spawning by all anadromous species is prevalent (Julie Klacan, Tasha Geiger, WDFW, pers. comm. Jan 2012). Areas such as Wicks Slough, Levitt's Slough, the Falls Creek Side-channel, and Bear Creek Slough all see high levels of use by all of the anadromous species present in the reach (Figure 46). When side channels are formed with in the active channel area, away from the margins, they are less heavily used for spawning, although chum salmon still key in on the prevalent groundwater emergence areas within the braids (J. Klacan/ T. Geiger, WDFW, pers. comm. Jan 2012). This may be related to the stability of the marginal channels relative to the braided active channel area. Because of these observations, the project focused on four side channel areas listed above that have seen high levels of chinook spawning in the past.

The Falls Creek Side Channel is heavily used by steelhead and chinook. Chinook mostly use the lower portion of the side channel because of better flow during spawning season due to the influence of Falls Creek. Steelhead, which will spawn later when flows are higher, will use the portion of the side channel upstream of the tributary. The Wick's Slough area is the most heavily used spawning area in the project reach, and is one of the highest density spawning sites in the North Fork. The side channel area can be limited by low flows, and an obstruction at the upstream end has reduced the flow into the side channel. This obstruction is partly associated with a previous habitat restoration project in the reach (NF Channel Island Augmentation Project). Bear Creek Slough is also heavily used for spawning by all species. While mapped as a long side channel in 2005, the upstream head of this channel has been obstructed the last several years, and only high flow accesses the channel.

Figure 46: Side channel areas with high levels of spawning use in the Farmhouse Reach.

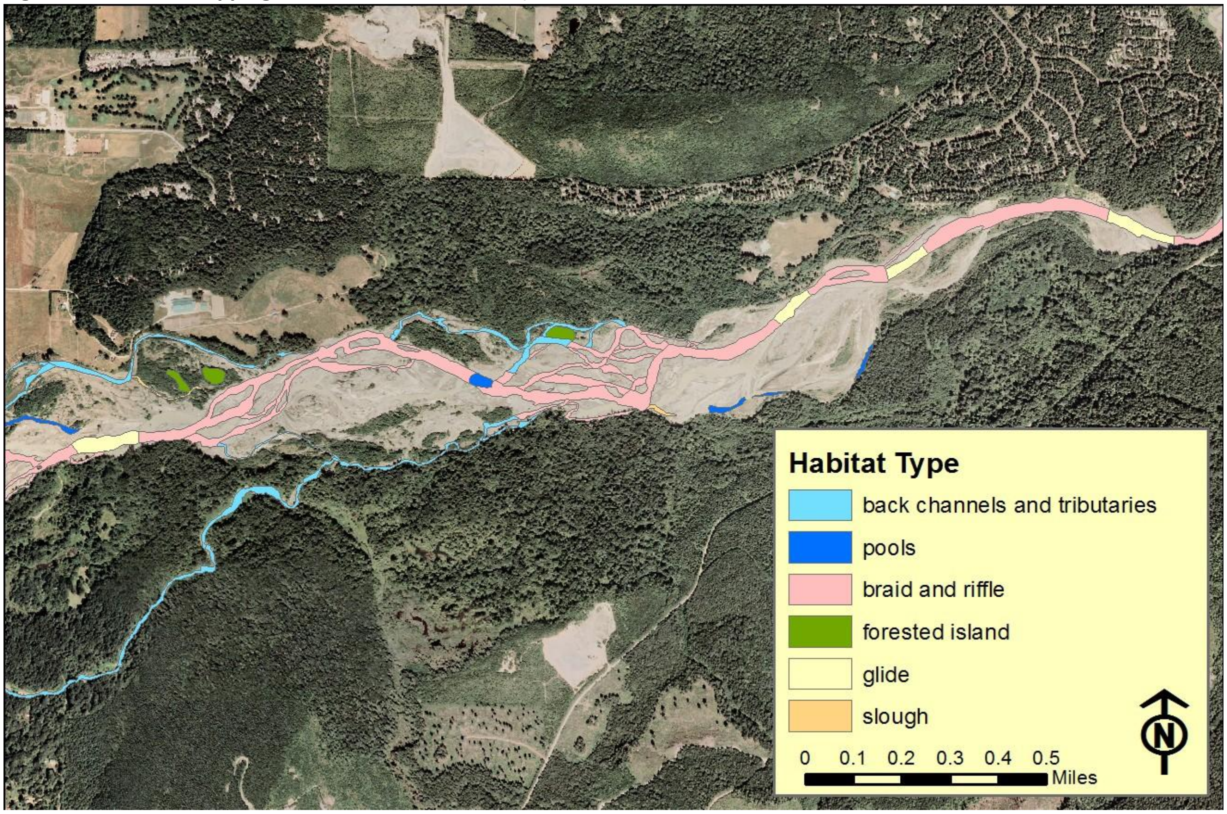


Project Objectives

Pool Formation

The project had the objective of increasing the number of pools, especially in side channel areas. The baseline mapping that occurred in 2005 found only one large convergence pool between the Phase 2 and Phase 3 reaches that occurred where three channel braids were joined, but noted that the pool had disappeared the following year (Figure 47). This mapping did not break-out habitat units in side-channels, but it is assumed that the side channel habitat unit density and pool spacing in these areas is comparable to the side channels that were mapped in 2014 and 2015. The side channel length will be used for comparison to the 2005 conditions and then future monitoring will compare the pool spacing to the 2014 and 2015 conditions. Changes in side channel length through time will be captured in the Secondary Channel Length objective.

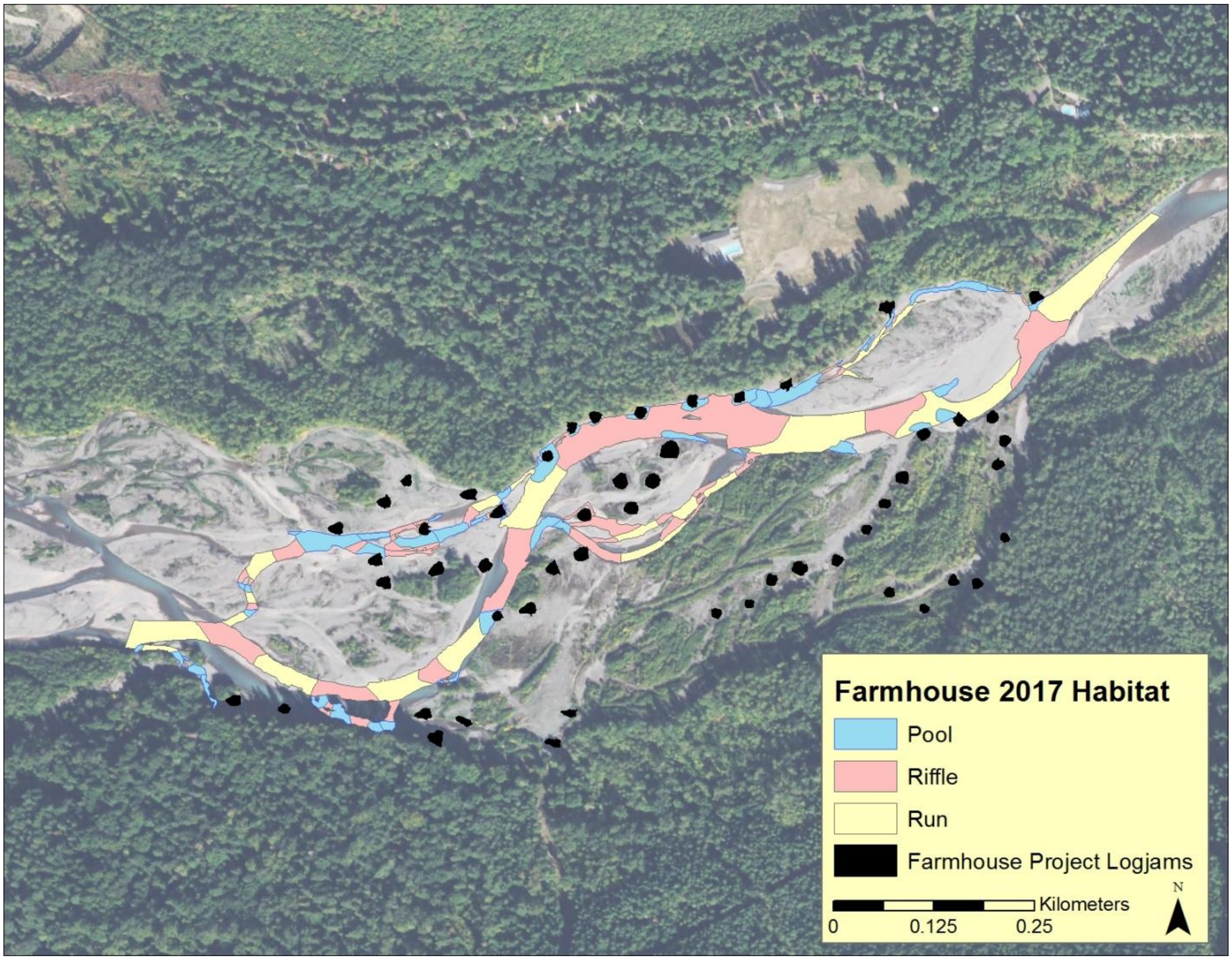
Figure 47: Habitat mapping in the Farmhouse Reach (Source: NNR 2005 mapping, on 2009 NAIP Aerial photo).



At the time of the monitoring in both 2017 and 2018, Falls Creek was a groundwater-fed channel rather than a side channel. The main stem of the river has been migrating toward the head of the channel over the last 5 years, so connectivity may improve with time, but currently, there is only evidence of high flow connectivity. Structure-scale mapping of habitat functions for the structures that were constructed in the Falls Creek target area for Phase 1 and Phase 2 found that 4 of the 13 structures constructed in the side channel had formed pools. Much of the channel was dry at the time of the survey, so it is possible that when the channel has more flow that other structures would be providing additional habitat benefits. Of the four pools, two were isolated from the channel. The two pools that formed in the wetted channel were both in locations that were previously mapped as runs, so this represents an increase in pools in the Falls Creek area from four to six pools in the wetted channel. The Levitt's Slough side channel has not developed since the project was constructed and no structures have been built in this location. This area is still planned to be treated as a part of the final phase of the project.

Main channel habitat mapping in 2017 found an increase in pools in the main channel and braids of the project reach (Figure 48). The project reach saw an increase in main channel pools from zero in 2005, to three pools that would likely have met the criteria for inclusion in the 2005 mapping. In total, 49 pools were mapped in the main channel and braids of the project reach in 2017 and 15 of those were associated with the engineered logjams. Every location where the channel was interacting with a logjam, a pool with wood cover was formed. Similar to the Wildcat Project Reach, the engineered logjams were also related to the deepest pools in the reach. Seventeen pools were greater than 1m deep and 10 of these were formed by engineered logjams. Of the 5 pools that were greater than 2m deep, all of them were formed by engineered logjams.

Figure 48: Habitat mapping in the Phase 1 and 2 reaches of the Farmhouse Project (NNR 2017 data, photo from 2017).



Structure-scale mapping in 2018 found that 25 of the structures that were built in the first two phases were providing instream cover for the channel and 19 of the 53 structures had a pool associated with it. Cumulatively, the engineered logjams built in Phase 1 and 2 provided 3,675 m^2 of pool habitat and 1,060 m^2 of wood cover within the wetted channel. Three of the pools were primary pools (spanning the majority of the main channel width), which would indicate that the main channel pool density is continuing to increase in the reach. Each of these three pools had a maximum depth approaching 3 m and together they were responsible for over 1900 m^2 of pool area and over 250 m^2 of wood cover in the channel.

While no specific target was presented in the grant application materials, the North Fork Farmhouse Feasibility and Alternatives Analysis (Nooksack Tribe 2014) presented a target for evaluating different project alternatives. The target for pools was 30 pools in the project reach, including mainstem and side channels, with an emphasis on the target side channel areas. Based on this target for the reach, the first two phases have exceeded the pool target. However, the pools have not been located in the target area for the project.

Secondary Channel Length

The Phase 1 and Phase 2 projects focused primarily on encouraging side channel formation in the Falls Creek and Levitt's Slough areas. At the time of the project, there was no channel in Levitt's Slough area and the Falls Creek area was fed by groundwater emergence on the bar and the flow of Falls Creek, which enters the side channel ~300m upstream of the confluence with the main channel. The Phase 3 project was focused on increasing connectivity of the Wicks Slough area.

Following construction, the Falls Creek side channel is still a groundwater-fed channel and Levitt's Slough area has not developed a side channel. While the two target areas have not seen an increase in side channel habitat, the 2015 and 2017 mapping did show that the logjams were splitting flow and forming stable patches of floodplain that could become forested islands and side channels with time. Since this project is relatively young, it may take some time for the vegetation to respond to the project and increase stability in the areas that were not the focus for side channel development. Although, based on the observations of the spawner survey crews, these areas within the active channel area may not provide the same benefit to spawning chinook as the marginal side channels do.

The feasibility report used 11,000 feet (3,350 m) of side channel as the target for the Farmhouse Reach. This corresponds to the majority of the length of three of the four target side channel areas. Currently, only the Wicks Slough side channel is connected, which is providing approximately 1,500 m of side channel. Neither of the two target areas for the Phase 1 and 2 projects has been reconnected as a result of the project.

Riparian Habitat

The riparian habitat objectives for the project are to narrow the active channel area by encouraging vegetation to establish on gravel bars and to increase the longevity of forested islands by increasing the bank resistance on young, emerging islands. The feasibility report identified targets for these objectives: 200 acres (81 hectares) of active channel in the project reach and conifer dominated patches within the forest islands and a mosaic of forest stands across the floodplain.

Habitat mapping from aerial photos and historic maps by Collins and Sheikh (2004) found an increase in active channel area (low flow and unvegetated gravel bars) through time in the Farmhouse Reach (Figure 49, Nooksack Tribe 2014). This trend mirrors the overall trend for the North Fork identified by Hyatt (2007). GeoEngineers (2012) also characterized the active channel changes in the Farmhouse Reach (Table 46). The average width increased considerably in the 1986 and 1994 photo years, which corresponds to the period where forest patches were being eroded faster than they were being created. This was also a period that saw three floods that exceeded the 10-year recurrence interval. This increase in width likely reflects periods of rapid channel migration in the reach, often associated with floods and sediment deposition (GeoEngineers 2012). The annual channel migration rate for the reach averaged nearly 17 meters (~55 feet) per year from 1933-2005, although this has occurred in a relatively narrow portion of the floodplain (Hyatt 2007).

Table 46: Historic channel width in the Farmhouse Reach (GeoEngineers 2012).

Photo Year	Active Channel Area		
	Average width (m)	Change in Width Relative to Historic Average (m)	Percent Change from Previous Record
1938	219	-37	-
1955	232	-24	6%
1976	226	-30	-3%
1986	308	52	36%
1994	323	67	5%
1998	238	-18	-26%
2005	235	-21	-1%
2010	259	3	10%

The widening of the active channel area has come mostly at the expense of forest floodplain at the margins of the channel, rather than from a significant loss of forested island area in this reach. While the overall area of forested islands has varied through time, the island area appears more driven by changes in the number of small islands rather than the coalition and destruction of larger islands, as seen by the relatively small average area for most years (Table 47). None of the 2016 islands were associated with the Phase 1 and 2 project reaches.

Figure 49: Change in area (acres) of habitat types through time (1891-1998). Source: Collins and Sheikh (2004), cited from Nooksack Tribe 2014).

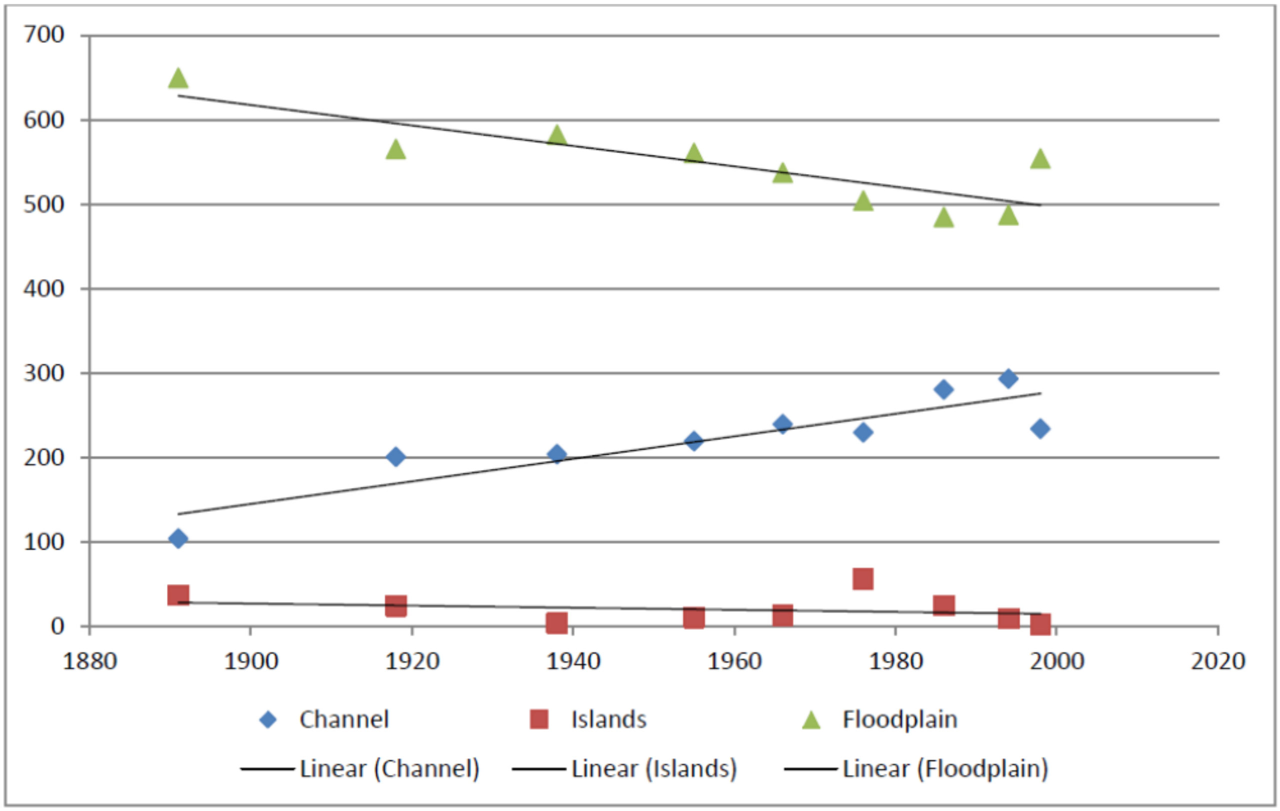


Table 47: Total forest island area, count, average and maximum single island area through time in the Farmhouse Project Reach (Collins and Sheikh 2004, NNR 2005 data), all areas are measured in hectares.

Photo Year	Total Island Area	Count	Average Island Area	Maximum Single Area
1938	1.7	6	0.3	0.6
1955	4.1	6	0.7	1.9
1966	5.5	9	0.6	1.5
1976	22.9	7	3.3	10.8
1986	10.0	16	0.6	2.2
1994	3.8	7	0.5	1.2
1998	1.0	1	1.0	1.0
2005	0.8	3	0.3	0.3
2010	10.3	9	1.1	4.1
2016	13.7	8	1.7	6.0

The second project objective was to increase to longevity of forested islands in the reach. Looking at the age and fate of forest patches that initiated as islands in the Farmhouse Reach shows the rapid growth and destruction of forest islands (Table 48). An exception is where these islands are along the margin of the channel and become incorporated into the floodplain forest. The river has undergone periods where island formation has outpaced island destruction, as it did from 1938-1976, and periods where islands have been eroded faster than new islands have formed 1976-2005. Since 2005, island area has been increasing in the reach. The period between 1966 and 1976 is the greatest for new forest establishment in the active channel of the river. During this time, 18.7 hectares of new forested island formed, with only 2.8 hectares lost to erosion. Much of this occurred as three large islands on the margins of the active channel that were subsequently incorporated into the floodplain forest. In the twelve years between 1998 and 1986, there was only 2.1 hectares of new forest formed in the Farmhouse Reach, while losing approximately 8.3 hectares during that time.

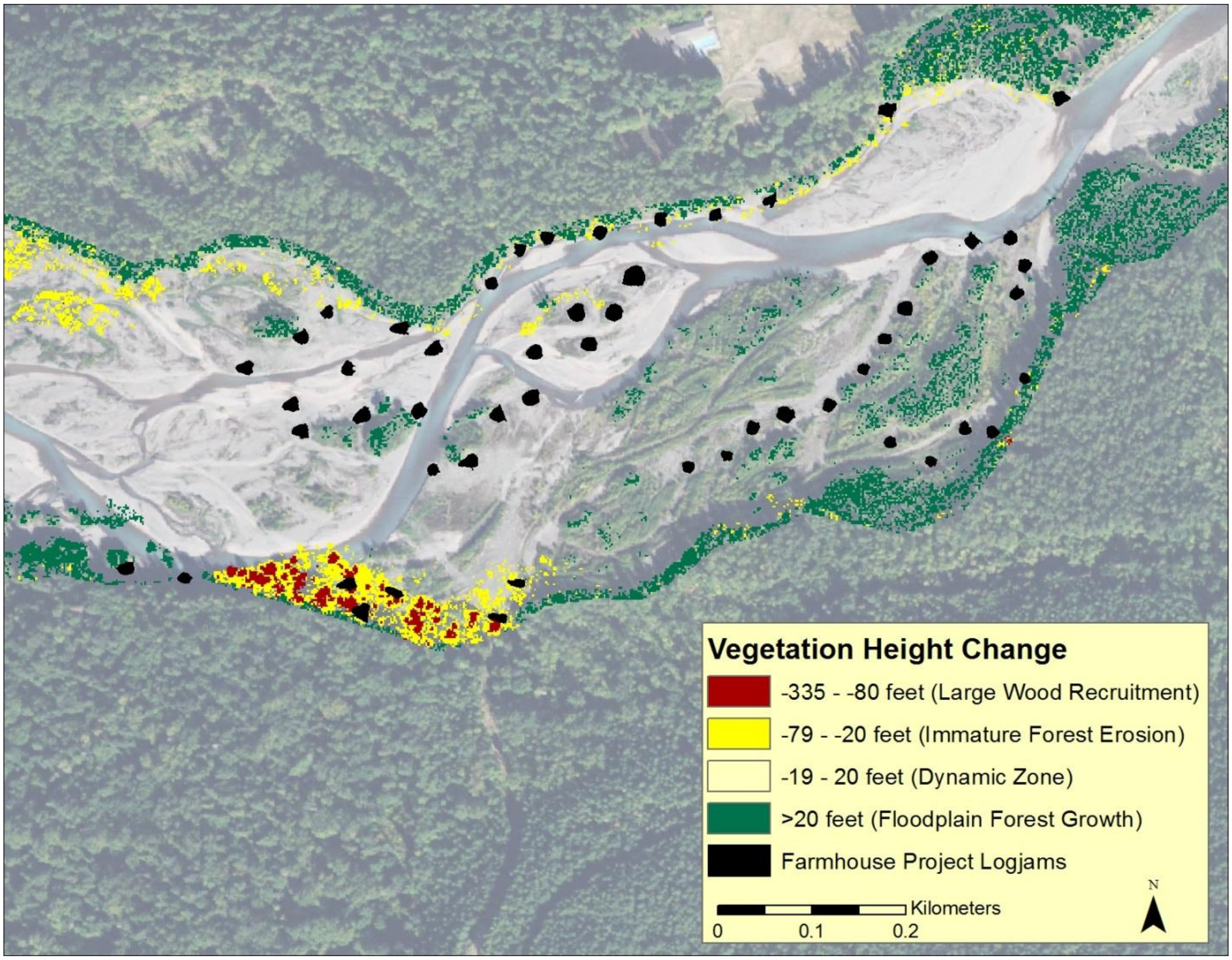
Table 48: Persistence of floodplain patches that initiate as islands (1933-1998) (all values in hectares).

Year	Total Area	Area persisting from all previous photo years							Area change since the previous photo year		
		1933	1938	1955	1966	1976	1986	1994	New Forest	Lost Forest	Persisting forest
1933	6.8	-	-	-	-	-	-	-	-	-	-
1938	2.0	1.8	-	-	-	-	-	-	0.2	5.1	1.8
1955	4.3	0.2	0.2	-	-	-	-	-	4.1	1.8	0.2
1966	7.3	<0.1	<0.1	1.8	-	-	-	-	5.5	2.5	1.8
1976	23.2	<0.1	<0.1	1.1	4.5	-	-	-	18.7	2.8	4.5
1986	17.6	<0.1	<0.1	0.2	3.0	11.0	-	-	6.6	12.2	11.0
1994	12.8	0	0	0	2.5	9.1	10.9	-	1.9	6.7	10.9
1998	11.4	0	0	0	2.5	8.9	9.8	11.2	0.2	1.6	11.2

The age of forested islands visible in the 1998 show that even during the period of island erosion, a small portion of the floodplain forest has been able to persist for more than 30 years. Over 2.5 hectares (22%) of the 11.4 hectares of forest seen in the 1998 photo dates from the 1966 aerial photo, 6.4 hectares (56%) from the 1976 photo, 0.9 hectares (7%) from 1986 and 1.54 hectares (12%) from the 1994 photo. This indicates the importance of protecting the existing forest patches to increase their persistence, since floodplain forest is not being formed as rapidly as it is being eroded. No patches seen in the photo record have been able to persist long enough to provide mature conifer recruitment to the channel. Comparing the current stand age to the targets for the instream habitat indicators, the area of floodplain vegetation older than 75 years and the area older than 20 years both meet the targets for "Very Good" conditions in the reach.

When looking at patterns of forest growth in the Phase 1/ 2 project reach between 2005 and 2017, the rapid migration and floodplain turn-over rate is evident (Figure 50). Nearly the entire floodplain is in the "dynamic zone" classification, with large areas of immature forest erosion and some large wood recruitment. Given the lag between the logjam construction and the growth of trees greater than 20 feet (6.25 m), it is still too early to be able to see a response in the floodplain vegetation to the project. It is expected that the vegetated areas associated with the logjams will continue to mature and will become large enough to be classified as “floodplain forest growth” over the next several years.

Figure 50: Vegetation height change in the Phase 1 and 2 projects in the Farmhouse Reach.



Conclusions and Recommendations

The Farmhouse Project is still being implemented, with only two of the four phases covered in this monitoring report. It is expected that once the entire reach is treated that the project will be more likely to meet the objectives that have been developed for the reach (Table 49). The logjams have proven to be effective at forming pools where the channel is interacting with the structures, but have yet to create side channels in the areas targeted by the design. Low flow connectivity of the Levitt’s Slough and Falls Creek side channels has not occurred yet in the Phase 1/2 project reaches. The Wicks Slough side channel is currently connected in the Phase 3 reach, but that reach has yet to be evaluated for effectiveness. Due to the lag in vegetation response, it is too early to detect stable forest islands in the reach. It is evident that large portions of the floodplain appear to be revegetating, but have not yet persisted long enough to be considered forested.

Table 49: Farmhouse project objectives (cited from NNR SRFB grant proposals).

Stated Project Objectives	Objective Group	Objective Success
Increase key habitat quantity (defined as primary and backwater pools, complex edges and tail outs), especially in side channel areas by placing LWD structures that cause local scour and provide complex edge habitat.	Pool formation	**Partially met**- the project reach has seen an increase in pools and has exceeded the target presented in the feasibility report. The pools have not formed in the target side channel areas.
Improve low flow connectivity of key marginal side channel areas – Bear Creek Slough, Wicks Slough, Levitt's Slough and Falls Creek Side Channel by separating and encouraging flow toward marginal channel areas	Secondary channel length	**Not met**- the project has not improved connectivity in either of the two target side channel areas included in Phases 1 and 2. Target length from the feasibility report has not been met.
Narrow the active channel area by encouraging vegetation establishment and succession on existing exposed gravel bars.	Riparian habitat	**Uncertain**- there is a lag between construction and vegetation growth to a size that indicates stability. There are large areas of the floodplain that are beginning to reforest, but have not met the 20' threshold for forest. The active channel area has not met the target presented in the feasibility report.
Increase longevity of forest islands for riparian habitat by increasing the bank resistance along existing and emerging forest islands.	Riparian habitat	**Uncertain**- there is a lag between construction and vegetation growth to a size that indicates stability. The logjams have slowed migration into marginal forest and split flow around forest patches.

North Fork Channel Island Augmentation Project

Project Description

Similar to the Nesset's LWD Stabilization project in the South Fork Nooksack, the North Fork Island project consisted of stabilizing existing and added woody debris with piles driven with an excavator (Figure 51). The project was originally scoped for three reaches of the North Fork, but included two reaches of the North Fork: the Kendall Hatchery Reach (RM 45.8-46.1) and the Bennet Farm (Farmhouse) Reach (RM 46.7-47.3). The Bennet Farm area was focused on protecting the forest near Wicks Slough. The project was completed in 2010 and a total of 51 sites were selected- 18 in the Hatchery Reach and 33 in the Farmhouse Reach (Figure 52). The project had the objectives of improving incubation success by forming side channels and protecting forest islands, and encouraging vegetation growth in braided channels (Table 50). The project has seen limited effectiveness monitoring, although the structures were assessed in 2013 as a part of the structure-scale effectiveness assessment.

Figure 51: An augmented island logjam in the Hatchery Reach.

Figure 52: NF Island Augmentation Project- Bennett Farms area is upstream (east), Hatchery is west.

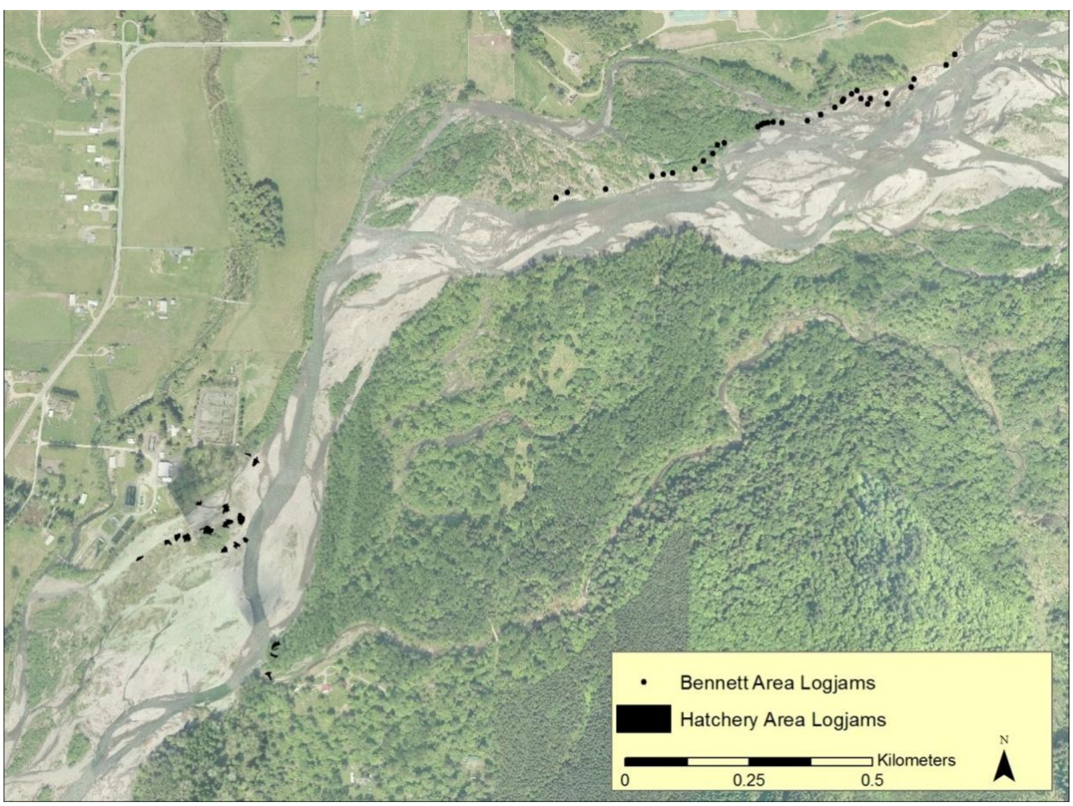


Table 50: North Fork Channel Island Augmentation project objectives (cited from NSEA SRFB #07-1828 proposal)

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Improve egg-to-fry and juvenile rearing survival by providing stable, off-channel spawning habitat and flood refuge	Redd scour	Channel stability
Reset process of floodplain and channel island formation by providing stable hard points behind which vegetation can establish and mature.	Riparian habitat	Channel stability
Shift braided habitat to protected back-channel habitat by encouraging channel island stability	Riparian habitat	Channel stability

Project Objectives

Redd Scour

The redd scour objective was focused on improving the egg-to-fry survival for incubating chinook in stable off-channel areas. Monitoring of side channel length from aerial photos found in 2005 there was approximately 1,425 m of side channel in the project reach- located in the Bennett Farm area at Wicks Slough. At the time of the field surveys in 2013, none of the structures in either each were described as splitting the low flow channel, although 15 of the structures were potentially spitting the high flow channel. Review of the 2016 aerial phot found an additional 215 m of side channel at Wicks Slough and 950 m of side channel at the Hatchery project site. The timing of the photos may not represent side channel connectivity during the chinook spawning season, while the field survey did occur at the on-set of spawning.

The Bennett Farm structures were likely inhibiting the connectivity of Wicks Slough due to sediment deposition at the head end of the channel in 2013. At the time of the field survey there were 29 structures present along the edge of the channel, although 13 had some level of damage. By 2016, nearly all of the structures had been damaged by high flow and the channel was less obstructed than in the 2013 surveys.

Riparian Habitat

The project had two objectives related to riparian vegetation- creating stable hard points for vegetation growth and encouraging the stability of forest islands. The Bennet area focused on the islands associated with Wicks Slough. These islands have continued to mature through the life of the project, although recently all of the structures that were designed to protect the island have been lost to channel migration. The forest patches associated with the Hatchery area have continued to grow and all but three of these structures have remained in place (Table 51). The channel has not migrated in this direction within the life of the project, so it is uncertain whether these structures will continue to function as stable hard points when subjected to the flow of the river.

Table 51: Forest island area in the NF Island project reach since 2005

Year	Forested Island Count	Forested Island Area (hectares)
2005	3	0.78
2010	6	6.34
2016	5	17.48

Pool Formation

While not a primary project objective of the project, pool-formation and wood cover were monitored in 2011 as a part of the structure-scale monitoring. Sixteen of the eighteen structures that could be located were visited. There was one structure forming a shallow (0.3 m) pool. It was isolated from the river at the time of that survey, but contained abundant juvenile salmonids. Wood cover was noted for two of the structures, totaling ~7 m^2 of instream cover.

Conclusions and Recommendations

The project has been associated with a dramatic increase in forest island area and increased side channel length through time (Table 52). The loss of nearly all of the structures in the Bennet Slough area has been compensated for by the construction of Phase 3 of the Farmhouse Project, which focused on protecting the same forest patches and the Wicks Slough side channel area. The structures in the Hatchery area of the project continue to function, although several of the structures have been lost to high flow since 2010. Since the Hatchery Reach is considered a high priority for restoration, periodic monitoring will be important given the lack of stability observed in the Bennett Farm area.

Table 52: North Fork Channel Island Augmentation Project.

Stated Project Objectives	Objective Group	Objective Success
Improve egg-to-fry and juvenile rearing survival by providing stable, off-channel spawning habitat and flood refuge	Redd scour	**Partially met**- Wicks Slough currently provides stable spawning habitat, but the structures appeared to inhibit the low flow connection when surveyed in 2013. It is uncertain if the side channel at the Hatchery is connected during spawning. Both of these areas provide high flow refuge habitat.
Reset process of floodplain and channel island formation by providing stable hard points behind which vegetation can establish and mature.	Riparian habitat	**Partially met-** While they provided short-term protection for vegetation, many of the structures have been washed-out and are no longer stable hard points.
Shift braided habitat to protected back-channel habitat by encouraging channel island stability	Riparian habitat	**Met**- the forest island area has increased in the areas associated with the structures. The loss of the majority of the structures within 10 years makes continued island stability questionable.

South Fork Instream Projects

Like the North Fork Project section, this section evaluates project success relative to the stated objectives for each of the instream habitat restoration projects that were constructed in the South Fork Nooksack Watershed. Objectives were identified from grant proposals where they are available, design reports, or from subsequent monitoring reports. The stated objectives were then generalized into objective groups for comparison across the watershed and linked to the habitat limiting factors from the WRIA 1 Salmonid Recovery Plan (WRIA Salmon Recovery Board 2005). Project-scale monitoring generally followed methods presented in the *Quality Assurance Project Plan* (QAPP) *for Implementation and Effectiveness Monitoring of Nooksack River Watershed Habitat Restoration Projects* (Coe 2013).

There are 18 instream habitat projects that have been completed in the South Fork watershed, and this report covers those that were constructed before 2019, excluding the second phase of the Nesset's Project (Figure 53, Table 53). For each of the projects below, the project objectives will be presented and evaluated for success using available monitoring data. Projects in the Upper South Fork were evaluated as part of a separate effectiveness monitoring project (Natural Systems Design (NSD) 2019 Draft). For these projects, only a brief summary is provided and a summary table showing the success relative to the project objectives. For the projects in the lower South Fork geographic area, we will provide an opinion on whether the objective was met, partially met, or not met. In some cases, it will be inconclusive. Data that informs the reach-scale habitat indicators will also be presented by project reach. In many cases the project reaches do not conform to the planning reaches, so projects will be evaluated within the extent of the project, rather than the extent of the planning reach. Following the evaluation of the project objectives and the habitat indicators, recommendations will be provided.

Figure 53: South Fork Nooksack project locations.

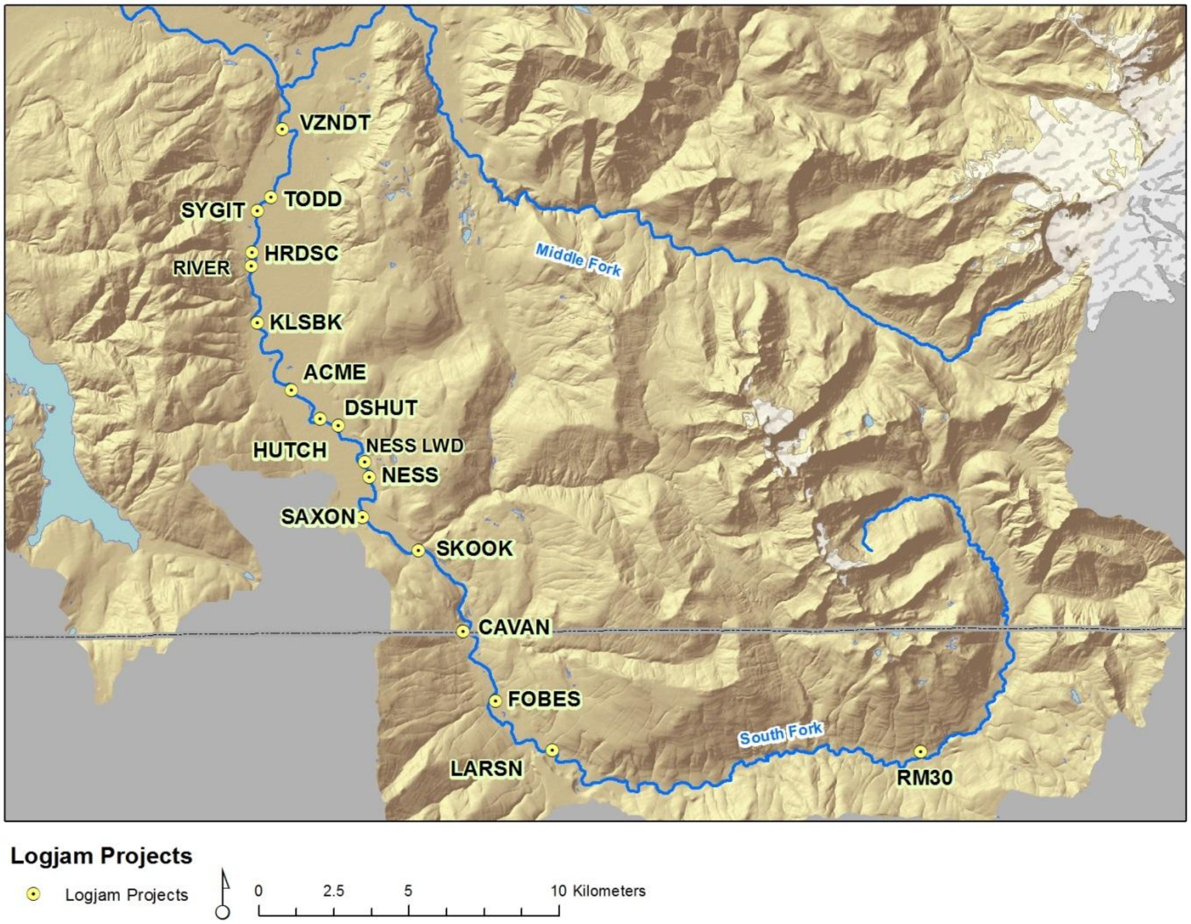


Table 53: South Fork Nooksack restoration projects.

Map ID	Project Name	River Mile	Year	Lead Sponsor
VZNDT	Van Zandt	1.1	2010	Nooksack Tribe
TODD	Todd	3.5	2008	Nooksack Tribe
SYGIT	Sygitowicz	4.0	2010	Nooksack Tribe
HRDSC	Hardscrabble	5.1	2012	Nooksack Tribe
RIVER	Riverfarm	5.5	2015	Whatcom CD
KLSBK	Kalsbeek	6.7	2007	Nooksack Tribe
ACME	Acme	9.0	2010	Whatcom County
DSHUT	DS of Hutchinson	9.8	2015	Nooksack Tribe
HUTCH	Lower Hutchinson	10.5	2006	Lummi Nation
NESS	Nesset's Reach LWD	11.5	2008	Lummi Nation
NESS	Nesset's Reach	11.5	2016-18	Nooksack Tribe
SAXON	Saxon	12.5	2012	Lummi Nation
SKOOK	Skookum	14.3	2010	Lummi Nation
SKOOK	Skookum 2	14.3	2017	Lummi Nation
EDFRO	Skookum-Edfro	15.3	2018	Lummi Nation
CAVAN	Cavanaugh	16.8	2012	Lummi Nation
FOBES	Fobes	18.5	2010	Lummi Nation
LARSN	Larson's Bridge	20.0	2001	Lummi Nation
LARSN	Larson's Bridge 2	20.0	2016-17	Lummi Nation
CMP18	Camp 18	21	2019	Lummi Nation
RM30	River Mile 30	30.0	2007	Lummi Nation

River Mile 30 Project

Project Description

Constructed in 2007, this project included 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 installation of four engineered logjams (Figure 54). 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 habitat objectives of the project included isolating the channel from a stream-adjacent landslide, creating scour pools, and sorting gravel to provide areas for spawning (Table 54). Project objectives were described in detail and success was assessed as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 54: Habitat structures in the RM 30 project reach.

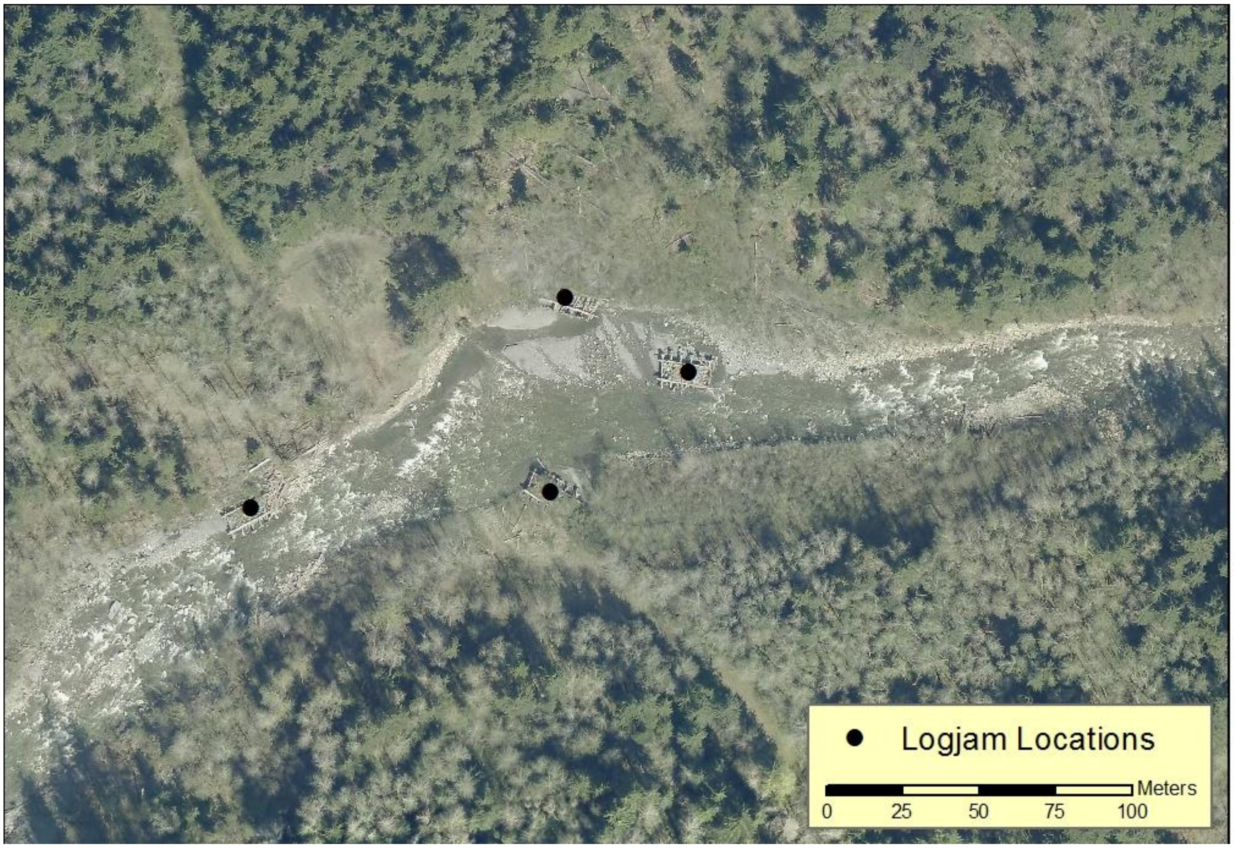


Table 54: RM 30 project objectives (cited from Natural Systems Design (NSD) 2019).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Alleviate scour impacts of the right bank landslide immediately upstream of the bridge imprint.	Sediment source reduction	Elevated fine sediment
Increase spawning use of the reach.	Spawning gravel retention	N/A
Increase channel type and unit diversity.	Habitat unit diversity	Low habitat diversity, Key habitat quantity
Increase instream habitat complexity through large woody debris (LWD) loading.	LWD Loading	Low habitat diversity
Create catchments for finer substrate.	Spawning gravel retention	N/A
Improve floodplain connection throughout the reach.	Floodplain reconnection	Low habitat diversity
Abandon spur road to the site, closing it to vehicle traffic.	Sediment source reduction	Elevated fine sediment

Project Objectives

Sediment Source Reduction
Based on aerial photo review, the majority of the unstable slope is vegetated and the road abandonment appeared effective (NSD 2019 Draft).

Spawning Gravel Retention
Finer sediment appears to be accumulating in the lee of the logjams, although no chinook spawning has been observed in this reach since the project has been completed (NSD 2019 Draft).

Habitat Unit Diversity
Habitat units have increased from six in 2005 (pre-project) to 10 in 2019 (Figure 55 and Figure 56). Previous monitoring showed an increase in pools associated with the structures and an increase in braiding relative to single-thread main channel (LNR 2009a, Maudlin and Coe 2012).

Figure 55: 2005 habitat mapping in the RM 30 Project (LNR 2005 data, photo from 2016).

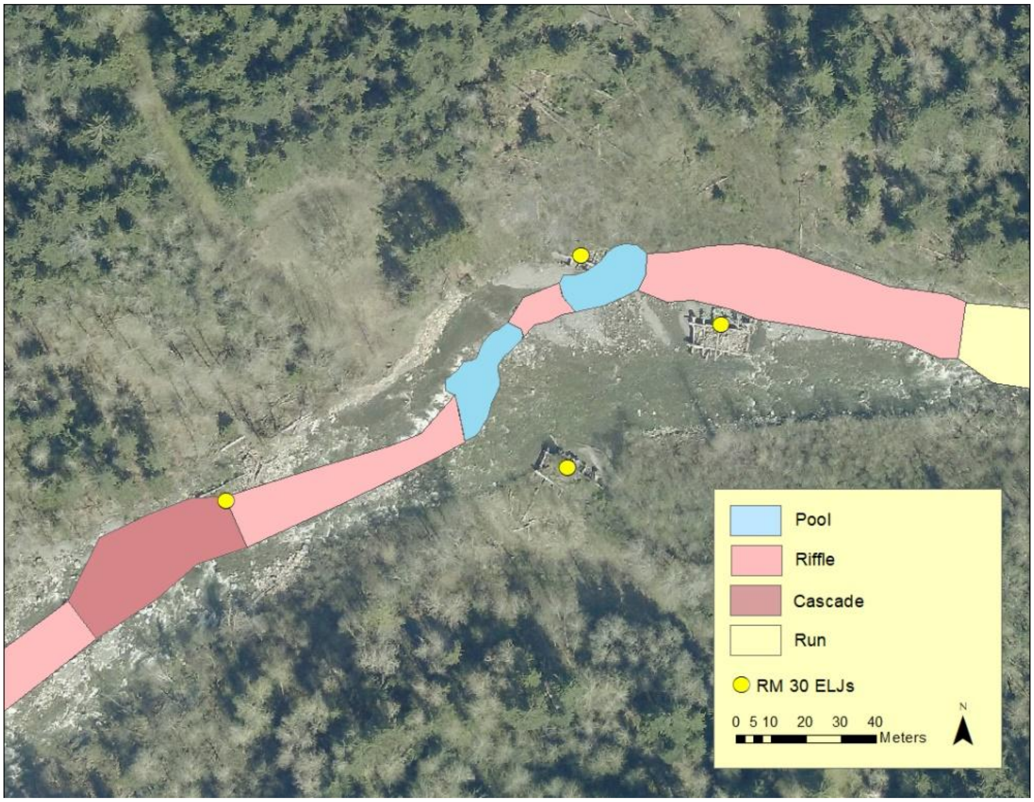
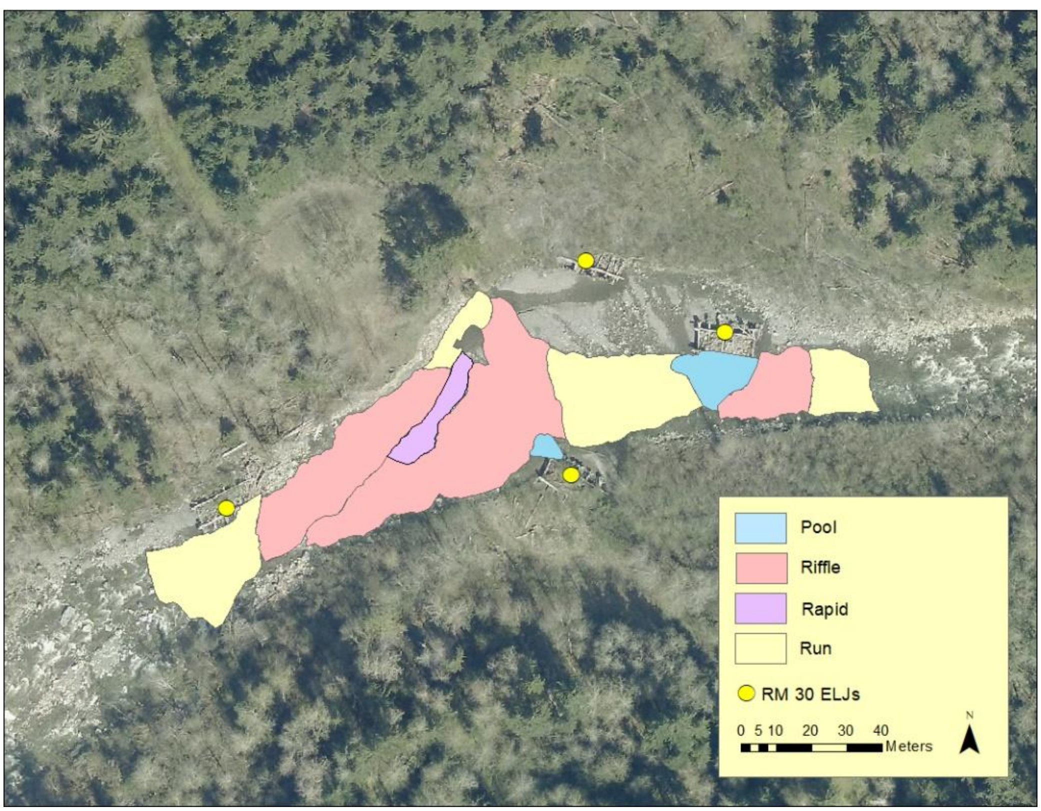


Figure 56: 2019 habitat mapping in the RM 30 Project (LNR 2019 data, photo from 2016).



LWD Loading

Engineered logjams have increased the wood loading in the reach (NSD 2019 Draft). The ELJs built in 2007 added nearly 600 square meters of wood to the project reach. There was only 300 square meters of logjams pre-project.

Floodplain Reconnection

Small floodplain has developed within the project reach (NSD 2019 Draft).

Conclusions and Recommendations

Natural Systems Design (2019 Draft) concluded that the project has been effective at achieving most of its objectives (Table 55). They suggested that increasing spawning use may not have been reasonable due to the partial fish passage barrier at RM 25 and note that increasing habitat diversity significantly is difficult given the channel gradient in the reach. The logjams constructed in this project have succeeded in slowing erosion of the hillslope adjacent to the bridge abutment that was removed 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 have been effective at trapping sediment, but because of the channel confinement, there is a low potential for additional floodplain habitat development. They note, based on habitat classification from hydraulic modeling, that the project does not have a great deal of benefit at low flows, although field mapping in 2009, 2011 and 2019 showed pool formation and instream cover associated with the structures. Additionally, habitat units have increased from six in 2005 to 10 in 2019.

Table 55: River Mile 30 Project objectives and success (NSD 2019 Draft).

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	Spawning gravel retention	**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	**Met**- increase in the number of logjams in the reach; habitat diversity not compared to target values. 569 square meters 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	**Partially Met**- small floodplain is 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.

Larson's Bridge and Larson's Bridge Phase 2 Projects

Project Description

The monitoring of these two projects was not separated in the *Upper South Fork Nooksack River Effectiveness Monitoring* report (NSD 2019 Draft). Constructed in 2001, the Larson's Bridge project included the construction of six engineered logjams, one of which was a 130 m woody revetment at the base of a large landslide. The logjams were constructed by excavating below the expected scour depth and stacking and inter-weaving the logs up to a height where the wood and back-filled gravel was providing adequate ballast. This project was the first major instream project in the Nooksack Watershed and one of the first engineered logjam projects built in the region. The project objectives included stabilizing a large landslide, pool formation, increased woody cover, increased side channel length, and gravel sorting for improved spawning (Table 56).

The Larson's Phase 2 project extends beyond the footprint of the original project, covering RM 21.1 to 19.7 of the South Fork (Figure 57). The project revisited the Larson's Bridge restoration work completed in 2001 to address additional habitat limitations in the reach and expand the area treated. The project included 28 structures including three log-reinforced riffles that spanned the channel. The Phase 2 project was completed in 2014-2015 and was intended to address the limiting factors of low habitat diversity and elevated water temperature through the placement of rock-ballasted engineered logjams, engineered log riffles, and excavated conventional engineered logjams within the main channel, side channels, and floodplain areas (Table 57). The Phase 2 project objectives were described in detail and success was assessed as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 57: Larson's Bridge and Phase 2 project.

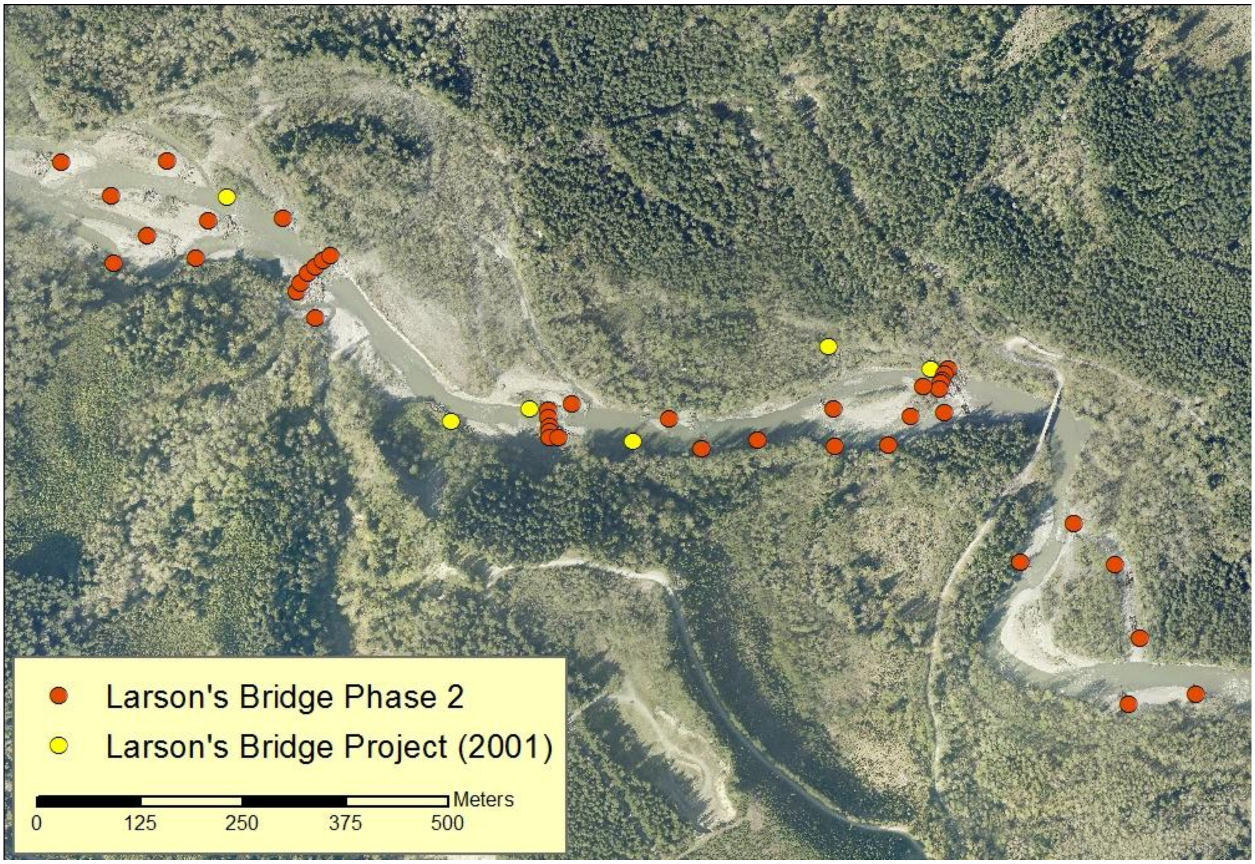


Table 56: Larson's Bridge project objectives (Lummi Natural Resources (LNR) 2002).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase secondary channel length	Habitat unit diversity; secondary channel length	Low habitat diversity
Relocate the thalweg away from the landslide	Sediment source reduction	Elevated fine sediment
Reduce fine sediment originating in the reach	Sediment source reduction	Elevated fine sediment
Increase pool frequency, residual depth and cover	Pool formation	Lack of key habitat
Increase channel roughness	Floodplain connectivity	N/A
Increase abundance of adult salmonids	Increase salmon population	N/A

Table 57: Larson's Bridge Phase 2 project objectives (cited from NSD 2019 Draft).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
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	Elevated water temperature
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	Low habitat diversity
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	Low habitat diversity
Create 13 primary pool habitat units by 2016 through placement of wood structures.	Pool formation	Lack of key habitat
Reestablish an anabranching channel planform by 2020 by improving the stability of up to 5 existing mid-channel forested islands using wood structures.	Secondary channel length	Low habitat diversity

Project Objectives

Pool Formation

Based on field surveys, pools were immediately formed at each of the logjams in the Phase 1 project (LNR 2002, Figure 58). Subsequent monitoring showed the pools persisted in 5 of the 6 logjams and were some of the deepest pools found in a survey of all South Fork projects (Maudlin and Coe 2012).

Habitat monitoring in the summer of 2019 found 13 primary pools and three secondary pools in the project reach (Figure 59). Eleven of the pools were formed by ELJs, and one was a natural logjam. The deepest ELJ-formed pool was over 3 meters deep.

Figure 58: 2005 habitat mapping in the Larson's Phase 1 and 2 Project area (LNR 2005 data, photo from 2016).

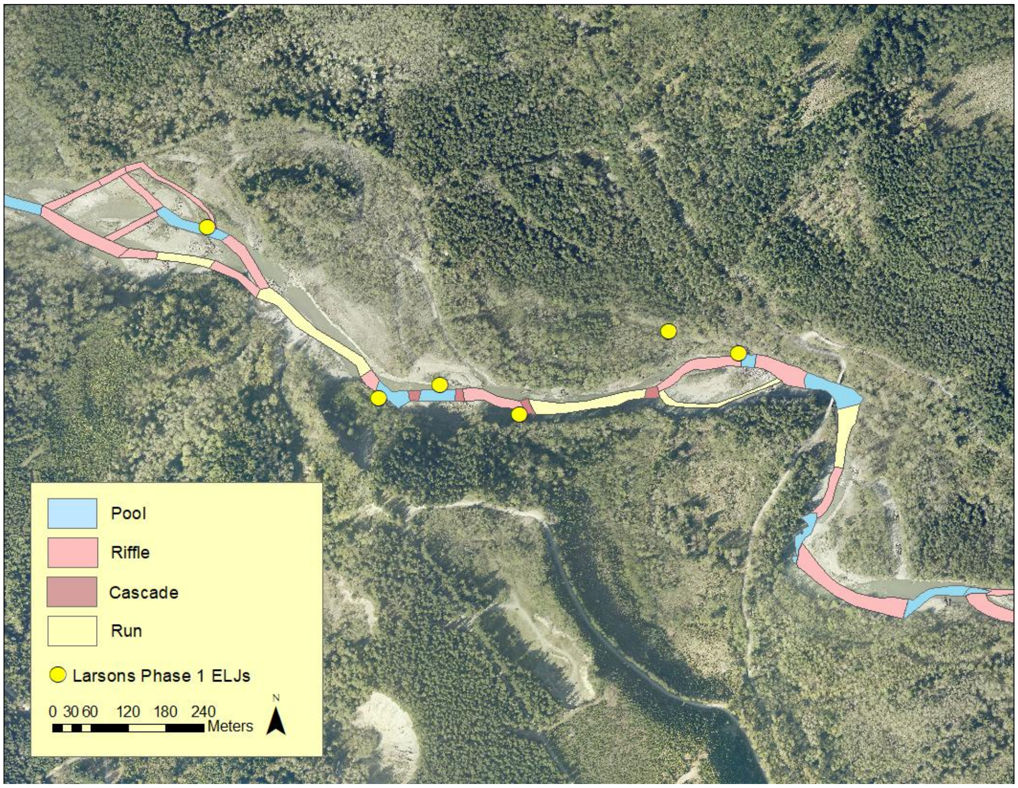
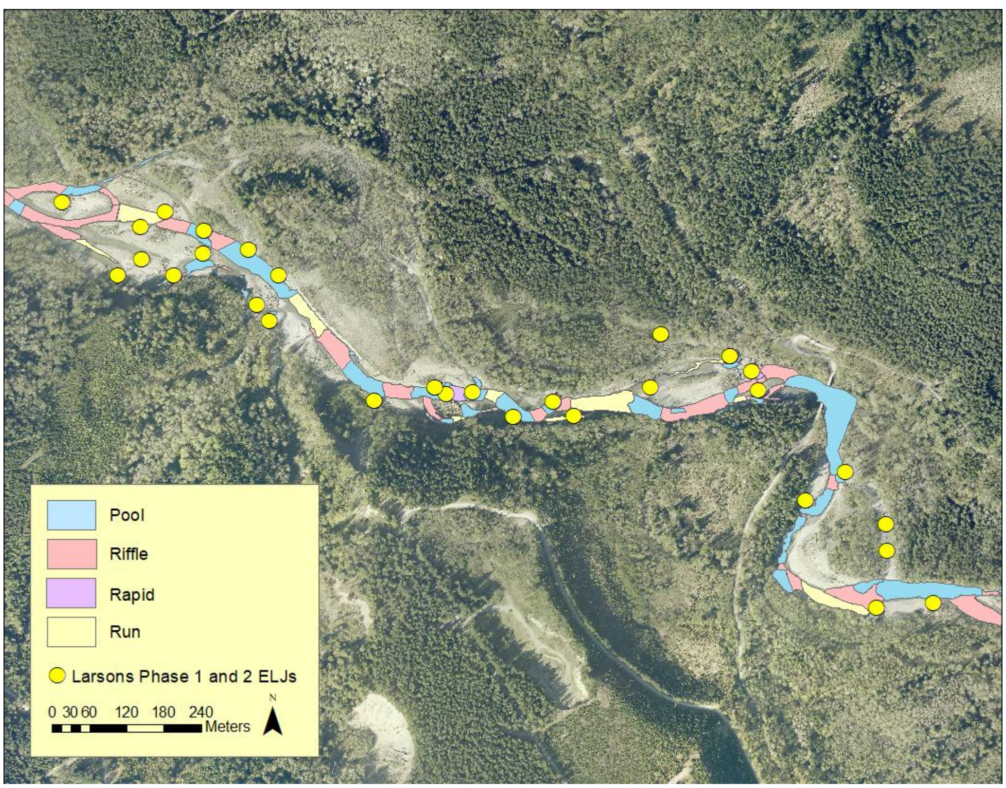


Figure 59: 2019 habitat mapping in the Larson's Phase 1 and 2 Project area (LNR 2019 data, photo from 2016).



Secondary Channel Length

The Phase 1 project led to an immediate increase in floodplain channel length at higher flows and a decrease in main channel length (LNR 2002). In the time between the two phases of the project this secondary channel length was lost due to channel changes and the mainstem channel continued to shorten slightly.

Based on hydraulic modeling, NSD found an increase in side channel length at the 1-year peak flow discharge (NSD 2019 Draft). NSD further identified that the project was beginning to establish an anabranching channel planform.

Floodplain Reconnection

Monitoring of the Phase 1 project showed the project increased the amount of woody debris interacting with the channel (LNR 2002, NSD 2019 Draft). Monitoring of other roughness elements found bed-form variation increased between 1998 and 2002 due to pool formation (LNR 2002).

Based on hydraulic modeling of the post-project conditions, NSD found increased floodplain activation due largely to the increase in side channel length rather than a broader reconnection of the floodplain surfaces (NSD 2019 Draft).

Sediment Reduction

Based on aerial photo review, the Phase 1 project has isolated the river from the landslide. The slide continues to fail, but the lower slopes are revegetated and the sediment basin that was created behind the logjam has filled with landslide debris and revegetated.

Fine sediment monitoring of the substrate found no change in percent fine sediment or embeddedness following the Phase 1 project (LNR 2002).

Thermal Refuge

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 data). In summer 2019, continuous temperature data showed no thermal refuge at the primary pool at the downstream channel-spanning logjam (LNR 2019 data).

Increase Salmon Population

The reach has consistently seen a high number of spawners. LNR (2002) could not separate an increase in population from a redistribution of fish into the newly created habitat. Snorkel surveys in the Upper South Fork Nooksack in summer 2018 found nearly 75% of chinook salmon preferred large wood, with nearly 50% of all chinook in the Upper South Fork observed in the Larson's Reach (NSD 2019 Draft).

Conclusions and Recommendations

Monitoring found that the Phase 1 project met objectives related to pools and sediment source reduction, but failed to increase the side channel length after an initial increase and subsequent loss (Table 58). Going forward it will be difficult to separate the influence on the channel of the Phase 1 project from the Phase 2 project spanned the original Phase 1 project reach. Monitoring the landslide stability can still be related to the Phase 1 project, since the Phase 2 project did not include sediment source reduction as an objective. NSD (2019 Draft) concluded that the Larson's Phase 2 project is on its way to achieving most of the project objectives (Table 59). They found that the single thread channel was beginning to become a more complex anabranching channel and that much of the wood was interacting with the low flow channel. Based on modeling, NSD found pools were present throughout the Phase 2 project reach, but did not identify many primary pools. Over 7,500 square meters of logjams is in the project reach, an increase from about 1,700 square meters in the 2002 logjam survey.

Table 58: Larson's Bridge Phase 1 objectives and success.

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase secondary channel length	Habitat unit diversity; secondary channel length	**Not met**- the project led to an immediate short-term increase in secondary channel length, but this has been lost.
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	**Met**- increase in pools and wood cover, uncertain how Phase 2 affected these results.
Increase channel roughness	Floodplain Reconnection	**Met**- increase in wood flow impedance and bed-form roughness.
Increase abundance of adult salmonids	Increase salmon population	**Uncertain**- adult and redd monitoring show consistent use.

Table 59: Larson's Bridge 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. The Phase 1 project also met this objective for a period of time.
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 13 primary pool units in 2019.
Reestablish an anabranching channel planform by 2020 by improving the stability of up to 5 existing mid-channel forested islands using wood structures.	Secondary channel length	**Partially met**- the project is increasing channel braids; longer-term monitoring of bar stability and vegetation growth is needed to determine island formation.

Fobes Project

Project Description

The Fobes project was constructed in 2010 and consisted of 14 engineered logjams to provide improved holding habitat (deep pools with wood cover) in the core spawning area for South Fork Nooksack early chinook (Figure 60). The project also intended to provide local scour and woody cover in the cool water influence area of Fobes Creek (Table 60). The structures were built of large pieces placed around piles and tied together with manila rope. Project objectives were described in detail and success was assessed as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 60: Fobes Project reach and structures.

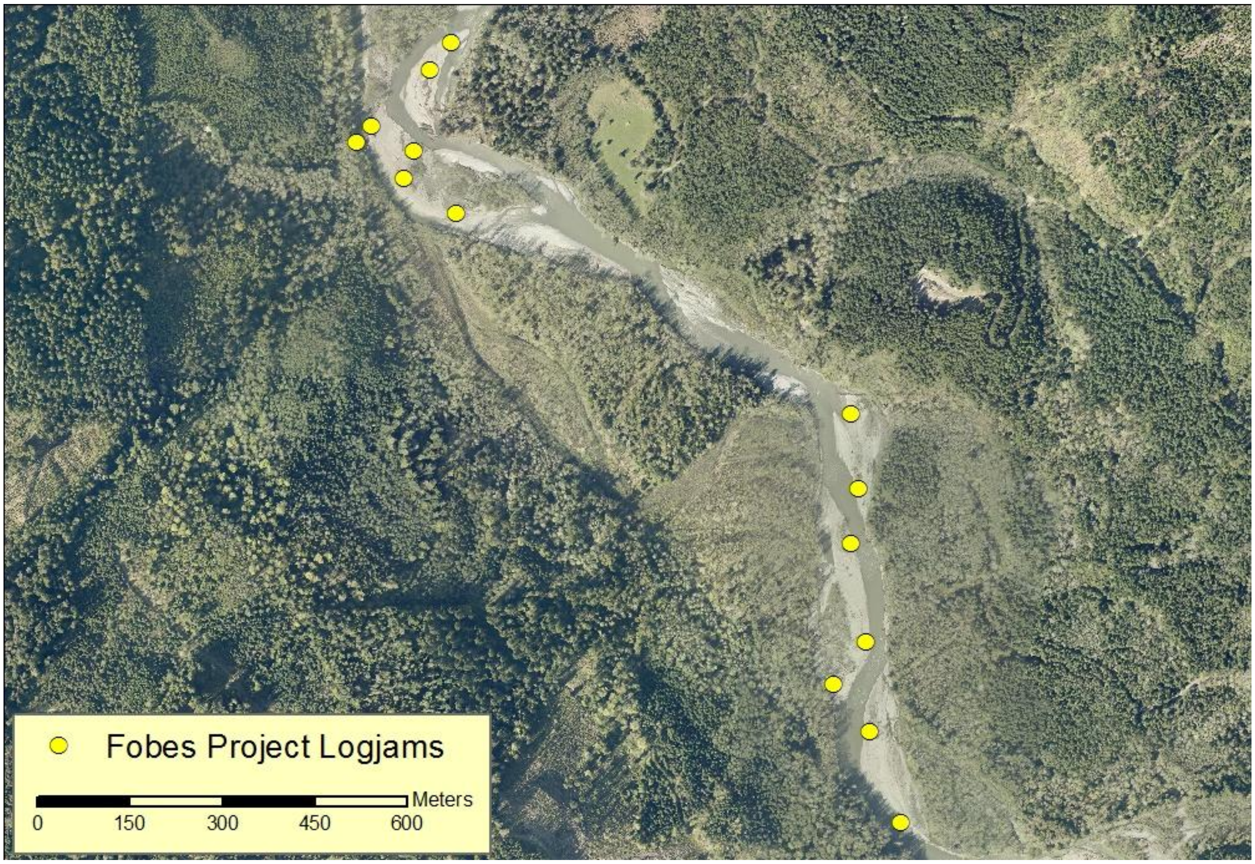


Table 60: Fobes project objectives (cited from NSD 2019).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
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	Low habitat diversity
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	Lack of Key Habitat
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	Elevated water temperature
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	Low habitat diversity

Project Objectives

Habitat Diversity

Based on remote sensing, NSD (2019 Draft) found that 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. Habitat unit diversity increased from 19 primate habitat units in the project reach in 2005 to 34 in 2019 field surveys (Figure 61 and Figure 109). In high flow conditions, the amount of wood cover is more than 6,000 m^2, while the amount in contact with the low flow channel is approximately 2,200 m^2 (LNR 2019 data).

Figure 61: 2005 habitat mapping in the Fobes project area (LNR 2005 data, photo from 2016).

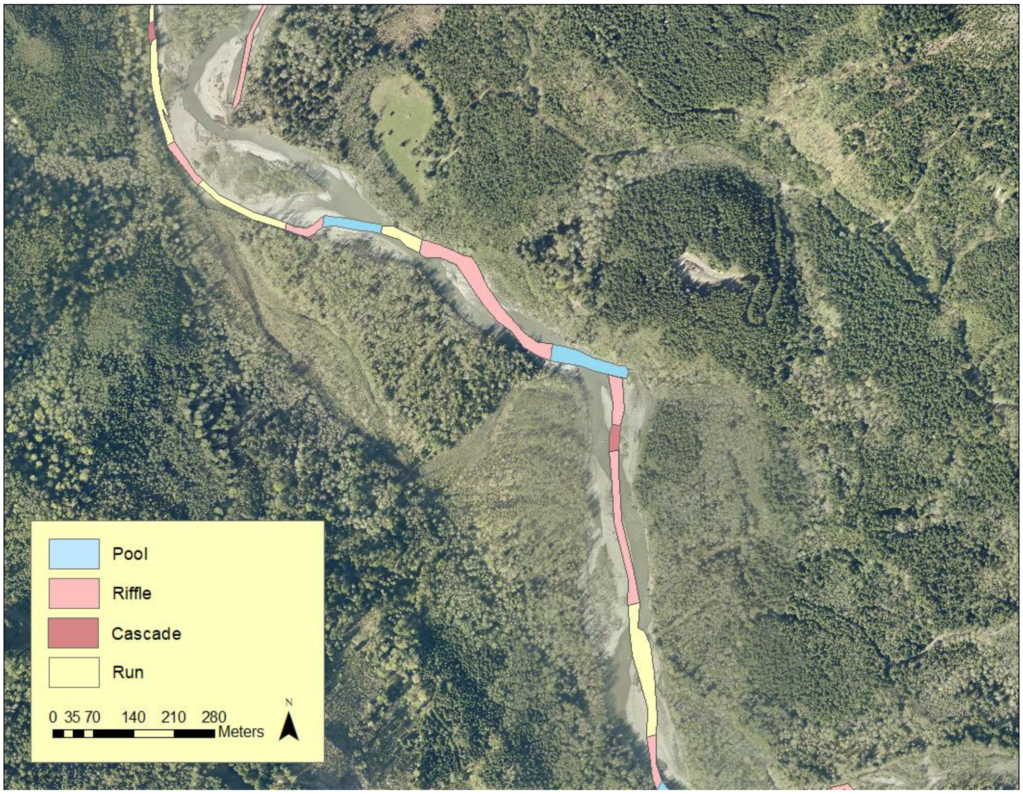
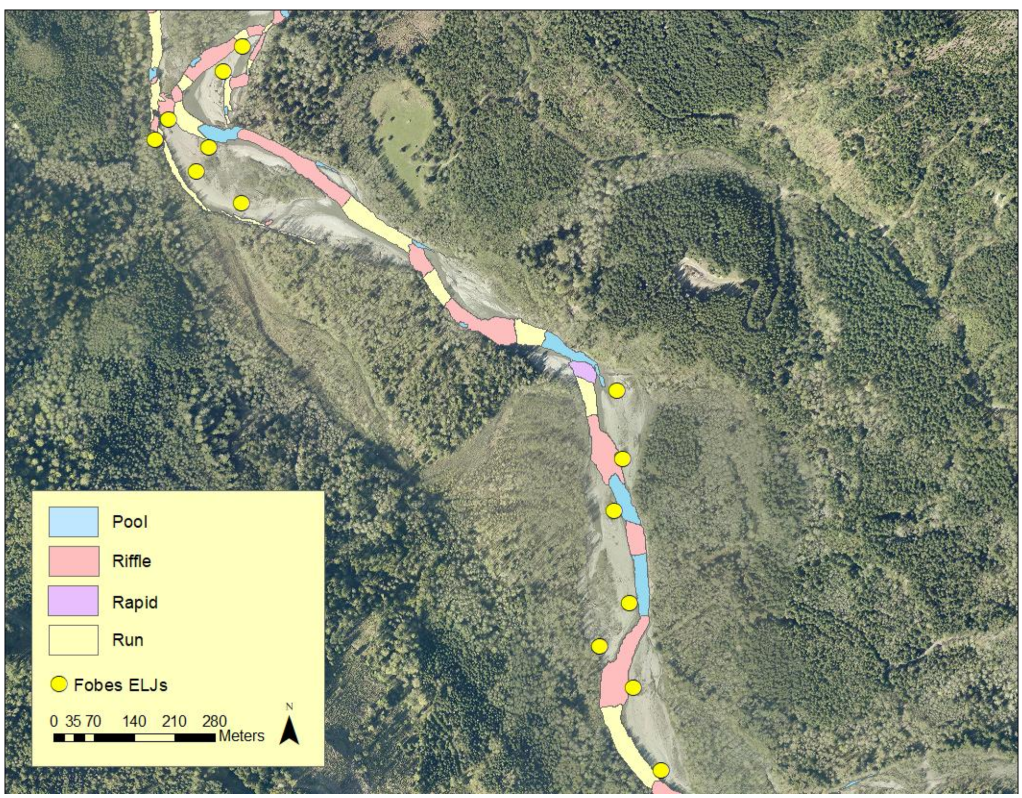


Figure 62: 2019 habitat mapping in the Fobes project area (LNR 2019 data, photo from 2016).



Pool Formation

Based on 2019 habitat surveys, LNR found the pools increased from four to seven primary pools. However, only five primary pools have residual pool depths of 1 meter or greater. Large wood formed 20% of the pools in 2019.

Thermal Refuge Creation

Three pools were measured and no thermal refuges were detected, although a survey focused on finding refuge areas was not conducted (NSD 2019 Draft). Discrete temperature data in August 2019 indicated no thermal refuge about 100 meters downstream of the Fobes Creek confluence.

Floodplain Reconnection

Hydraulic modeling of the project reach in 2017 showed 1.43 acres of off-channel habitat compared to 0.82 acres from the pre-project area, which was based on field surveys. This indicates a potential increase in available off-channel habitat (NSD 2019 Draft). Modeling of the 2-year peak flow showed additional habitat is connected at higher flows (NSD 2019 Draft). Counter to the modeling comparison, channel incision was measured up to 4 feet locally between 2013 and 2017 LiDAR (LNR data).

Conclusions and Recommendations

While most of the project objectives were met, NSD (2019 Draft) concluded that the restoration design and construction methodology employed for the Fobes project were not aggressive enough to enact significant geomorphic change (Table 61). They found that most of the logjams were not interacting with the low flow channel at the time of their surveys and felt that the lack of interaction of the ELJs with the channel has prevented the project from dramatically influencing geomorphic and habitat conditions.

Table 61: 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 habitat units, 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 6,000 square meters under the OHW. The amount in contact with the low flow channel is only about 2,200 square meters. Habitat diversity increased from 19 to 34 main channel units since baseline conditions.
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 in the reach and increased the average maximum depth of pool. Pool spacing was not compared to targets.
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 was observed. 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	**Uncertain-** hydraulic modeling showed a potential increase in off-channel habitat when compared to field mapping; field observations and surface model interpretation indicate continued local floodplain incision.

Cavanaugh Island Project

Project Description

The Cavanaugh Island project extends from RM 17.1 to 16.5 along the Upper South Fork Nooksack River (Figure 109). The project was completed in 2012 and was intended to address low habitat diversity and elevated summer water temperatures through the placement of six engineered logjams along gravel bars and banks of the main-stem channel and nine small habitat structures within the Cavanaugh Island side channel (Table 62). 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). Project objectives were described in detail and success was assessed as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 62: Cavanaugh Island project location.

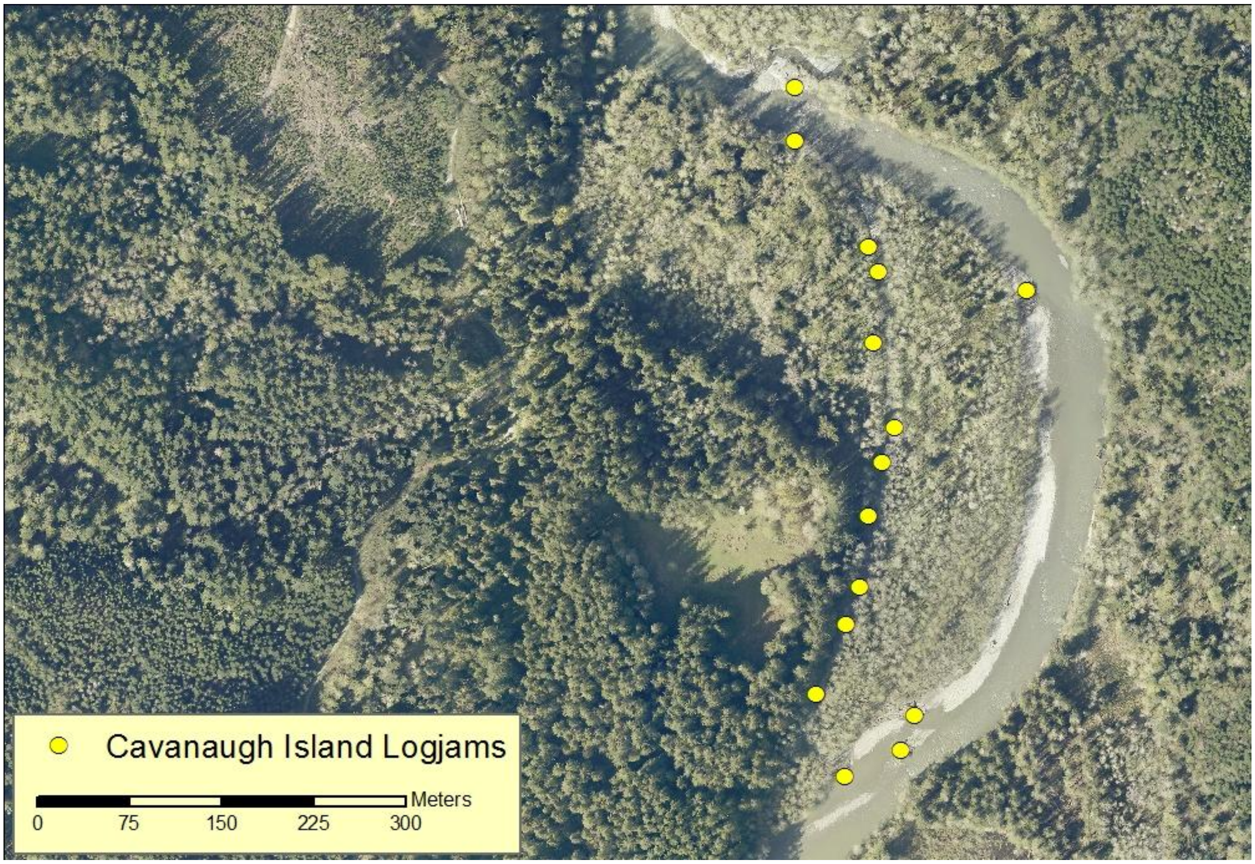


Table 62: Cavanaugh Island project objectives (cited from NSD 2019 Draft).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
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	Lack of Key Habitat
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	Low habitat diversity
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.	Thermal refuge creation	Elevated water temperature
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.	Riparian habitat	Elevated water temperature

Project Objectives

Pool Formation

Habitat monitoring in the summer of 2019 showed that primary pools remained at two (Figure 63 and Figure 64). Neither of these pools are formed by wood or ELJs. Many of the engineered logjams were not interacting with the low flow channel. Eight of the 14 logjams in the project area are interacting with the low flow channel, totaling nearly 500 square meters of wood. The NSD report (2019 Draft) will provide updates to these numbers with a more comprehensive analysis.

Figure 63: 2005 habitat mapping in the Cavanaugh Island project area (LNR 2005 data, photo from 2016).

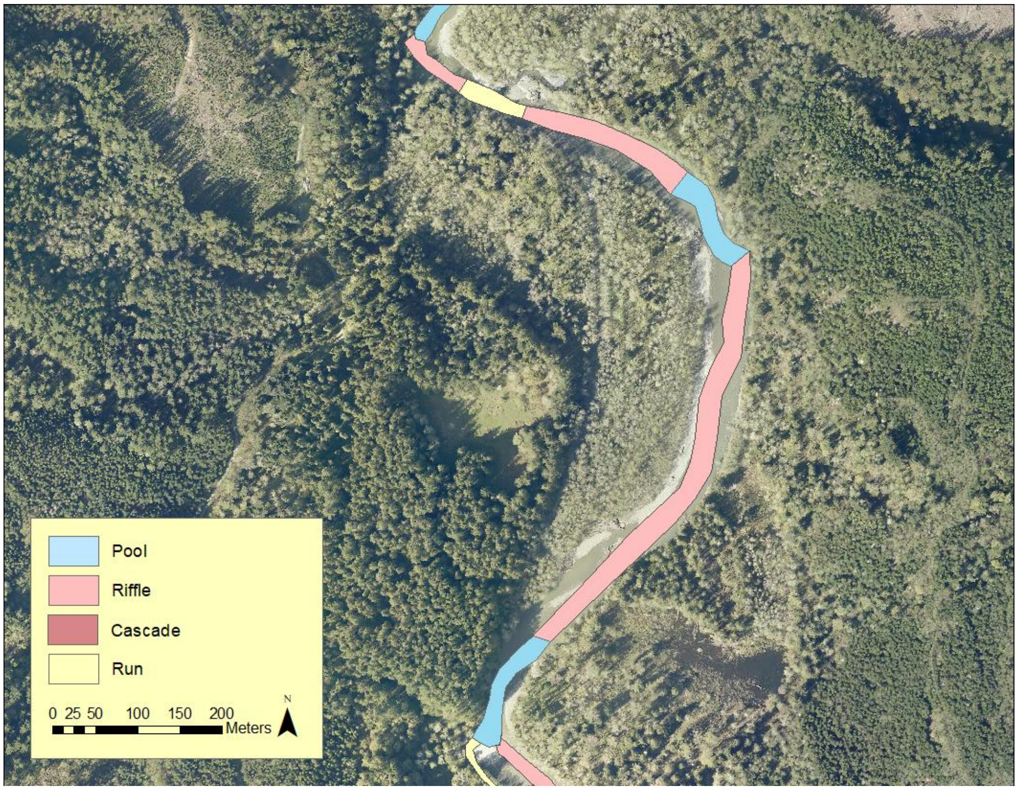
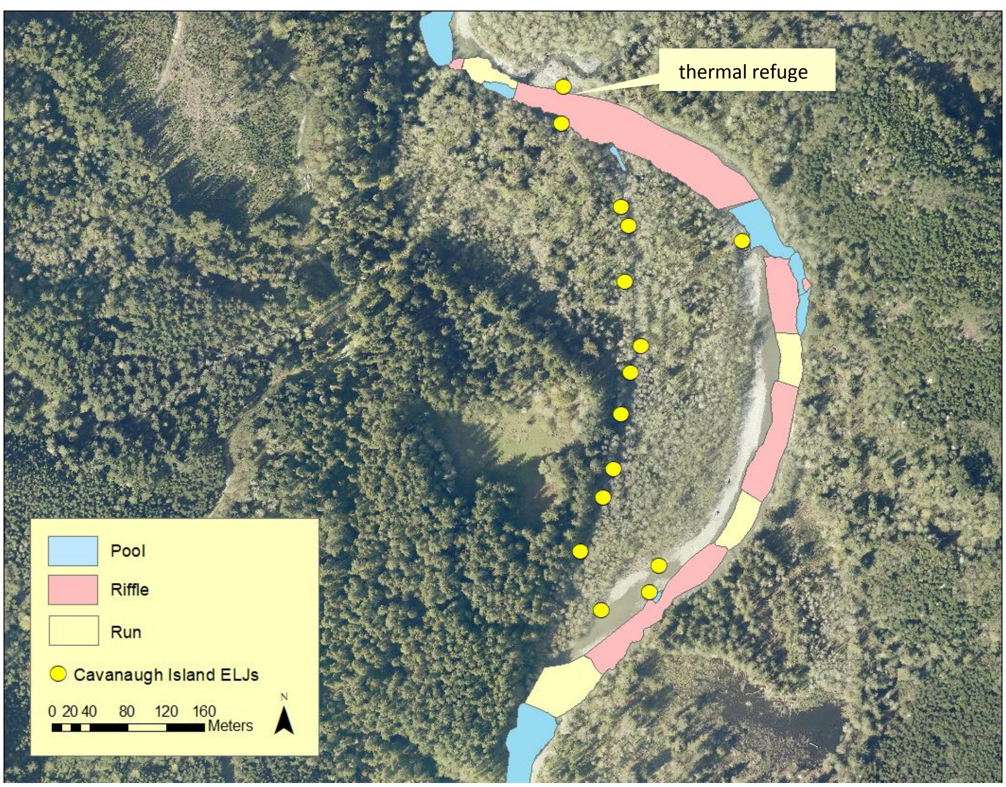


Figure 64: 2019 habitat mapping in the Cavanaugh Island project area (LNR 2019 data, photo from 2016).



Secondary Channel Length

The Cavanaugh Island side channel does not maintain enough flow during the low flow period to allow spawning and no increase in spawning use was noted (NSD 2019 Draft).

Thermal Refuge

A 1.2°C decrease in temperature with depth was noted for one of the two locations selected as potential thermal refuges (NSD 2019 Draft). This refuge was located at the confluence with Cavanaugh Creek; the other structure located at a seep did not show a cool water influence. Discrete temperature measurements on July 9, 2019 indicated a thermal refuge in the small ELJ scour pool (13.6°C) at the mouth of Cavanaugh Creek compared to ambient temperature upstream (15.6°C) of the Cavanaugh Creek confluence (LNR 2019 data) (Figure 64). At low flows, the small pool is mostly isolated from main channel the South Fork.

Riparian Habitat

There is a time lag before riparian function can be assessed. Logjams were constructed to protect the upstream end of the island and the ORV trail was decommissioned. While planting occurred following construction, riparian conifer planting was not noted (NSD 2019 Draft).

Conclusions and Recommendations

Effectiveness monitoring found that the majority of engineered logjams built within the Cavanaugh Island project reach are not interacting enough with the mainstem channel to meet the project's habitat objectives (NSD 2019 Draft) (Table 63). They suggest that the logjams do not obstruct enough flow to raise water surface elevations at the upstream end of the side channel during low flow periods, or create deep scour pools for holding adults. They did find that the logjam at the confluence of Cavanaugh Creek had formed a secondary pool and observed some temperature decrease with depth in the pool where the flow was unmixed. Cavanaugh Creek avulsed and is now interacting with the ELJ at its mouth, creating a thermal refuge in the small (secondary) scour pool.

Table 63: 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 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 channel from the terrace bordering the western side of the channel.	Thermal refuge creation	**Partially Met**- The logjam located at the confluence with Cavanaugh Creek showed a decrease in temperature with depth. At low flows, 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.	Riparian habitat	**Met**- Logjams have been constructed and the ORV trail has been recommissioned. Initial planting occurred and additional riparian planting was suggested.

Skookum-Edfro Phase 2 Project

Project Description

The Skookum-Edfro Phase 2 project is located downstream from the Cavanaugh Island project and extends from RM 15.4 to RM 14.9 (Figure 65). The project was built during the summer of 2018 and was intended to address the limiting factors of low habitat diversity, high water temperatures, and lack of key habitats through the placement of fifteen ELJs along the banks of the mainstem channel and on gravel bars (Table 64). Project objectives were described in detail as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 65: Skookum-Edfro Phase 2 project location.

Table 64: Project objectives from the Skookum-Edfro Phase 2 project (cited from NSD 2019 Draft).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase habitat diversity and key habitats by forming 7 primary pools with ELJs within 5 yrs.	Habitat Unit Diversity	Low habitat diversity
Increase pool frequency by constructing 12-13 ELJs in areas that would provide holding adjacent to stable spawning habitat.	Pool formation	Lack of Key Habitat
Create one thermal refuge by co-locating the primary pool with cool-water input within 5 years.	Thermal refuge creation	Elevated water temperature
Increase floodplain activation at a broader range of flows to reduce hydraulic energy and provide velocity refugia for juveniles.	Floodplain reconnection	Low habitat diversity
Improve viable spawning areas by placing ELJs along the channel margin to increase deposition and storage of bedload sediments.	Spawning gravel retention	N/A
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	Low habitat diversity

Project Objectives

Habitat Diversity

The number of primary habitat units in the main channel in the project area increased from eight units in 2005 (pre-project) to 11 units in 2019, although this increase doesn't appear related to the recently constructed engineered logjams (LNR data). Engineered log jams also added complex cover and 13 new secondary pools (Figure 66 and Figure 67).

Pool Formation

No new primary pools were identified in the first year of post-project monitoring. Engineered log jams formed 13 new secondary scour pools, three of which are adjacent to existing spawning areas (NSD 2019 Draft). Seven of these pools were isolated at low flow during summer 2019 habitat surveys (LNR 2019 data, Figure 67).

Figure 66: 2005 habitat mapping in the Skookum Edfro Phase 2 project area (LNR 2005 data, photo from 2016).

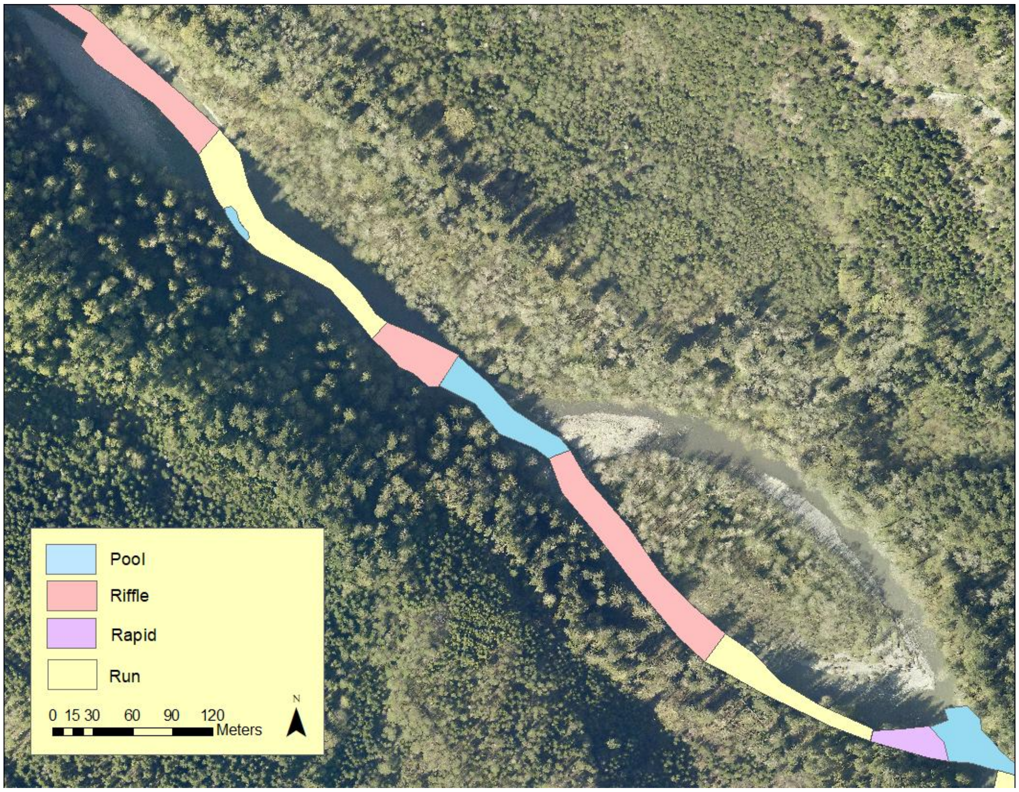
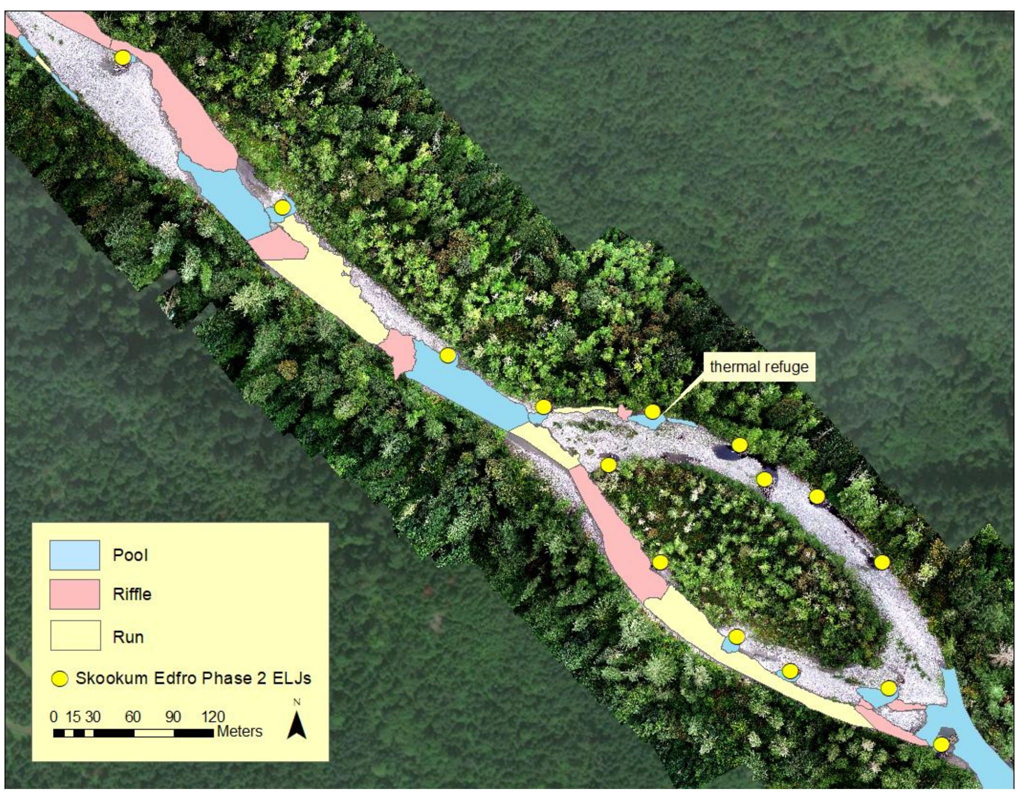


Figure 67: 2019 habitat mapping in the Skookum Edfro Phase 2 project area (LNR 2019 data, photo from 2019).



Thermal Refuge Creation

The scour pool at ELJ 7 located just downstream of the mouth of Edfro Creek provides thermal refuge in the right bank side channel from warm summer temperatures in the main channel of the South Fork (Figure 67 and Figure 68). However, during low flows, adults are unlikely to be able to access this refuge; many coho juveniles have been observed here.

Floodplain Reconnection

There has been no monitoring to date of floodplain activation.

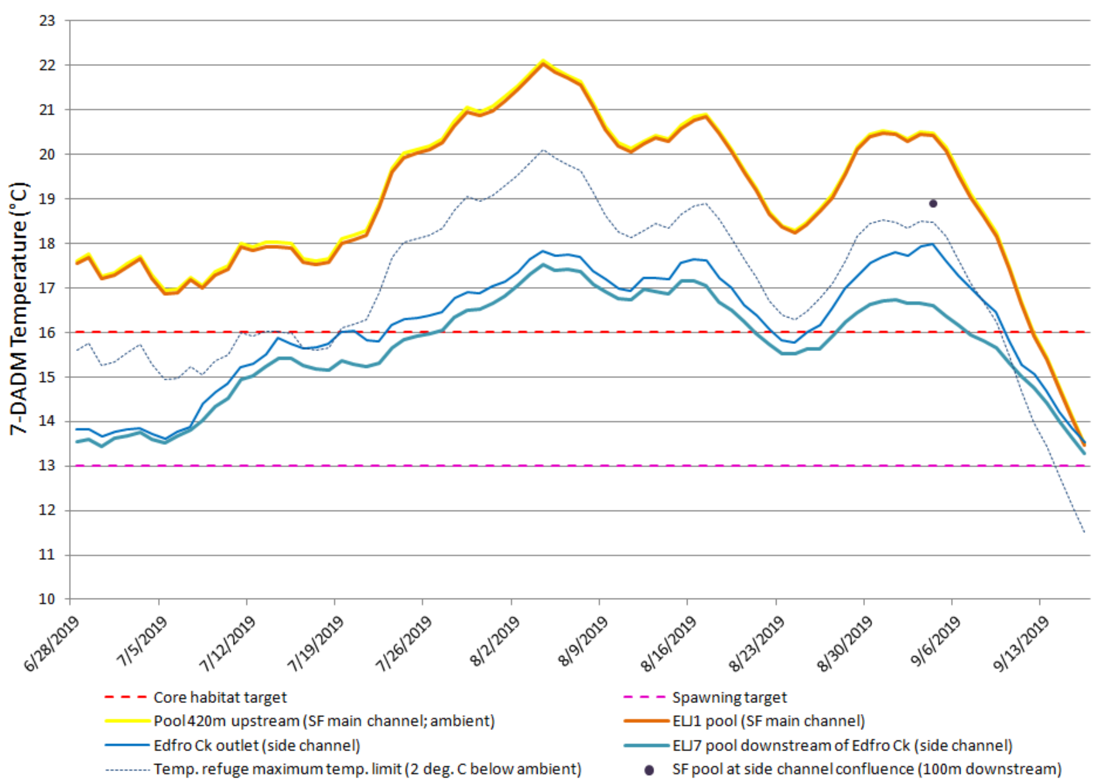
Spawning Gravel Retention

There has been no monitoring to date of sediment deposition and storage.

Secondary Channel Length

Monitoring in 2019 did not find a low flow split and side channel associated with the Edfro forested island. Pool formation and wood deposition associated with the engineered logjams on the north side of the island indicate connection at higher flow. A groundwater-fed slough was present in the lower section of this area (Figure 67).

Figure 68. 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).



Conclusions and Recommendations

The project has been in place for one year and the monitoring results are limited. Engineered log jams increased pool frequency but no new primary pools have yet formed. ELJ 7 created a thermal refuge in the slough channel though access is limited at low flows (Table 65). Continued monitoring will inform the status of project objectives.

Table 65: 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.	Habitat unit diversity	**Not Met**- No new primary pools have been formed in the first year of post-project monitoring.
Increase pool frequency by constructing 12-13 ELJs in areas that would provide holding adjacent to stable spawning habitat.	Pool formation	**Met**- ELJs formed 13 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	**Uncertain** – This objective lacks monitoring data.
Improve viable spawning areas by placing ELJs along the channel margin to increase deposition and storage of bedload sediments.	Spawning gravel retention	**Uncertain** – This objective lacks monitoring data.
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	**Uncertain** – There is evidence of high flow connectivity around Edfro Island, but the area was not connected during the low flow period in 2019.

Skookum Reach Project

Project Description

The Skookum Reach Project was constructed in 2010 and included the setback of ~850 m of stream-adjacent road, the installation of 3 engineered logjams along a terrace of the South Fork Nooksack, and revegetation of the old road. Following the acquisition of the south bank of the river by the Whatcom Land Trust, the project was revisited in 2016-17 (the Skookum-Edfro Phase 1 project) with the addition of four more logjams, four habitat structures in the side channel, the removal of ~100 m of riprap bank protection, a culvert removal over Christie Creek, and the removal of a cabin in the 100-year floodplain (Figure 69). The Phase 1 project also revisited the three structures built in 2010 and enhanced them so that they projected further into the channel. The goal of the project was to take advantage of the cool water influence of Skookum Creek and the hatchery outfall 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. The structures were intended to scour deep pools with woody cover in the plumes of these two cool water sources (Table 66). Project objectives were described in detail and success was assessed as a part of the *Upper South Fork Nooksack Habitat Effectiveness Monitoring* (NSD 2019 Draft).

Figure 69: Skookum-Edfro Phase 1 project location.

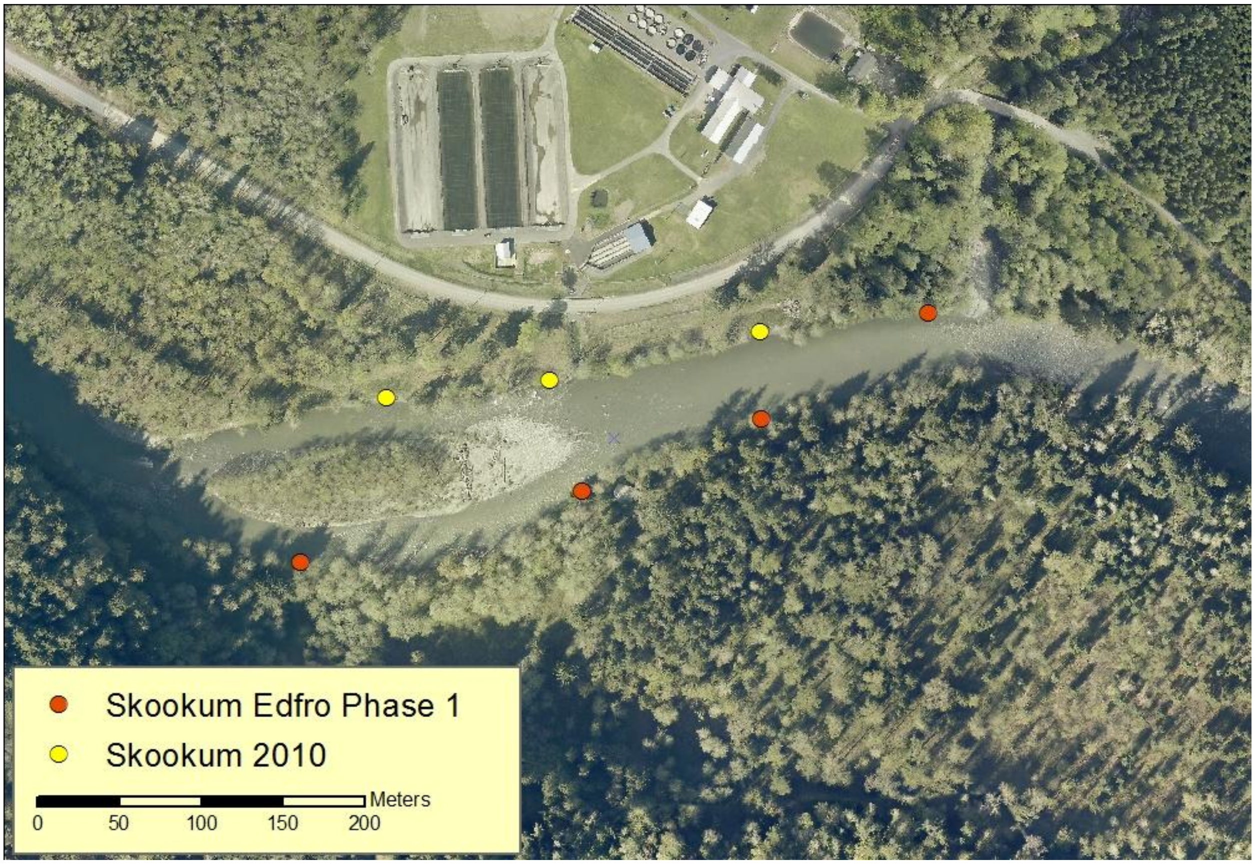


Table 66: Project objectives from the Skookum and Skookum-Edfro Phase 1 projects (cited from NSD 2019 Draft).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase habitat diversity and key habitats by forming four primary pool units with ELJ placement within five years.	Pool formation	Lack of Key Habitat
Create two thermal habitat refuge areas by co-locating new primary pool units with existing cool-water inputs within five years.	Thermal refuge creation	Elevated water temperature
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	Low habitat diversity
Increase key habitat quantity in 3,400 ft of South Fork channel	Pool formation	Lack of Key Habitat
Relocate 3,800’ of stream-adjacent road, well away from the river (replace with 3,000 ft of road).	Riparian habitat	Elevated water temperature
Increase habitat diversity in 1,100 ft of South Fork channel	Habitat unit diversity	Low habitat diversity
Provide refugia from elevated water temperatures in three holding pools (previously two pools).	Thermal refuge creation	Elevated water temperature

Project Objectives

Pool Formation

Baseline monitoring in 2005 identified one pool at the confluence of the two channels around a small forest patch in the reach (Figure 70). Effectiveness monitoring in 2011 found that two of the three structures built in 2010 had formed small secondary pools (Maudlin and Coe 2012). In 2018, NSD identified two secondary pools during habitat modeling and a field survey in the project reach. One of the pools was associated with the engineered logjam at the confluence with Skookum Creek (NSD 2019 Draft). Habitat surveys in 2019 found five secondary pools at engineered log jams (Figure 71), but only one pool was deeper than 1 meter residual pool depth.

Figure 70: 2005 habitat mapping in the Skookum and Skookum Edfro Phase 1 project area (LNR 2005 data, photo from 2016).

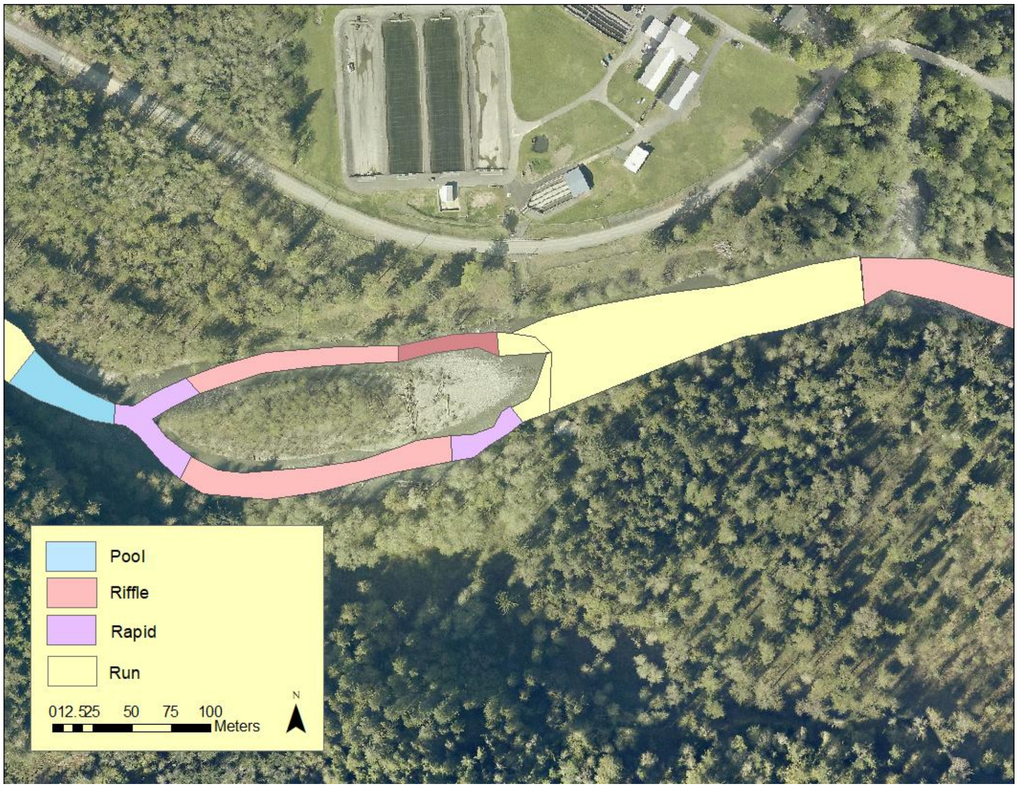
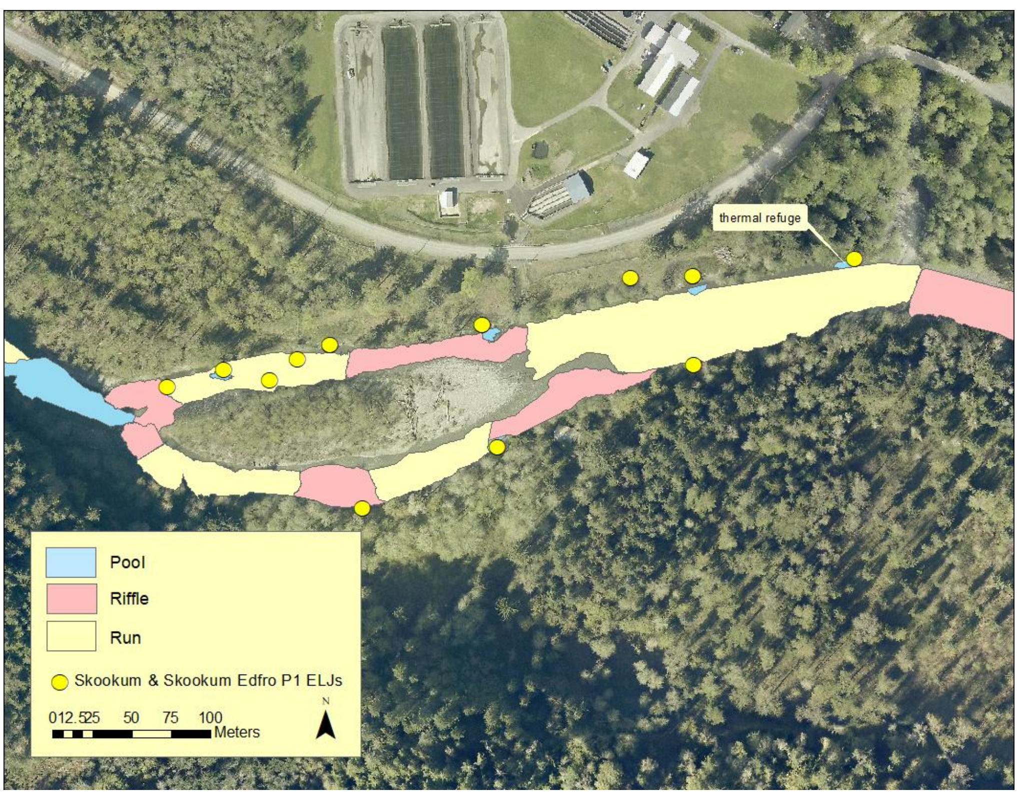


Figure 71: 2019 habitat mapping in the Skookum and Skookum Edfro Phase 1 project area (LNR 2019 data, photo from 2016).



Edge Habitat Improvement

NSD (2019 Draft) noted that the four habitat structures were providing complex edge habitat in the side channel. Riprap bank armoring was removed as a part of the project.

Riparian Habitat

Saxon Road was relocated out of the riparian zone and the old road was reforested.

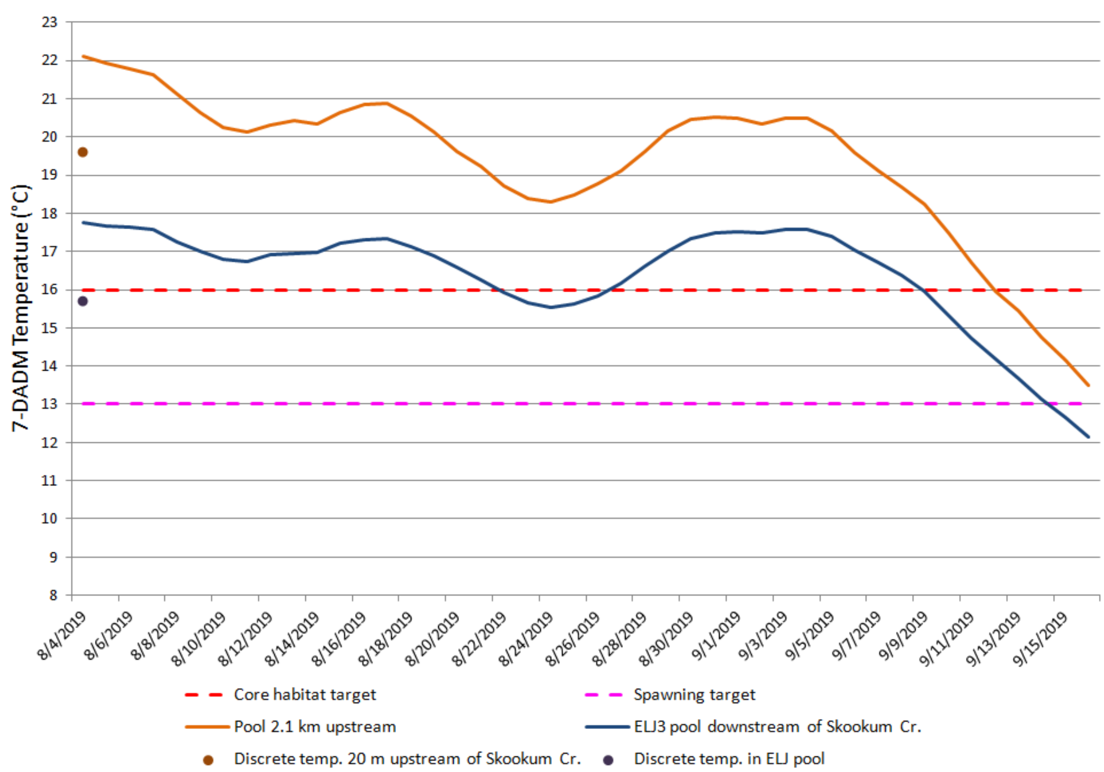
Habitat Unit Diversity

Habitat units in the project reach increased from eight in 2005 (pre-project) to 10 in 2019 (LNR 2019 data) (Figure 70 and Figure 71).

Thermal Refuge Creation

Three logjams were installed adjacent to the cool water area of Skookum Creek and the hatchery outfall and one of these has formed a secondary pool (NSD 2019 Draft). Temperature measurements in June of 2018 showed a reduction in water temperature at Skookum Creek (1.2°C less) and in an isolated pool (1.5°C less) ~40 m downstream of Skookum Creek relative the average main channel temperature. In summer 2019, continuous temperature loggers were installed above the Skookum Creek confluence and below the Skookum Creek confluence in the secondary pool at ELJ 3. The upstream logger was lost in high flows but a discrete temperature measurement in August was 3.9°C warmer than the discrete ELJ pool temperature, indicating a thermal refuge in the small pool (Figure 72). The nearest continuous ambient temperature logger was 2.1 km upstream and averaged 3.9°C warmer than the ELJ 3 pool, suggesting the potential for a more continuous thermal refuge.

Figure 72. 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).



Conclusions and Recommendations

NSD (2019 Draft) concluded that the engineered logjam placements in the Skookum Edfro Phase 1 project and the Skookum Reach Project were built into the bank and are not hydraulically engaged enough to exert geomorphic influence on the channel to form deep, large pools (Table 67). This allowed the channel to migrate slightly away from the structures instead of forming pools. They also suggest that pools may be filling with sediment delivered to the reach from Skookum Creek. They felt that the project design was still likely constrained by the potential flood impacts to adjacent landowners. Habitat diversity has increased and a thermal refuge has been created due to the presence of engineered log jams.

Table 67: 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 in the 2018 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**- one secondary pool was formed as a result of the project.
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 hydraulic modeling, the habitat diversity has increased. Field mapping showed an increase from 8 to 10 units.
Provide refugia from elevated water temperatures in three holding pools (previously two pools).	Thermal refuge creation	**Not Met**- One thermal refuge and other cooler water areas are present along the bank, but no primary pools have been formed.

Saxon Project

Project Description

The Saxon Reach Restoration Project was built in 2011 and 2012 between river miles 12.7 and 11.6 on the main stem of the South Fork Nooksack (Figure 73). The project consisted of six engineered logjams, 1 stabilized natural LWD pile and ~200 meters of wood-based bank protection to protect houses and the county road. The stabilized LWD site has since washed-out. The detailed project objectives were based on a slightly different design that included 12 engineered logjams. The primary difference in the design is that 5 of the logjams along the eroding bank at Saxon Road were replaced with the wood-based bank protection. The remaining seven logjams are also in slightly different locations. The project's objectives focused on pool and thermal refuge formation, increasing habitat diversity and protecting property from erosion (Table 68).

Figure 73: Saxon Project logjam locations.

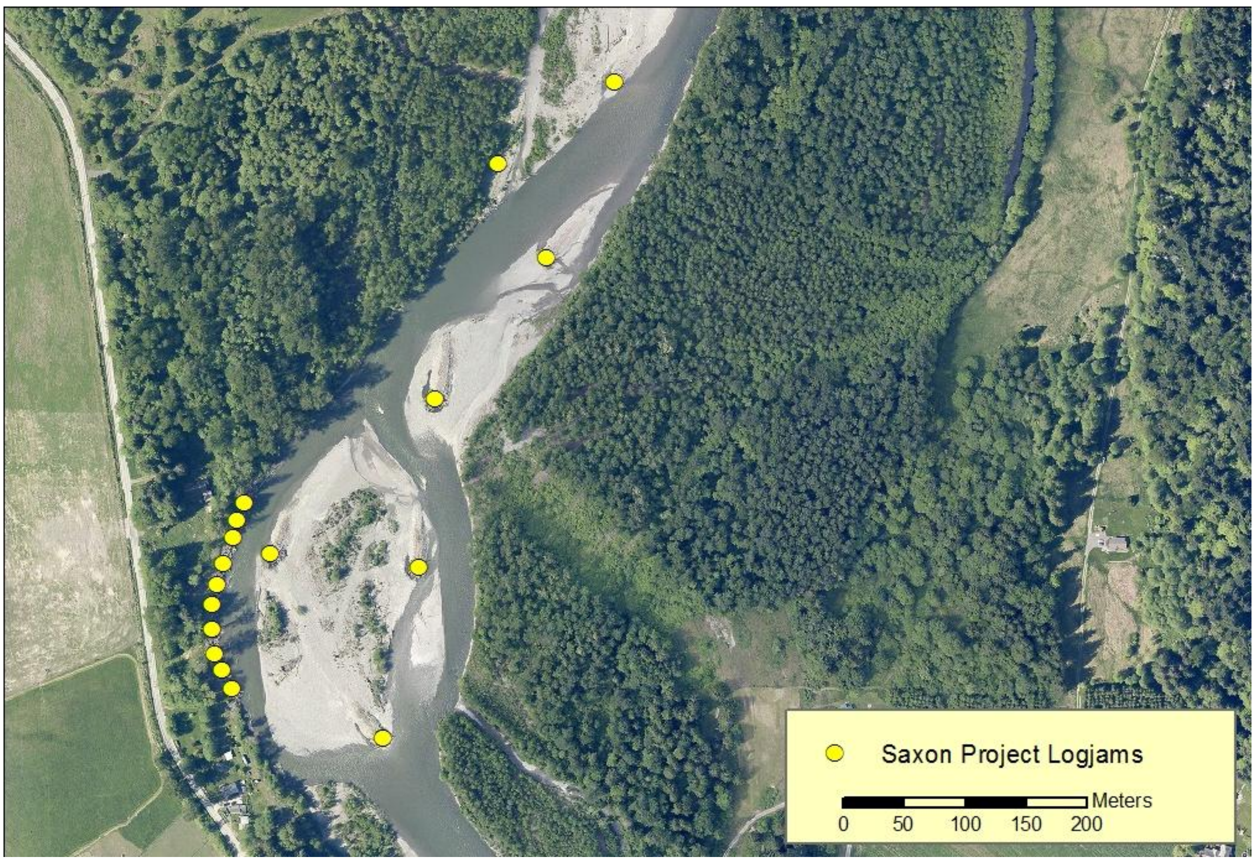


Table 68: Saxon project objectives (LNR 2010 SRFB application Project #10-1300)

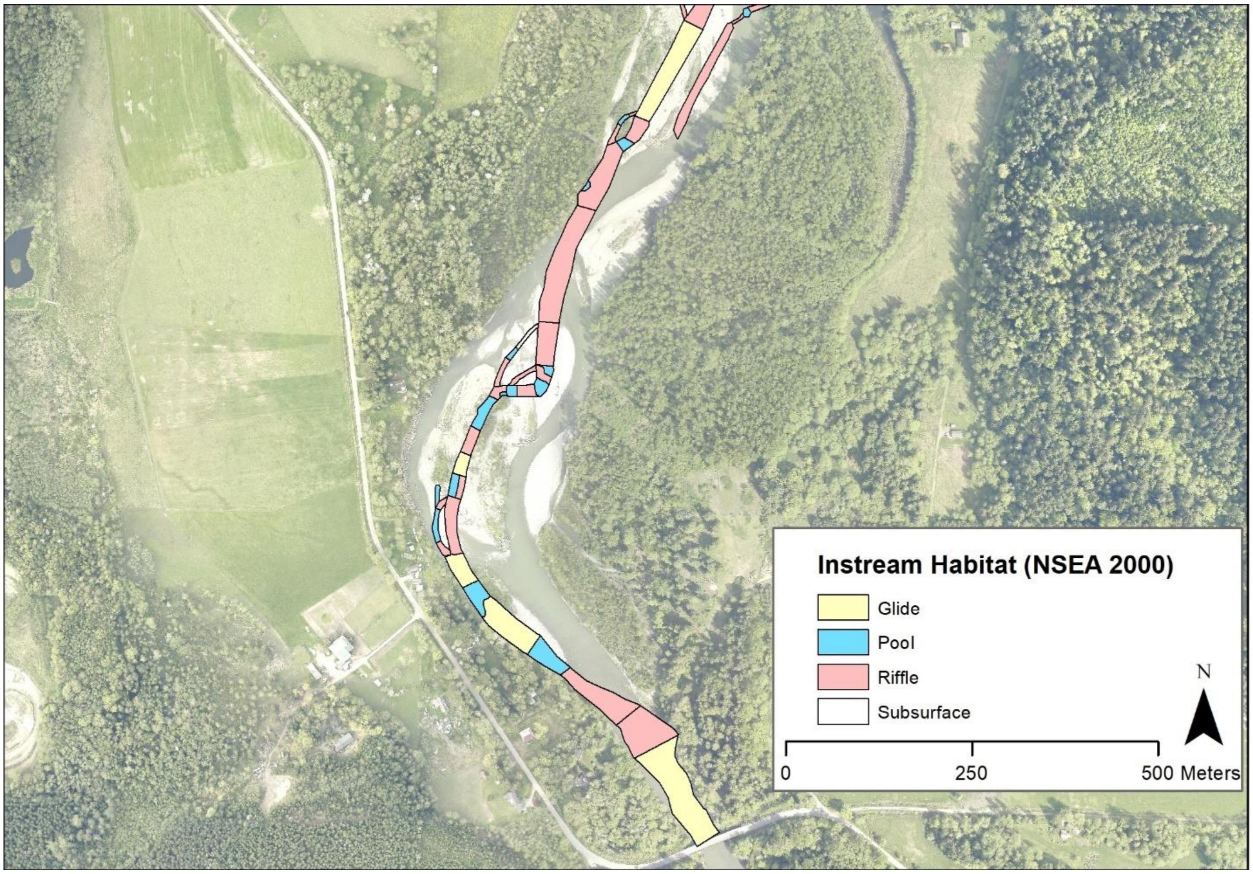
Stated Project Objectives	Objective Group	Limiting Habitat Factors
The project will increase the key habitat quantity for the targeted fish species by directly creating 12 pools with complex woody cover in a reach of the river where groundwater emergence is thought to moderate the surface water.	Pool formation	Lack of Key Habitat
Scour pools provide thermal refugia (holding pools) from elevated South Fork water temperatures during summer spawning months	Thermal refuge creation	Elevated water temperature
The project will increase habitat diversity by decreasing the pool spacing in the reach.	Habitat unit diversity	Low habitat diversity
Encouraging flow into the Nesset's side channel complex will increase channel length by approximately 3,000 feet with accompanying woody debris for cover and off channel rearing opportunities.	Secondary channel length	Low habitat diversity
Integrate the project with the goals of the local flood advisory group and Whatcom County River and Flood managers	Bank protection	N/A

Project Objectives

Pool Formation

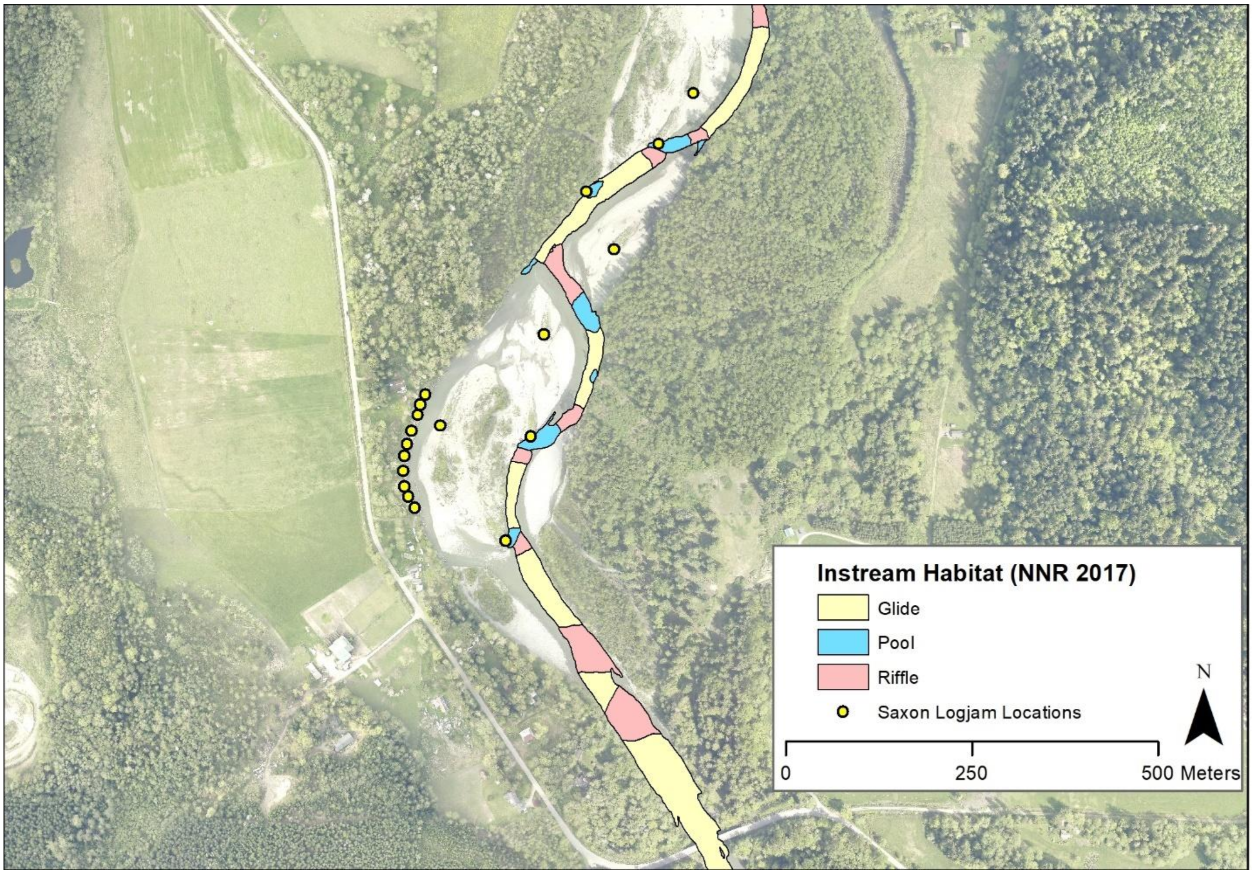
The Saxon Project had the goal of directly creating 12 pools in the project reach. Pre-project monitoring in 2000 found 12 pools in the reach- six primary and six secondary pools, all formed by wood debris (NSEA 2000 data, Figure 74). Of the 12 pools, only two met the minimum 1 m residual depth for inclusion in the pool spacing metric. In 2003, six pools were mapped in the reach (Ecotrust 2003 data). One of the pools was a primary pool and five were secondary pools.

Figure 74: Instream habitat mapping in the Saxon Reach (Nooksack Salmon Enhancement Association 2000).



Monitoring of the reach in 2017 found eight pools in the reach, including four primary pools, two secondary pools and two backwater areas (NNR 2017 data, Figure 75). Of the eight pools, four met the minimum criteria for depth. Four of the pools were associated with the engineered logjams and one was formed by a natural debris pile. Snorkeling to count adult chinook that occurred at the same time as the habitat mapping found that three of the four engineered logjams had holding chinook associated with them. Thirteen of the 15 holding adult chinook observed in the reach were associated with engineered logjams.

Figure 75: Instream habitat in the Saxon Reach (Nooksack Tribe data 2017).



Thermal Refuge Creation

The project design did not include the co-location of groundwater seeps, or cooler water tributaries with logjam structures. The reach had been identified as a zone of groundwater upwelling and it was thought that pool formation and increased channel bed-form variation could encourage groundwater-surface water interaction. Mapping was conducted on August 18, 2015 when mean daily flow was 89 cfs and the South Fork temperature ranged between 18.0 and 20.8°C (NNR 2015 data). Monitoring found that the revetment and one of the nearby engineered logjams were both associated with thermal anomalies (Table 69, Figure 76).

The Saxon 4 structure scoured a small isolated pool that was likely intercepting the shallow groundwater. The Saxon revetment is a ~200 m wood bank protection structure that lies at the edge of an eroding terrace. Two distinct refuge areas were located along the revetment (Figure 77). The upstream refuge area (Revet 1) was a series of deeper pools associated with the constructed revetment and some naturally recruited wood. These lie within the larger wetted blind channel, which flows all the way down to the South Fork. The South Fork at the time of the survey was 18.8°C and the refuge was 14.0, 13.6 and 13.2°C at its coolest points. The entire refuge was ~1,500 m^2 in area, with the coldest points (1a, 1b, 1c) all associated with the deeper local scour areas of the unit. The refuge was strongly stratified, with bottom temperature as cool as 13.2°C, and a surface temperature as high as 17.4°C. The surface flow of the South Fork Nooksack was almost totally disconnected at the upstream end, with a trickle of water (25.2°C) entering at the upstream end of the area.

A second refuge (Revet 2) was located slightly downstream of the first refuge. This refuge was ~300 m^2 in area and associated with the deepest point of local scour (1.3 m) in the pool. While not as cool as the upstream refuge, it was still more than 3°C cooler than the mainstem channel. The water was slightly more turbid in this refuge than the upstream refuge.

Juvenile fish were abundant in both refuge areas (Figure 78), and were concentrated in the deeper and cooler pools under woody cover. While the majority of fish were under the wood, many were actively feeding in the open water of the pool. From underwater videography it appears that the bulk of the fish are juvenile coho, although there may be other species present. It appears that local scour associated with the logjams has intercepted shallow groundwater and the lack of mixing from the warmer surface flow of the river has allowed stratified pools to develop in association with high quality woody cover. Because the refuge area is well connected to the mainstem, allowing ingress and egress, it appears that the juvenile fish are preferentially using this habitat.

Table 69: Temperature and depth associated with habitat structures in the Saxon Reach, bolding shows potential thermal refuge areas (NNR 2015 data).

Site ID	Minimum Temperature (°C)	Average SF Temperature (°C)	Depth at Minimum Temperature (m)
Saxon 1	N/A	N/A	N/A
Saxon 2	18.6	18.0	0.7
Saxon 3	18.5	18.3	0.1
Saxon 4	**16.5**	**18.8**	0.1
Revet 1a	**14.0**	**18.8**[a]	1.6
Revet 1b	**13.2**	**18.8**[a]	1.4
Revet 1c	**13.6**	**18.8**[a]	1.5
Revet 2	**15.5**	**18.8**[a]	1.3
Saxon 5	N/A	N/A	N/A
Saxon 6	20.3	20.3	0.75
Saxon 7	20.5	20.8	0.35
Saxon 8	N/A	N/A	N/A

[a] used the same mainstem temperature as the Saxon 4 mainstem measurement.

Figure 76: Saxon Reach Project showing Site ID for temperature monitoring.

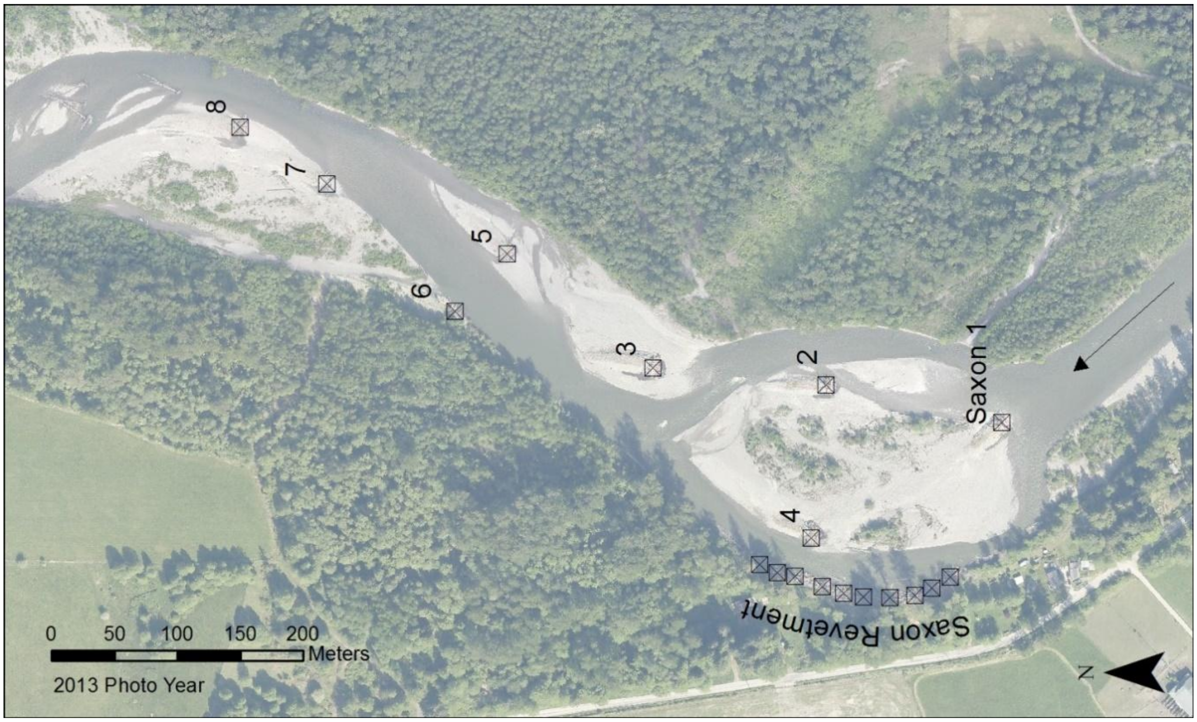


Figure 77: Thermal refuge boundaries for the Saxon Revetment area.

Figure 78: Juvenile fish present in the "Revet 1" refuge area.

Habitat Unit Diversity

The project had the goal of increasing habitat diversity by reducing the pool spacing in the reach. Prior to the project, there were 12 pools mapped in the reach in 2000, although only two of these met the minimum depth requirement to be considered "deep" (>1 m residual depth) (NSEA 2000 data). Mapping in 2017 found fewer overall pools in the reach, but an increase in the number of deep pools (NNR data).

Overall habitat unit diversity (number of primary habitat units in the reach) showed a similar decrease from 18 units in 2000 to 14 units in 2017. The high number of units in 2000 was related to a series of natural logjams that scoured closely spaced pool and riffles through a short section of the channel. The mapping in 2003 showed that these debris piles had washed out and the habitat unit diversity dropped to 13 units in the reach, which was dominated by riffle and run sequences and contained only one primary pool.

Secondary Channel Length

The project had the objective of encouraging flow into the Nesset's Slough area. The project has encouraged channel migration toward Nesset's Slough and may have increase the high flow connectivity of the habitat, although changes in high flow connectivity have not been monitored. At low flow, the project has not reconnected the slough into a side channel of the river. Habitat quality has likely not changed in the Nesset's Slough channel following construction. The slough remains a groundwater-fed channel that is seasonally connected to the river at the downstream end.

Bank Protection

The project provided protection for several residences along Saxon Road using a wood-based revetment. The revetment provides local scour and wood cover and the associated backwater was a cool water rearing area for juvenile fish.

Conclusions and Recommendations

The Saxon Project has partially met the majority of its objectives (Table 70). Although the project has not met the targets for pool spacing or pool count, the logjams have formed pools that appear to be preferentially used by adult holding chinook. The project has formed a thermal refuge area in a backwater that is heavily used by rearing juveniles, but is not associated with holding adults. The project has protected Saxon Road using an approach that increases the habitat quality in the reach. The one objective that has not been met to date is the reconnection of Nesset's Slough. The channel has been migrating in that direction and may be improving high flow connectivity of the habitat, but this has not been monitored as a part of the project.

Table 70: Saxon Project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
The project will increase the key habitat quantity for the targeted fish species by directly creating 12 pools with complex woody cover in a reach of the river where groundwater emergence is thought to moderate the surface water.	Pool formation	**Partially met**- the logjams have formed pools, but have not met the target of 12 pools in the reach. The logjam-formed pools appear to be preferentially used by chinook.
Scour pools provide thermal refugia (holding pools) from elevated South Fork water temperatures during summer spawning months	Thermal refuge creation	**Partially met**- the backwater area next to the revetment has created a thermal refuge area. The pools that provide holding habitat had no measurable difference in water temperature.
The project will increase habitat diversity by decreasing the pool spacing in the reach.	Habitat unit diversity	**Partially met**- the project has not decreased the overall pool spacing in the reach, although the project has decreased the spacing of pools >1m residual depth.
Encouraging flow into the Nesset's side channel complex will increase channel length by approximately 3,000 feet with accompanying woody debris for cover and off channel rearing opportunities.	Secondary channel length	**Not met**- the project has not reconnected the Nesset's Slough area as a side channel. It is uncertain the extent that high flow connectivity is improved.
Integrate the project with the goals of the local flood advisory group and Whatcom County River and Flood managers	Bank protection	**Met**- the project protects houses along Saxon Road while providing local scour and a thermal refuge area.

Nesset's LWD Stabilization Project

Project Description

Constructed in the summer of 2008, the Nesset's Reach Project consisted of stabilizing eight existing woody debris piles in the South Fork Nooksack between RM 10.5 and 11.5 (Figure 79). In response to the concern about the cost of engineered wood projects in the watershed, a different approach was taken that relied on taking advantage of the woody debris that was already in the channel. The project sought to minimize the design, permitting and construction costs of an instream project. The original plan called for 10 sites, but two were not located by the helicopter when materials were staged. The goal of the project was to create deep scour pools with cover (Table 71). The sites were stabilized using piles driven with an excavator do a depth of ~5 meters, and several pieces of wood were placed with existing large wood to help ballast the structure. The project had no engineering design, instead opting for a "safe-fail" design that would minimize any downstream impacts of the added pieces of wood, by sizing them similarly to the large wood that was already present in the channel. Of the eight sites stabilized in 2008, four have subsequently washed-out.

Figure 79: Nesset's LWD stabilization sites.

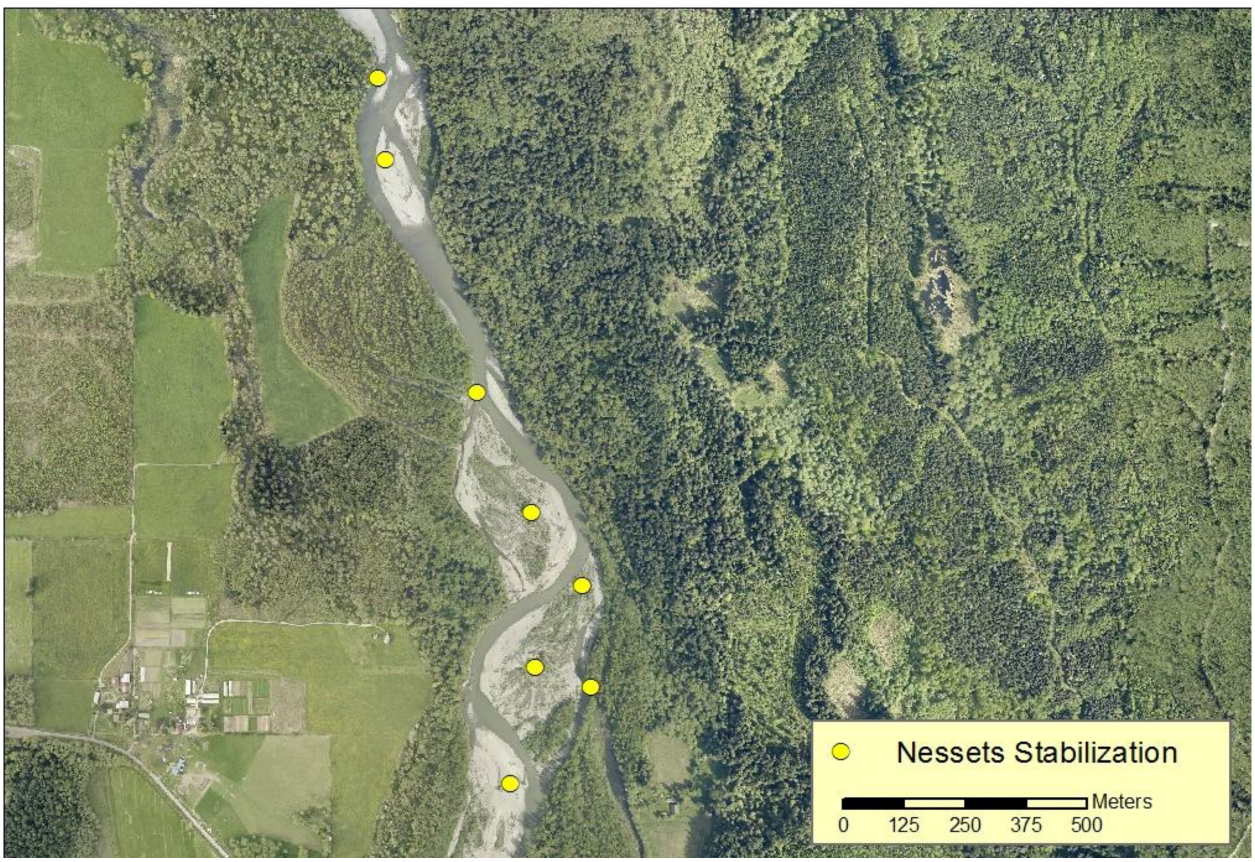


Table 71: Nesset's LWD stabilization project objectives (LNR 2009b).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase the residence time of wood in the project reach	LWD loading	N/A
Increase the abundance of large wood in the project reach	LWD loading	N/A
Increase channel type and habitat unit diversity	Habitat unit diversity	Low habitat diversity
Increase pool abundance in the reach	Pool formation	Lack of Key Habitat
Increase the amount of wood cover for rearing and migrating salmon	Instream cover	Low habitat diversity
Increase stability of sediment deposited in relation to the structures	Spawning gravel enhancement	N/A

Project Objectives

Wood Loading

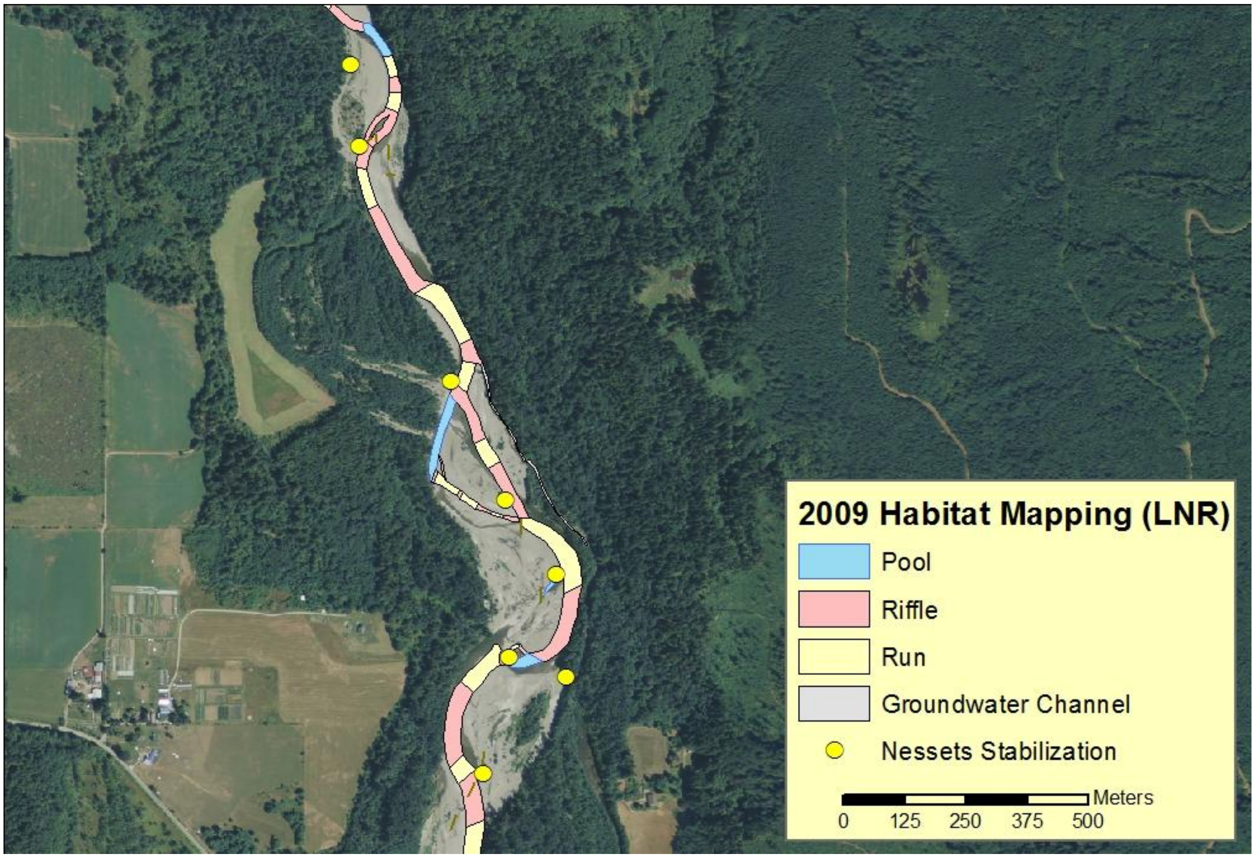
The project had the goals of increasing the residence time of wood in the reach by stabilizing accumulations of mobile wood and of increasing the abundance of wood by capturing wood being transported through the reach. The success of both of these objectives was strongly influenced by the stability of the wood accumulations. Of the eight structures that were completed, four of them were strongly interacting with the low flow channel at some point and four have only interacted with high flow. Of the four that were in the low flow channel, all have been washed-out. One structure functioned in the low flow channel for several years before being scoured out (Figure 80). Monitoring of the site showed that the stabilized portions of the accumulations did persist longer than the portions that were not stabilized, although the lifespan of the structures was less than five years when subjected to the flow of the river. Structures that continue to be on the gravel bars have grown over with deciduous trees and provide only high flow habitat functions. The pre-project mapping of natural logjams in the reach showed that the only natural logjams that have persisted were the four remaining stabilized accumulations (LNR 2007a). None of the four remaining structures have accumulated a substantial amount of wood since the project was completed.

Figure 80: A natural logjam that was partially stabilized with piles. The stabilized portion persisted through the high flow, while the rest of the logjam was transported downstream.

Habitat Unit Diversity

The project had a short-term benefit on channel type and habitat unit diversity. Mapping in 2009 by the Lummi Nation showed 23 primary habitat units in the project reach, which was dominated by riffles and runs (Figure 81). This is consistent with the baseline unit diversity mapped in 2000 (20 units) and 2003 (22 units) in the project reach. Only one of the structures was forming a pool at the time of the survey. The project appears to have had a stronger influence on channel type diversity, with two of the structures splitting the low flow channel into secondary channels. This led to ~385 m of secondary channel length. Pre-project monitoring showed ~490 m and ~420 m of secondary channel length in 2000 and 2003, respectively, so while the channels were associated with the logjams, the project did not increase the channel length over the pre-project conditions. This is likely due to the lack of stability of the structures when subjected to the flow of the river.

Figure 81: Habitat mapping in the Nesset's Reach in 2009 (Lummi Nation data).



Pool Formation

Mapping in 2000 found eight pools in the reach (3 primary pools), six of the eight met the minimum residual depth criteria. In 2003, the reach contained ten pools (three primary pools), two of which met the minimum depth requirement of >1 m residual depth. Following construction, mapping in 2009, the project had four pools (two primary pools) mapped in it- one formed by one of the stabilized wood piles. Structure-scale monitoring of the project in 2011 found that three of the five remaining sites had a pool associated with it. Two of these pools were isolate form the low flow channel and the third was a small (6.0 m^2), shallow (0.2 m maximum depth) secondary pool in a groundwater channel that initiated at the structure. Mapping for baseline monitoring of the Nesset's Reach project in 2014 found that one of the stabilization sites was interacting with the low flow channel, but that none were forming pools. A survey of temperature refuges in August of 2015 found that there were two very small, isolated pools and a secondary pool in a side channel of the South Fork. Both of the isolated pools appeared to be influenced by groundwater and provided thermal refuge for the ~10 fish observed rearing in the structures. The pool in the side channel was not deep enough to qualify as a deep pool and showed no decrease in temperature relative to the main channel temperature. Similar to the habitat diversity results, the lack of stability of the structures likely impacted the pool-formation in the project reach. While at least one structure formed a pool for a brief period of time, none of the remaining structures are currently forming deep pools.

Instream Cover
The project provided some instream woody cover for rearing salmonids, while the structures were interacting with the wetted channel. Low flow monitoring showed that the projects generally weren't interacting with the channel. In 2009, at the height of the projects influence on habitat, four of the stabilized logjams were providing 91.2 m^2 of woody cover to the low flow channel. Three of the four sites have subsequently washed-out. In structure-scale monitoring in 2011, one structure was interacting with the low flow channel and was providing 0.1 m^2 of cover. In 2014, one structure was in the low flow channel and provided 4.3 m^2 of wood cover. Mapping in 2017 found that the structure that was providing cover in 2014 was washed-out and there was no cover associated with the remaining structures.

Spawning Gravel Enhancement
Sediment stability was not monitored as a part of the project, although the loss of structures that were interacting with the low flow channel suggests that this objective was likely not met.

Conclusions and Recommendations
The Nesset's LWD Stabilization Project has not met its objectives (Table 72). This was largely due to short lifespan of the structures in the project once they are subjected to the force of the river. In the brief period when the structures were interacting with the low flow period, they created primary scour pools, connected side channels and provided instream cover, although these never exceeded the pre-project conditions. Four of the structures remain in the reach and have created forested patches in the active channel area of the river. Continued vegetation growth may improve long-term stability, but it is not likely that the project will meet its objectives. Following the recommendations of the structure-scale monitoring (Maudlin and Coe 2012), the reach was revisited in 2016 and a new engineered design was implemented in the reach.

Table 72: Nesset's LWD Stabilization Project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
Increase the residence time of wood in the project reach	LWD loading	**Not met**- the lack of stability of the stabilization sites has not led to a long-term increase in residence time.
Increase the abundance of large wood in the project reach	LWD loading	**Not met**- the structures that remain in pace have not accumulated unstable wood drift.
Increase channel type and habitat unit diversity	Habitat unit diversity	**Not met**- the project did not increase habitat diversity or secondary channel length over the baseline conditions, although pool formation and secondary channels were associated with the sites.
Increase pool abundance in the reach	Pool formation	**Not met**- pool abundance decreased in the project reach following the project. One structure briefly formed a primary pool.
Increase the amount of wood cover for rearing and migrating salmon	Instream cover	**Not met**- there is currently no cover associated with the remaining structures.
Increase stability of sediment deposited in relation to the structures	Spawning gravel enhancement	**Uncertain**- sediment stability was not monitored, although a lack of structure stability makes it unlikely that this objective was met.

Nesset's Project

Project Description

The Nesset's Project revisited the reach of the Nesset's LWD Stabilization Project to improve the stability of the habitat structures to better meet the habitat limitations in the reach. The original project design was broken into three phases and included logjam construction and levee alteration to improve floodplain connectivity. Landowner support of altering the levee changed part way through design, so the Phase 3 project was dropped and the project just focused on construction of 25 habitat structures in two phases (Figure 82). For the purposed of this report only the 20 Phase 1 structures that were built in 2016-17 were monitored. The logjam structures were supported by driven piles and chained together for stability. The specific habitat objectives were developed for the Phase 1 and 2 projects and are combined where the objective was the same for both phases (Table 73). The project was constructed between 2016 and 2018 and there is only limited monitoring data available of the phase 1 project to date.

Figure 82: Phase 1 Nesset's logjam locations.

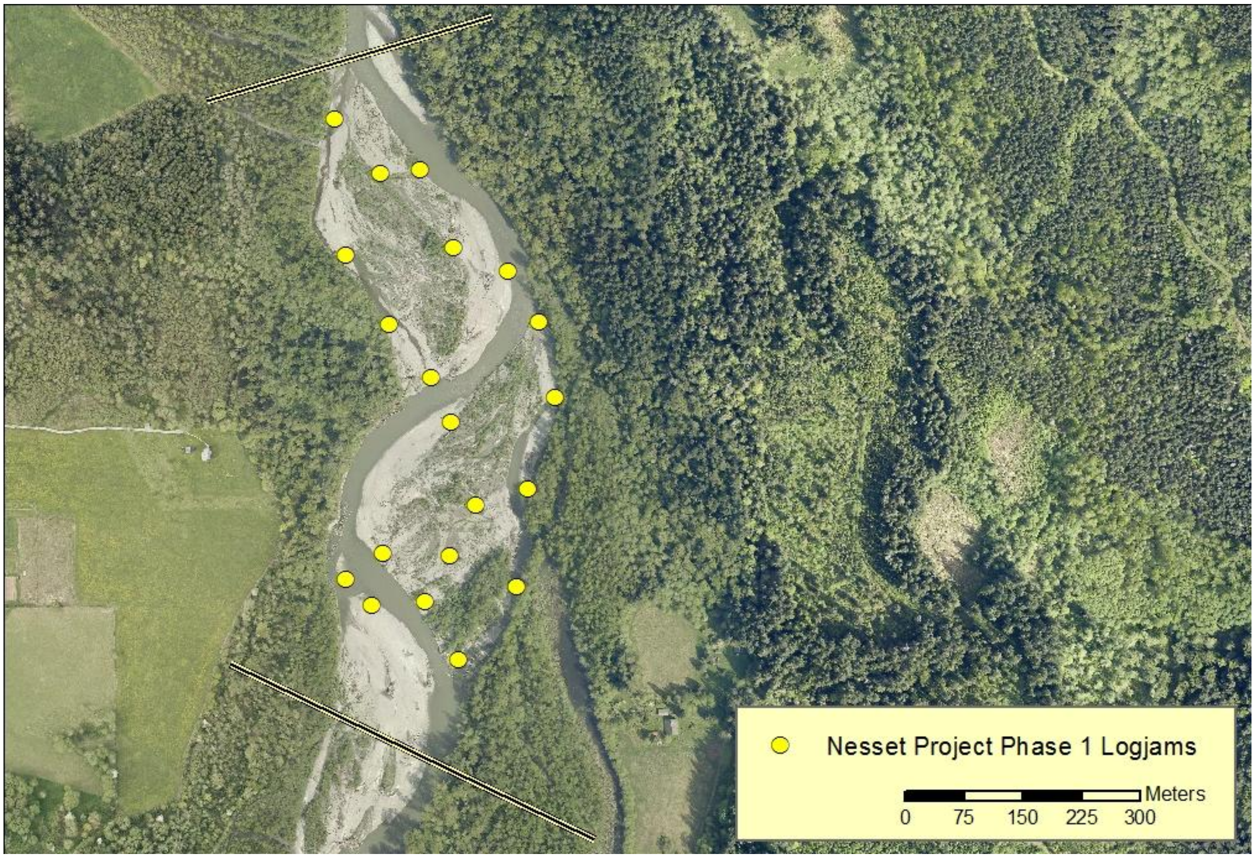


Table 73: Nesset's project objectives (Nooksack Natural Resources (NNR) 2015 and 2016 SRFB applications projects #15-1283 and #16-2049)

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase in count of stable log jams to 25.	LWD loading	N/A
Form 8 primary and 6 secondary pools.	Pool formation	Lack of Key Habitat
Increase the length of woody cover engaged at low flow by 760 meters, increase length at high flow by 1438 meters.	Instream cover	Low habitat diversity
Increase the number of temperature refuges by 5 areas.	Thermal refuge creation	Elevated water temperature
Increase the wetted length of side channels for rearing by 606 meters.	Secondary channel length	Low habitat diversity
Hydraulic modeling indicates that restoration through the broader reach will increase high flow connectivity of the left bank side channel.	Secondary channel length	Low habitat diversity

Project Objectives

LWD Loading

The project had the objective of installing 25 stable logjams in the project reach. Monitoring of the reach in 2019 following construction of the second phase found 25 engineered logjams in the reach. Longer-term stability of the structures will need to be assessed.

Pool Formation

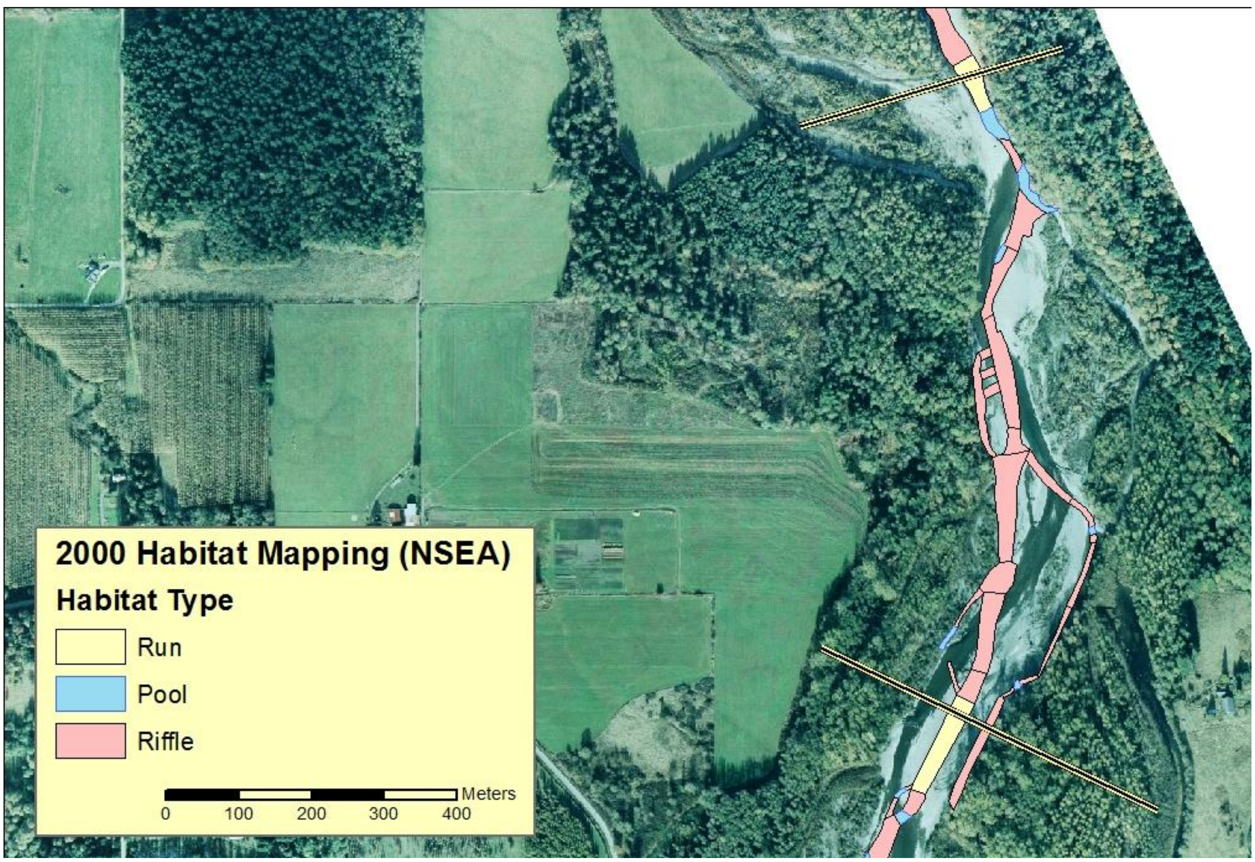
Both phases of the project had a combined goal of forming eight primary and six secondary pools in the project reach. Baseline habitat mapping of the project reach is available for several years- 2000 (NSEA data), 2003 (Ecotrust data), 2009 (LNR data) and 2014 (NNR data) (Figure 83). Mapping methods were different for each of the four baseline surveys, with the 2014 methods most similar to the as-built and 1-year effectiveness surveys. For this comparison, we ignored pools in secondary channels, such as sloughs, since differences in stage and season can strongly influence the number of connected pools in the reach. In 2000-2009, pool counts ranged between two and three pools associated with the main channel of the river (Table 74). Baseline mapping in 2014 found an increase in the number of pools in the reach- four primary pools and six secondary pools.

Table 74: Pool formation in the Phase 1 reach associated with the main channel (does not include slough, braid and side channel habitats).

Survey Year	Primary Pools	Secondary Pools
2000	2	1
2003	2	0
2009	1	1
2014	4	6
2016	2	12*
2017	5	7

*many of these pools were a result of excavation

Figure 83: Baseline habitat mapping of the project reach in 2000 (Nooksack Salmon Enhancement Association).

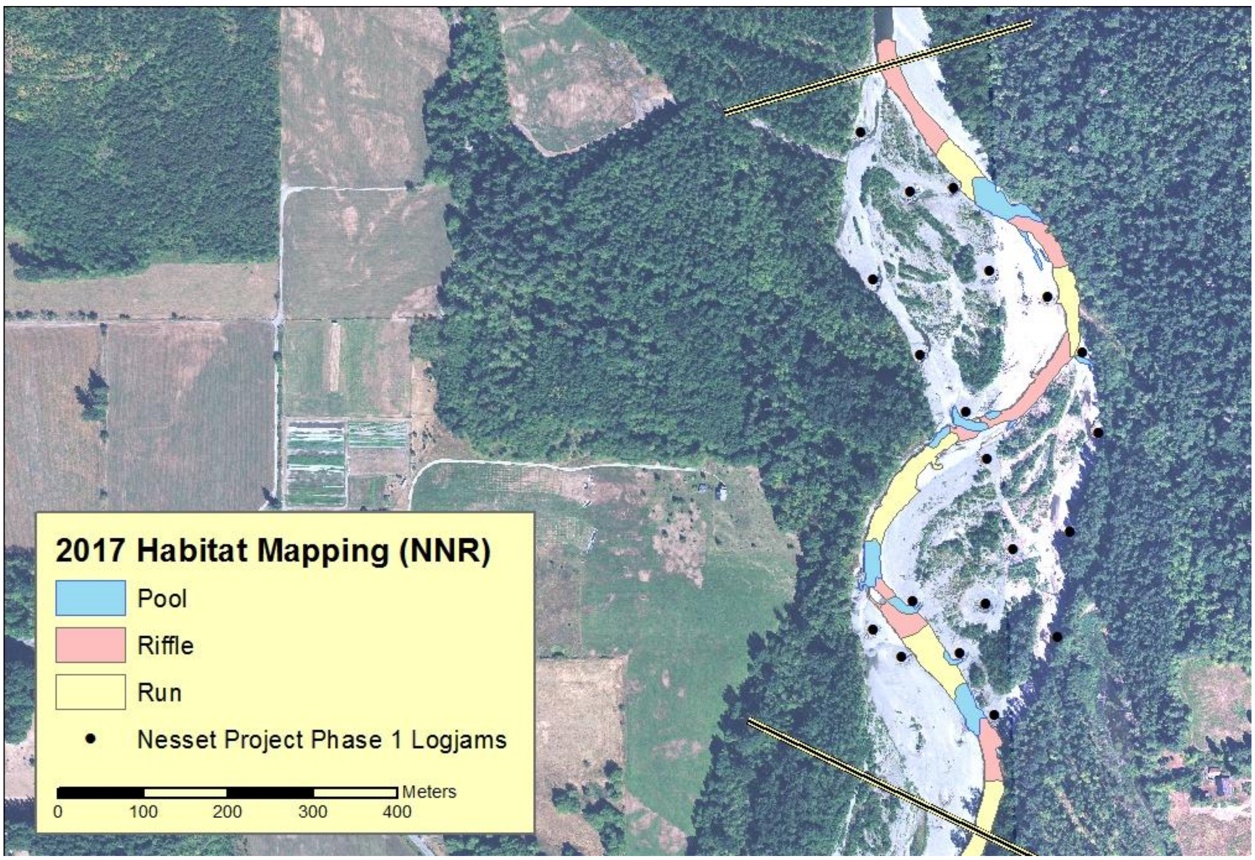


The 2016 as-built monitoring of the Phase 1 project area found two primary pools and 12 secondary pools associated with the main channel of the river (NNR data). The two primary pools persisted from the 2014 baseline mapping- one, a bedrock-formed pool at Preacher's Rock and the other associated with a mass of cabled wood along the bank. Six of the secondary pools were associated with the excavation for the construction of the logjams. As-built monitoring of the Phase 2 reach in 2018 showed similar results, with the construction of pools for the logjams dominating the habitat mapping (NNR data).

Phase 1 monitoring was completed in 2017 (Figure 84). Mapping found that the number of primary pools in the reach increased from two to five, with the same two primary pools from 2016 joined by three more pools formed by engineered logjams. One of the secondary pools was also formed by engineered logjams.

While there has been an increase in primary pools following the project, it has not met the target for the number of pools in the reach. The entire project has yet to be monitored, so it is likely that the counts will change once the second phase is included in the monitoring and the project is subjected to additional high flow events.

Figure 84: 2017 habitat mapping in the Nesset's project reach (NNR data).



Instream Cover

The instream cover provided by the project was mapped at low flow for both project phases immediately following construction. This includes the pre-formed scour pools that were left from the construction of the logjams. Cover was measured as area, rather than the length of woody cover. For the Phase 1, the project increased the wood area in the low flow channel by approximately 1,585 m^2 (877.5 m^2 in the main channel and 706.7 m^2 in groundwater slough areas. The Phase 2 project added an additional 125m^2 of woody cover. While the logjam cover was measured with a GPS as a polygon and no cover width measurements were taken for this project, previous monitoring has found that logjam-formed edges tend to be relatively wide- averaging over 3.0 m in width (NNR data). Estimating the length based on an average width of 3.0 m, the project would have increased the wood edge length by 570 m.

No monitoring of the high flow edge length was measured, but it is expected that may of the logjams that are not interacting with the low flow channel, would be interacting with the high flow channel. If the isolated pools are added into the cover estimate to reflect high flow interaction with the wetted channel, the amount of wood cover in the reach increases from 1,710 m^2 to approximately 3,550 m^2. This would roughly equate to 1,180 m of high flow wood edge length, meeting the target.

Thermal Refuge Creation

Thermal refuge and groundwater monitoring are underway, but has not been completed in the Nesset's project reach. Several continuous temperature probes were installed in the reach, but showed no thermal differences at the different locations.

Secondary Channel Length

All monitoring was done during the summer low flow period, but changes in stage and timing may still affect the length of mapped channels. The length of secondary channels has varied through time in the reach from zero in 2003 to 1,095 m in 2014, when a long side channel was connected and there was a substantial length of braided channel (Table 75).

The only available monitoring data for the Phase 1 reach showed that the secondary channel length decreased between 2014 and the as-built conditions in 2016. The side channel length continued to decline in 2017, when only a few short sloughs and one short section of braid were connected to the low flow channel. While the secondary channel length has not increased following the project, the main low flow channel has continued to lengthen though time in the reach, providing more main channel habitat, which is more important for adult chinook holding and spawning than secondary channel length.

Table 75: Length of different channel types through time in the Phase 1 project reach.

Year	Length (m) by Channel Type			
	Main Channel	Braided Channel	Side Channel	Slough
2000	928	207	0	593
2003	955	0	0	0
2009	1,107	0	476	496
2014	1,087	409	496	190
2016	1,132	0	0	700
2017	1,144	29	0	102

Conclusions and Recommendations

The Nesset's Project has had mixed success at meeting its project objectives (Table 76). Only the first phase has been monitored, reflecting the conditions one year after construction and the full reach is scheduled to be remapped in 2020. The project has met the objective of installing 25 logjams, although an assessment of stability will take time. The channel is already responding to the structures, giving an indication that the structures are stable. Longer term monitoring of temperature is on-going and has not yet provided a detailed assessment of thermal refuge count. The Nesset's project will need continued monitoring to evaluate the project success.

Table 76: Nesset's project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
Increase in count of stable logjams to 25.	LWD loading	**Met**- the project installed 25 logjams that have been stable over the monitoring period. Long term will need to be assessed.
Form 8 primary and 6 secondary pools.	Pool formation	**Partially met**- the Phase 1 project has formed 3 primary and 1 secondary pools, but has not met the target in the objective.
Increase the length of woody cover engaged at low flow by 760 meters, increase length at high flow by 1438 meters.	Instream cover	**Partially met**- the project increased wood cover area in the reach. Estimates of length based on average measured edge widths indicate the project did not meet the low flow length, but met the high flow length.
Increase the number of temperature refuges by 5 areas.	Thermal refuge creation	**Uncertain**- extensive thermal monitoring has not been completed.
Increase the wetted length of side channels for rearing by 606 meters.	Secondary channel length	**Not met**- low flow secondary channel length has not increased in the project reach.
Hydraulic modeling indicates that restoration through the broader reach will increase high flow connectivity of the left bank side channel downstream of the Phase 2 reach.	Secondary channel length	**Uncertain**- hydraulic modeling indicated an increase, but no monitoring of this has been done.

Lower Hutchinson Project

Project Description

The Lower Hutchinson Project was completed in 2006 and was the second engineered logjam project in the Nooksack Watershed. The project included removing ~150 m of levee and constructing six engineered logjams (Figure 85). The project was originally designed to focus on improving instream habitat, but community input lead to substantial design changes, including the construction of three of the logjams as a setback behind the three structures along the river and the construction of a riprap setback levee behind the structures at the edge of the historic channel migration area. The purpose of the setback was to both reassure the community regarding concerns for potential flooding or avulsion to the north and to encourage side channel formation between the river adjacent and setback jams roughly in the pre-project location of lower Hutchinson Creek. The structures were constructed by excavating below scour depth and driving piles. The key pieces were placed between piles and built up to above the 100-year flood elevation, with no cable or chain to secure the wood pieces. The structures were then back-filled with gravel for ballast. The project objectives included pool formation, improved wood cover, and reconnection of Hutchinson Creek to provide a cool water refuge (Table 77).

Figure 85: Lower Hutchinson Project immediately following construction (2006).

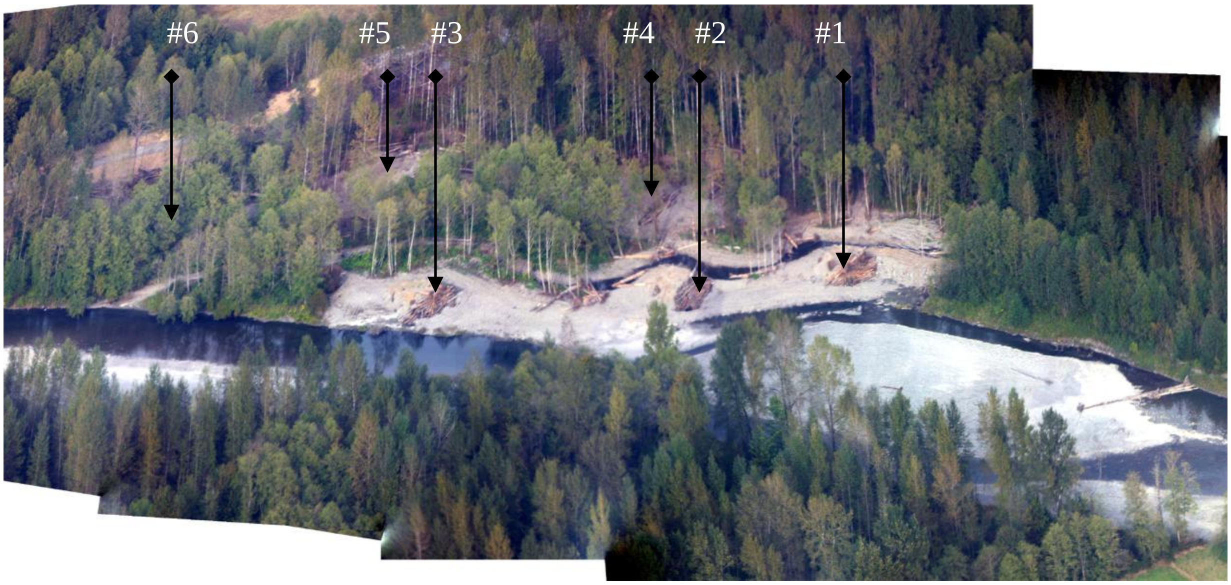


Table 77: Lower Hutchinson project objectives (LNR 2007b).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase channel length by 20%	Secondary channel length	Low habitat diversity
Increase residual pool depth by 20%	Pool formation	Lack of Key Habitat
Increase active channel area by 20%	Floodplain connectivity	N/A
Increase loading of wood in the floodplain	LWD loading	N/A
Create a thermal refuge at Hutchinson Creek	Thermal refuge creation	Elevated summer water temperature
Reduced fine sediment through floodplain storage	Floodplain connectivity	Elevated fine sediment

Project Objectives

Secondary Channel Length

One of the objectives of the project was to increase the channel length of the reach, through the effects of local scour and deposition associated with the engineered logjams and floodplain reconnection through the removal of the levee between Hutchinson Creek and the South Fork Nooksack. Main channel length was expected to increase due to migration into the floodplain and secondary channel length was expected to increase due to better low flow connection with Hutchinson Creek, and increased development of braided and side channels around the logjams.

Secondary channel length in the South Fork Nooksack was measured and divided into three categories: braided channel, side channel and floodplain tributary length. Side channel habitat is characterized by persistent vegetation between the channels, which braided channels lack. The project reach saw a drastic reduction in secondary channel length following construction of the riprap armoring that separates the South Fork Nooksack from Hutchinson Creek in the mid-1960s and the isolation of the South Fork into a single-thread channel.

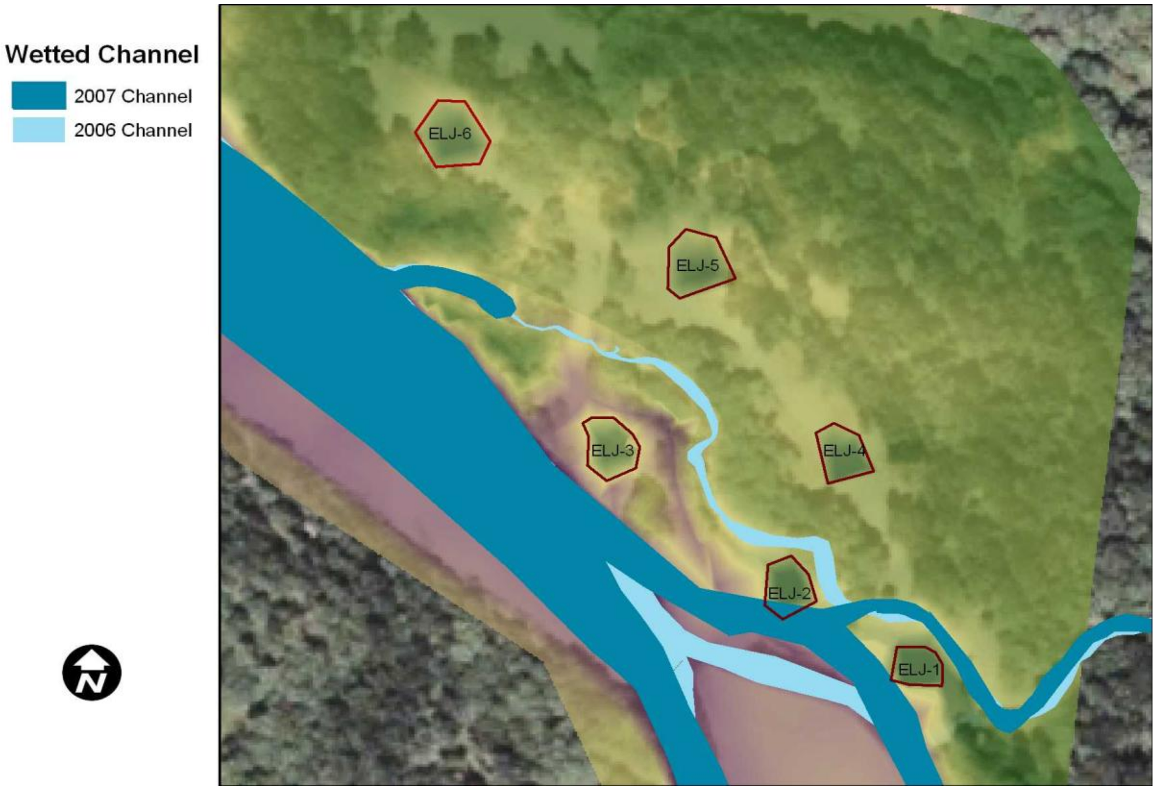
Mapping of braids and side channels in 2000 found that the project area had a single-thread main channel that was constrained by riprap with no secondary channel length (Table 78). By 2003, the channel had braided at the upstream end of the project reach, which increased secondary channel length in the project reach (Ecotrust data). This section of the channel remained braided until after 2009, when the channel became a single thread channel again at low flow. The braiding was likely related to the widening active channel area as the river migrated through the old levee prism and into the engineered logjams. It is also likely that the difference in discharge between the mapping periods contributed to some of the changes in wetted channel area, although the changing channel configuration likely impacted the distribution of braided channel length.

Following project construction in 2006, there was still no side channel habitat in the project reach and there was a loss of floodplain tributary habitat, as Hutchinson Creek avulsed and joined the South Fork ~220 m upstream of its former confluence (LNR data). Even though this was a loss of overall length, it was an increase in low flow length as Hutchinson Creek now maintains a connection with the South Fork throughout the low flow period, where is previously went subsurface as it flowed behind the levee. The former channel of Hutchinson Creek that once flowed along the backside of the removed levee became a depositional area for wood and sediment and has largely filled in since the project was constructed (Figure 86). The other main change in the reach is the increase in main channel length as the river has moved through the levee prism and into the engineered logjams. This represents an increase of approximately 8% in the main channel habitat, from 505 m to 545 m (NNR data).

Table 78: Channel length parameters for the Lower Hutchinson project reach.

Channel Type	Length (m) by Year						
	2000	2003	2006	2007	2009	2013	2016
Main Channel	525	505	505	530	535	545	545
Braid	0	215	205	245	500	0	0
Side Channel	0	0	0	0	0	0	0
Tributary	1,180	1,180	1,180	960	960	960	960

Figure 86: Confluence of Hutchinson Creek and the South Fork showing loss of tributary channel length.



Removing the bank protection has allowed the mainstem channel to migrate northeast into the floodplain it shares with Hutchinson Creek. As the channel has migrated, it widened the active channel area and led to a short-term increase in braided channel area at the upstream end of the project reach. It was expected that the engineered logjams would split the channel and rapidly create side channels in the floodplain. Rather than creating side channels between the structures, the river has deposited sand and gravel in the old channel of Hutchinson Creek, encouraging the creek to enter the channel between the first and second engineered logjams. While there has been an increase in main channel length and periodic increases in braided channel, the project has yet to meet the goal of increasing channel length in the project area by 20%.

Pool Formation

The project is expected to increase the residual depth of pools in the project reach by increasing the number of pools and their depth in the South Fork Nooksack near the project. Local scour near the engineered logjams should create deep pools adjacent to each of the structures when they are interacting with the channel. Before project construction, pool formation was dominated by the riprap that armored the levee between Hutchinson Creek and the South Fork. Another large, riprap-formed pool has been present throughout the monitoring period where the City of Bellingham water pipeline crosses the river at the upstream extent of the reach (Figure 87).

In 2000-06, the riprap dominated pool formation in the project reach, while following construction (2007) wood-formed pools dominated (Table 79). While only one of the wood-formed pools in 2007 was related to the engineered logjams, the removal of the bank protection reduced the number of riprap-formed pools. In 2003, the two riprap-formed primary pools were the only pools present in the reach and the lack of secondary pools account for the high depth (Figure 87). In 2016, the riprap-formed pool at the upstream bend City is still present, but the pools through the project reach are all formed by the engineered logjams (Figure 88).

Figure 87: 2003 Pre-project habitat mapping of the project reach, showing dominance of riprap-formed pools (Ecotrust data).

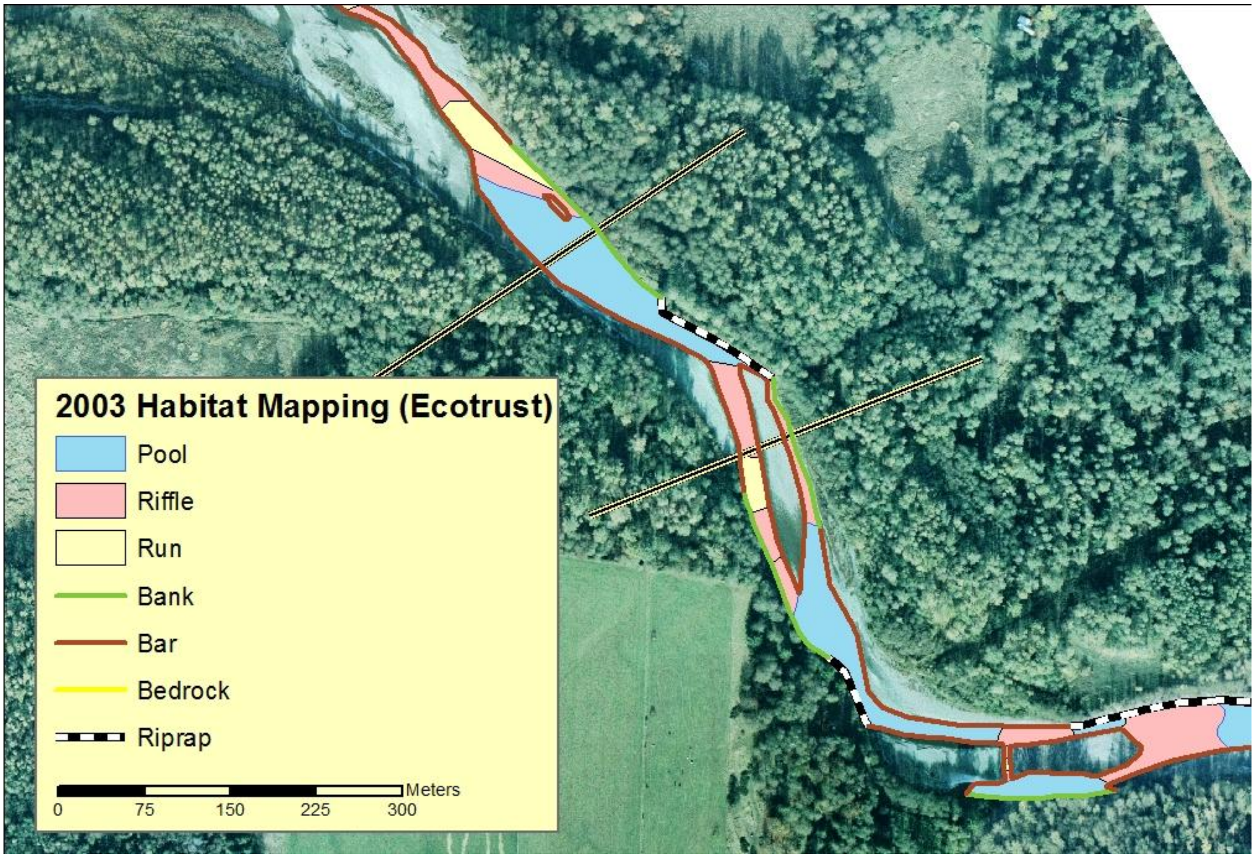
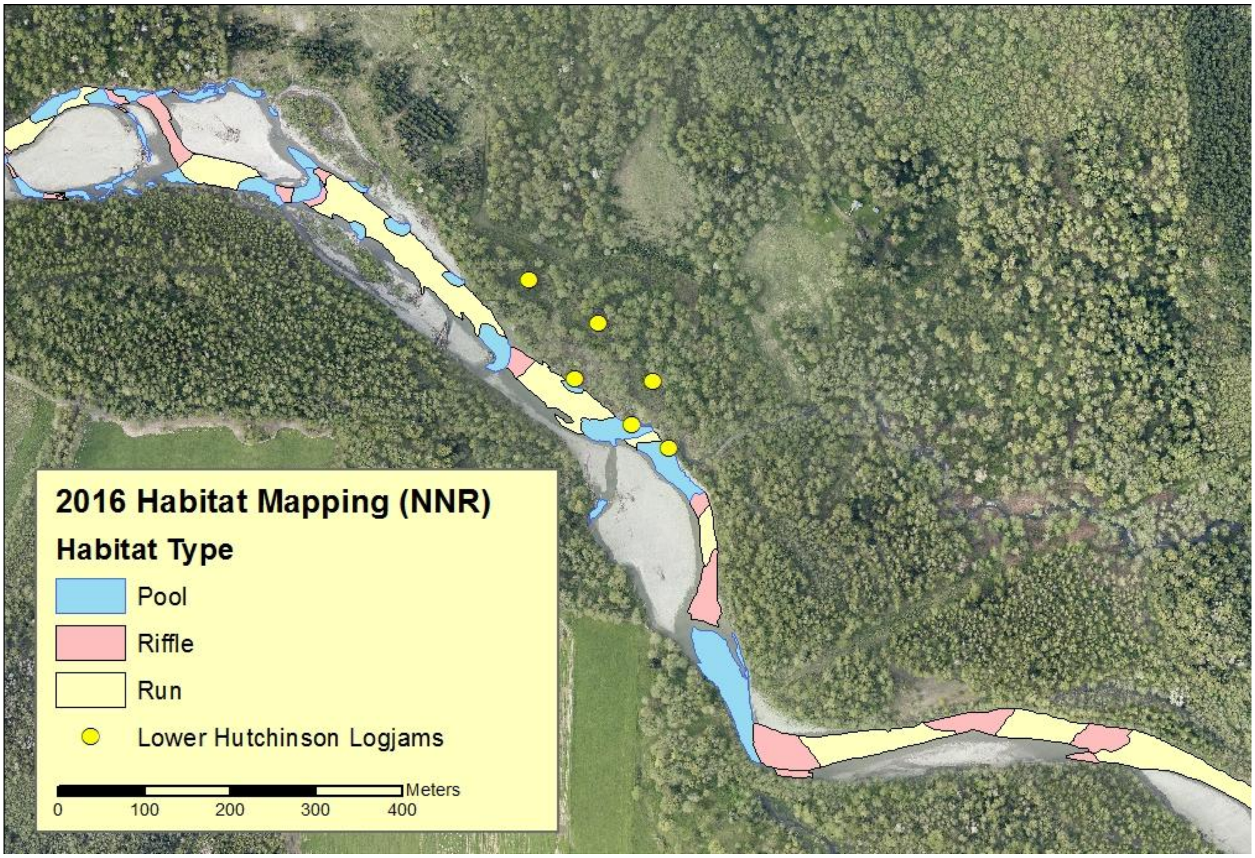


Table 79: Pool statistics for the Lower Hutchinson project reach.

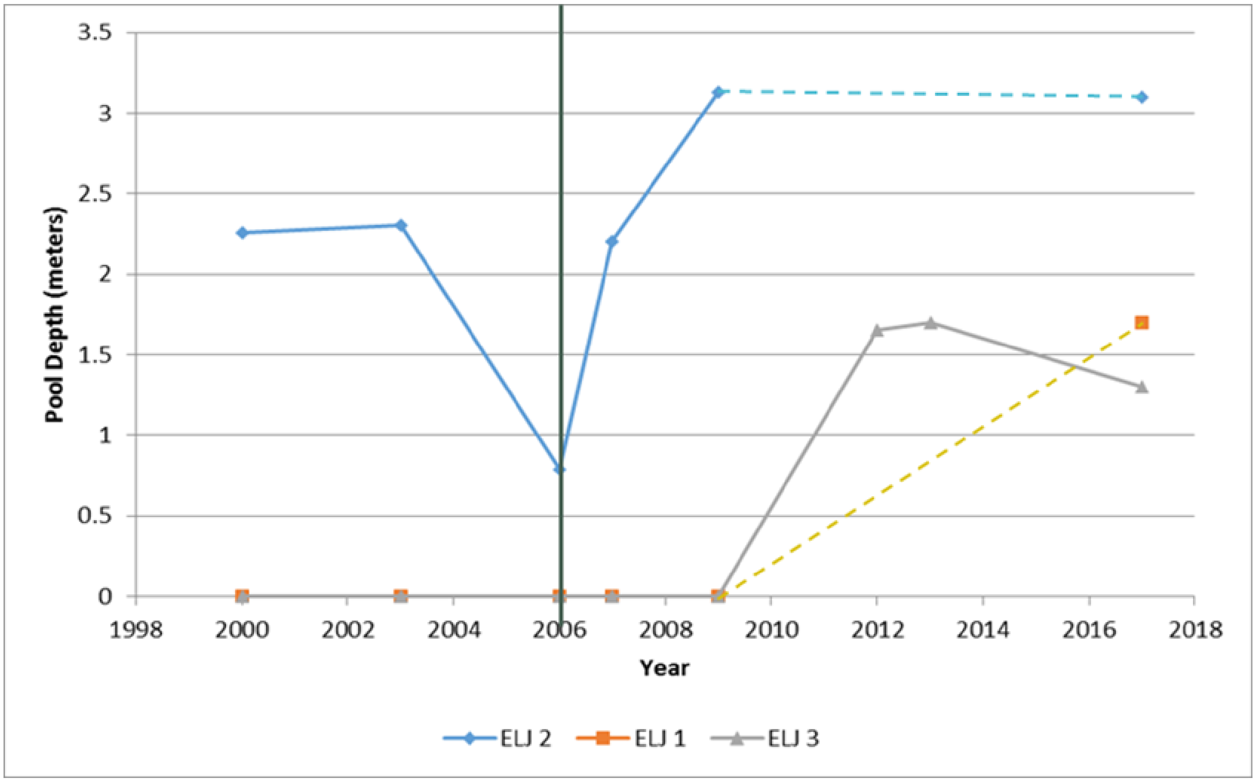
Pool Parameter	Year				
	2000	2003	2007	2009	2016
Total Pool Count (ELJ)	3	2	3 (1)	4 (1)	4 (3)
Primary Pools (ELJ)	2	2	2 (1)	2 (1)	3 (2)
Wood-formed (ELJ)	0	0	2 (1)	3 (1)	3 (3)
Mean Residual Depth (m)	1.68	~1.87	1.60	1.72	1.63

Figure 88: 2016 Habitat mapping showing the three pools formed by the three engineered logjams along the river (NNR data).



While mean residual depth in the reach has slightly increased since 2007, it remains below the pre-project average. This is due to the loss of the deep pool associated with the riprapped levee that confined the channel at the project area and the formation of several smaller wood-formed secondary pools. This resulted in more frequent pools with a greater variation in pool depths. Looking at the pool development associated with the three engineered logjams in the project, it is clear that the project is continuing to change after a decade (Figure 89). While the project has not met the objective of increasing the average residual depth in the reach, it has led to an increase in the number of pools in the reach.

Figure 89: Pool development through time at the three engineered logjam sites in the Lower Hutchinson Creek Project.

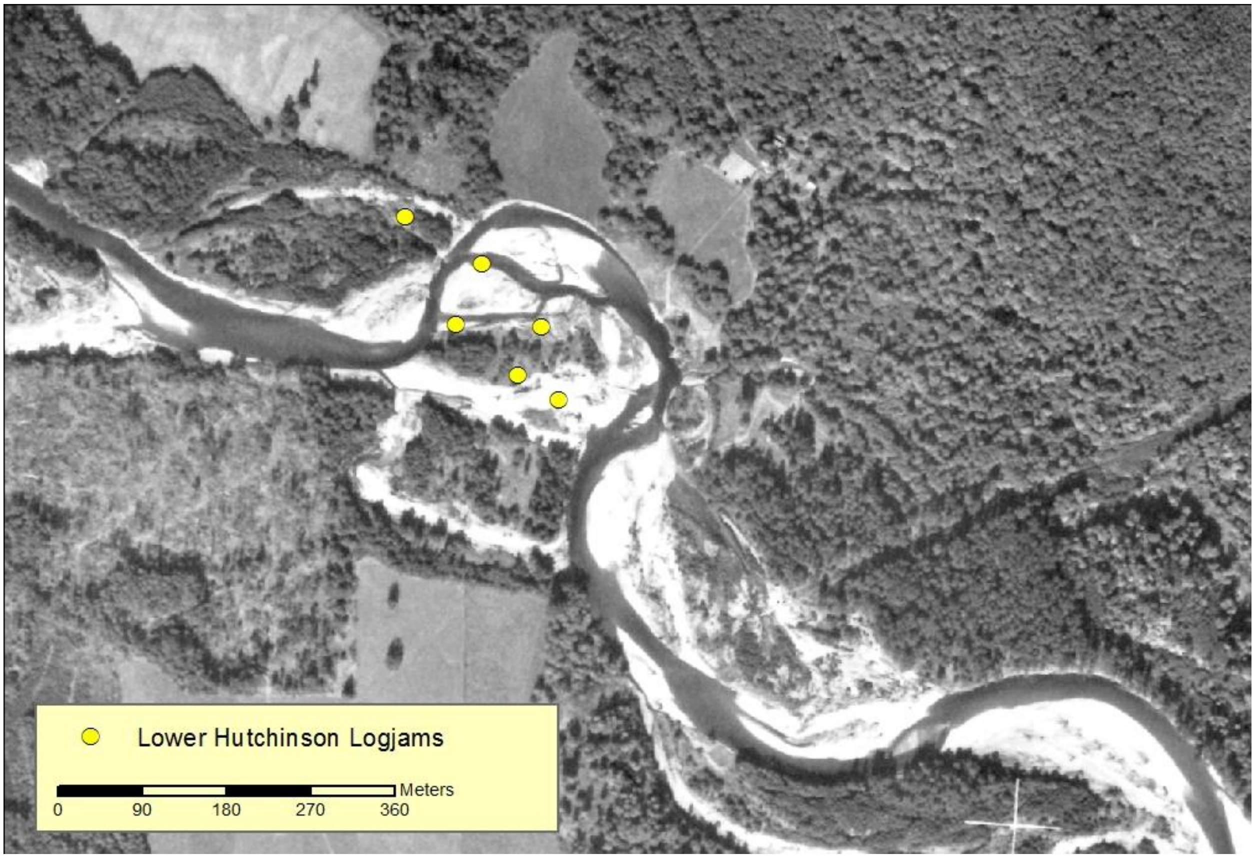


Floodplain Connectivity

Floodplain connectivity was reflected in two project objectives: increasing the active channel width in the artificially confined reach and increasing floodplain sediment storage. Changes in the active channel width can have important impacts on the quality and quantity of aquatic habitat in the reach. The active channel area is where most of the secondary channel development occurs, as bars and vegetated islands separate flow into smaller side-channels and braids.

The cross-sectional area of the active channel area has been decreasing steadily in the project reach since the mid-1960s, when the average width was approximately 200 m (Maudlin et al. 2002) (Figure 90). By 1998, it had reached a historic low of approximately 60 m. This narrowing was directly related to the bank protection placed to protect the City of Bellingham water pipeline.

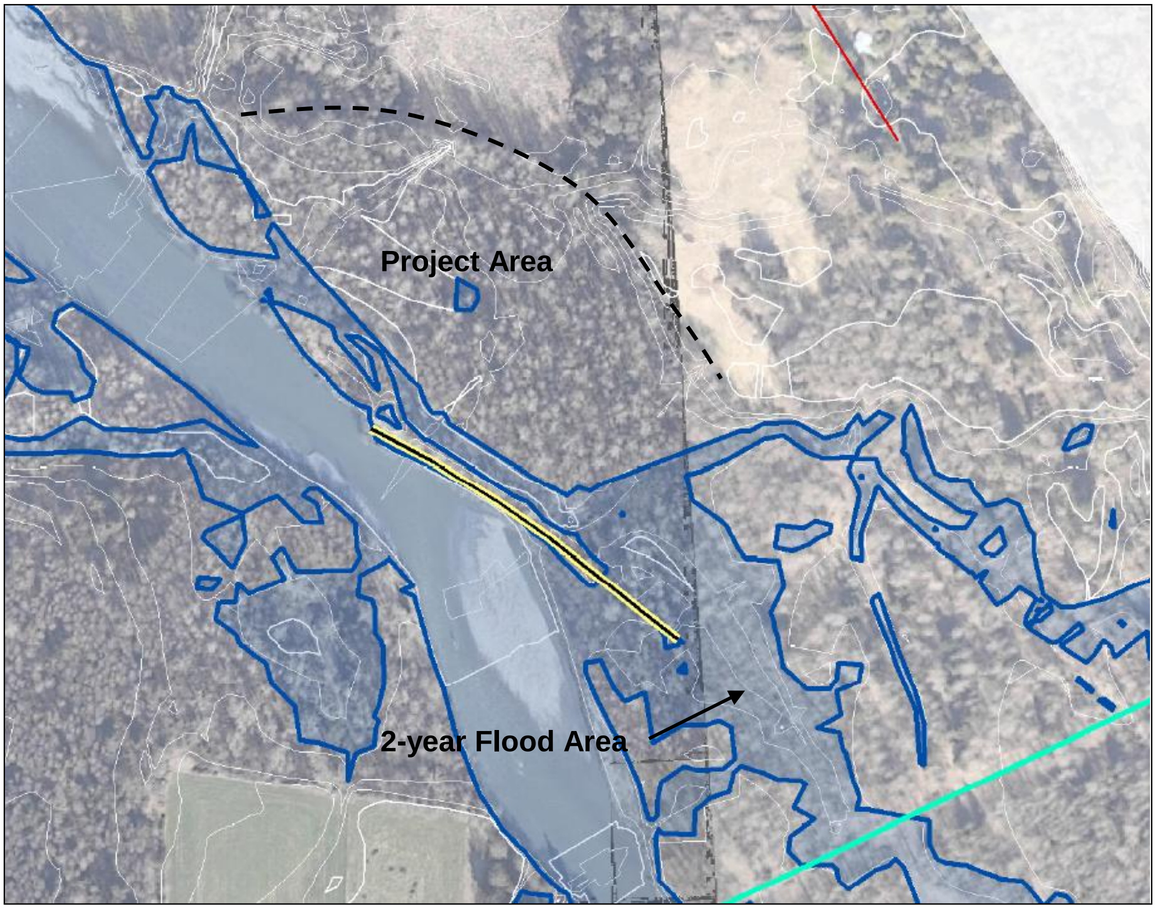
Figure 90: The Lower Hutchinson project reach in 1966, before riprap to protect the City of Bellingham pipeline, future logjams are shown for reference.



As a part of the Lower Hutchinson Creek project, a section of this bank protection was removed and replaced with a series of logjams that were designed to slow channel migration into the floodplain and split flow. Since the project was constructed, the active channel has widened 33% in the project reach from approximately 60 m to 80 m average width. Channel migration into the area where the levee was removed and widening just upstream of the project accounted for most of this change. This increase exceeded the 20% target that was proposed in the objectives.

The second floodplain connectivity objective of the project was to increase the floodplain area, so fine sediment would be deposited outside of the active channel area. The channel through the upstream end of the Acme Valley has a history of incision into its floodplain and terrace formation through the historic period (Maudlin et al. 2002). In addition to the channel incision, flood control works have further isolated portions of the floodplain from the channel. In the case of the project site, the levee that separates the South Fork Nooksack from Hutchinson Creek also isolated a portion of the floodplain, so that 2-year flows did not access much of the floodplain (Figure 91). The result of the floodplain incision is that flood flow is confined to a narrow area and sediment carried during the flood is moved more rapidly though the channel, instead of being stored on the floodplain.

Figure 91: The 2-year flood inundation area based on the South Fork Nooksack HEC-RAS model at the project site before project construction.



As a part of the project construction a portion of the levee was removed and it was expected that more of the floodplain in the project would be inundated under a similar discharge (Figure 92). Hydraulic modeling of the Nesset's project included this project reach and was based on a 2013 lidar-derived elevation model. This modeling showed that the 2-year flood covered the target floodplain area in the project reach. A comparison with pre-project conditions is difficult due to the differing quality of the topography data and the different modeling approaches, but the change indicates that the removal of the levee likely increased flood water storage on the floodplain.

Figure 92: Levee removal as a part of the Lower Hutchinson Project.

During November of 2006, the South Fork Nooksack experienced a ~10,000 cfs (mean daily discharge) flood. This was slightly larger than a 2-year flood event on the river. During this event, the entire floodplain in the project areas was inundated more than a meter deep (Figure 93, Figure 94), similar to the results shown for the Nesset's Project existing conditions modeling that included this reach. During the flood, the high velocity of the channel remained in the active channel area on the outside of the three water-ward logjams, while immediately behind the logjams the water was nearly still. The logjams provided an effective barrier to high velocity, while allowing floodplain inundation.

Figure 93: Looking downstream at Logjam #2 at the edge of the low flow channel during the November 6, 2006 flood.

Figure 94: Looking downstream at Logjam #4 in the floodplain during the November 6, 2006 flood.

While floodplain connectivity was not directly monitored for the project, based on field observations and recent hydraulic modeling it appears that the project has increased the connectivity of the floodplain behind the logjams. Removing the levee has also increased the active channel area in the reach.

LWD Loading

The project was expected to increase the wood load in the channel. The loss of stable wood from the channel and the reduction in wood recruitment to the channel has had a dramatic effect on habitat quality in the lower gradient, unconfined reaches of the South Fork Nooksack (Maudlin et al 2002, Soicher et al. 2006, Brown and Maudlin 2007). In addition to directly adding wood to the channel and constructing engineered logjams, removing the levee should improve wood recruitment to the channel.

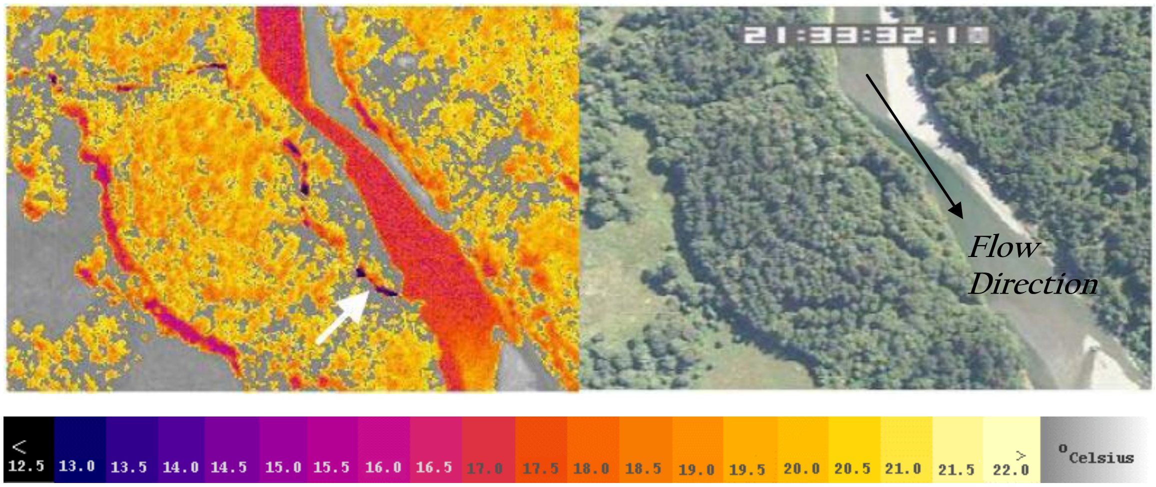
Wood mapping in 2000 identified 13 logs that had a volume more than 9 m^3 in the project reach, and approximately 250 smaller pieces of wood (NSEA data). Mapping in 2002 showed that there were only 2 large pieces and 5 logjams in the project reach (LNR 2007a). In neither year there were large pieces present in the floodplain behind the levee and the bulk of the wood was located in the unconfined area downstream of the levee. Wood mapping in 2007 found that the project reach saw a drastic increase in logjams and large pieces of wood as a result of the project (LNR 2007b). There were 52 large logs placed as floodplain roughness in the project area, in addition to the six engineered logjams. The project increased the wood load in the floodplain of Hutchinson Creek from zero pieces to 52 pieces and increased the amount of wood in the project area from 237 pieces to 289 pieces, an increase of 22%. This met the project objective of increasing the wood in the reach by 20%. There has been no additional wood mapping done in the project reach, but all six of the engineered logjams are still present. Based on field observations, two of the engineered logjams appear to have lost much of their racked wood and have a smaller volume than when they were constructed.

Thermal Refuge Creation

The South Fork Nooksack River is described as a temperature-impaired water body under standards implemented by the Washington State Department of Ecology (DOE). Summer temperatures in the South Fork regularly exceed fresh water aquatic life criteria. In 2001, a series of aerial flights measuring surface water temperatures describe this condition (Figure 95). During the flight, temperatures in Hutchinson were displayed below 13 °C, while the South Fork simultaneously runs between 17 and 21

°C. Late in the year, Hutchinson Creek would generally go subsurface in the reach behind the levee, but maintain flow upstream of that point. The project had two objectives related to thermal refuge creation: providing low flow access to Hutchinson Creek and enhancing the habitat at the confluence with the creek and the South Fork Nooksack. Conditions mapped in 2001 describe Hutchinson Creek as dry at the confluence with the South Fork, and a 2003 snorkel survey noted similar conditions.

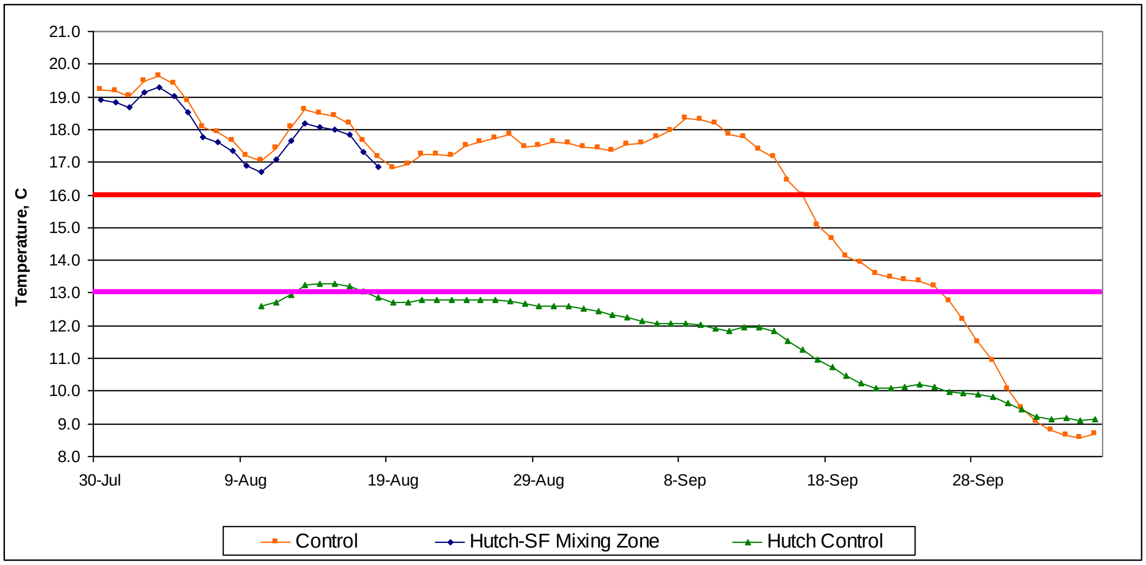
Figure 95. FLIR data (Watershed Sciences 2002) collected in the Hutchinson Creek reach in 2001; white arrow points to the mouth of the tributary.



Following the levee removal and logjam construction, Hutchinson Creek avulsed into the South Fork upstream of its previous confluence, shortening the channel length by ~220 m. The new confluence was at the location of one of the engineered logjams and the creek now flowed into a deep scour pool with complex wood cover, maintained by the flow of the river. This shortening of the channel allowed Hutchinson Creek to reach the South Fork during the low flow period and maintain low flow access to the cooler water tributary. The trade-off for the improved low flow connectivity was the loss of low gradient tributary length that was heavily used by species, such as steelhead, that enter the river during higher flow periods.

To evaluate the temperature in the pool at the confluence, temperature data loggers were launched at two Hutchinson Creek locations, paired with a main channel South Fork control probe (LNR 2007b). The loggers recorded hourly temperature at the bed of the channel from within a covered anchoring block. The control logger that was set in the main channel above the Hutchinson Creek confluence recorded temperatures that exceeded the maximum core summer salmonid habitat limit for most of the summer (Figure 96). The main channel temperature fell under the core habitat target (16 °C) in mid-September, but did not breach the spawning target temperature (13 °C) until the end of September, near the end of the spring chinook spawning season. The data logger placed in the well-mixed pool at the confluence with Hutchinson Creek recorded temperatures that mirrored the temperature pattern of the South Fork control site, but were slightly less than the control temperature. Hutchinson Creek maintained temperatures that met the spawning criteria throughout the summer.

Figure 96. South Fork main channel near Hutchinson Creek (paired probe controls) data recorded in 2007 and presented as 7-day average maximum temperatures (LNR 2007b).



In summer 2019, temperature data loggers were placed near the bottom of the engineered logjam pool at the confluence of Hutchinson Creek and the South Fork Nooksack (Logjam #2), and upstream of the confluence (Logjam #1). Data show no thermal refuge in the pool, possibly due to extremely low flow levels.

Thermal refuge mapping of the project was also done over several years using a fast response thermal probe. Refuges were identified as areas where the temperature was more than 2°C cooler than the adjacent main channel, regardless of meeting the water quality standards. Cooler areas were either mapped as a point or an area depending on the size of the refuge area. The mapping was done during the low flow period when stream temperatures exceeded 18 °C.

Mapping in the reach consistently found a thermal refuge area in the pool at the confluence of Hutchison Creek. The refuge size and habitat quality varied depending on the discharge of Hutchinson Creek and how the flow interacted with the logjam. In cases where the creek entered the river in a higher flow area immediately upstream of the pool, the cooler water was rapidly mixed into the South Fork and the refuge was small. In years when the flow entered into the sheltered backwater area of the pool, the refuge was larger.

Refuge mapping done in August of 2015, when the flow of the South Fork was a record low (89 cfs) found that Hutchinson Creek was dry at the confluence for the first time since the project was completed and was not providing a thermal refuge area (NNR data). Monitoring of the reach did find another thermal refuge in the newly formed pool near Logjam #3. This structure forms a 0.8 m-deep backwater pool that appears to be heavily influenced by groundwater. The minimum temperature measured in the pool was 16.8 °C, compared to 22.2 °C for the average temperature of the South Fork at this location. The refuge area, where the temperature was more than 2 °C cooler than the mainstem, was approximately 23 m^2 (Figure 97). Juvenile fish were abundant in this location.

Figure 97: Boundary of the thermal refuge area associate with the Lower Hutch3 Site.

The Lower Hutchinson Creek Project has been successful at creating and enhancing thermal refuge areas. The project has successfully reconnected Hutchinson Creek during the low flow period, proving access to a cooler water tributary. The project has also created a cooler water holding pool in the South Fork. The refuge area within the pool varies in size depending on the year, but it has consistently provided a refuge. Lastly, local scour associated with one of the logjams has created a cooler water backwater area. It is likely that the increased mixing with the South Fork will limit the area of the refuge, but while it remains a backwater it is providing thermal refuge habitat for juvenile salmonids.

Conclusions and Recommendations

The Lower Hutchinson Project met many of its project objectives (Table 80). The objectives that were not met were related to secondary channel length and pool formation. In the case of both of these objectives that lack of floodplain channel formation between the stream-adjacent logjams limited the success of the project. Rather than creating side channels, the river has deposited sediment and wood in this area and reduced the secondary channel length. The floodplain connectivity objectives were likely met, although no direct measure of fine sediment storage was done. Wood loading increased as a result of the wood added for floodplain roughness as a part of the project. Much of this wood is now obstructed by vegetation, so it is uncertain how the floodplain wood loading has changed since 2007. The project successfully reconnected Hutchinson Creek to the South Fork during summer low flow conditions and the logjam at the confluence improved chinook holding habitat in the known refuge area. The project also resulted in the formation of cooler water refuge area in a groundwater-fed backwater pool, so two of the three logjams that were in the low flow channel were providing cooler water refuges.

Table 80: Lower Hutchinson project objectives and success.

Stated Project Objectives	**Objective Group**	**Objective Success**
Increase channel length by 20%	Secondary channel length	**Not met**- the project has not increased side or braided channel length in the reach. There has been an increase in main channel length and a loss of tributary length.
Increase residual pool depth by 20%	Pool formation	**Partially met**- the project increased the number of pools, but did not increase the average residual pool depth in the reach.
Increase active channel width by 20%	Floodplain connectivity	**Met**- the project increased the active channel width by 33% from ~60m to ~80m.
Increase loading of wood in the floodplain by 20%	LWD loading	**Met**- wood added to the floodplain as a part of the project increased large piece counts by 22%
Create a thermal refuge at Hutchinson Creek	Thermal refuge creation	**Met**- the project improved habitat at the Hutchinson confluence and reconnected a cool water source. Recent monitoring showed that low flow from Hutchinson Creek can limit the available refuge area.
Reduced fine sediment through floodplain storage	Floodplain connectivity	**Uncertain**- direct monitoring has not occurred, but modeling and field observations suggest an increase in floodplain connectivity.

Downstream of Hutchinson Project

Project Description

The Downstream of Hutchinson project lies between river mile 9.6 and 10.2 of the South Fork Nooksack. The project consists of 19 engineered logjams and 2 sections of wood-based revetment that totals ~90 meters (Figure 98). The project was constructed in three phases between 2012 and 2015. The structures are built around driven piles and lashed together with a combination of rope, and chain. The project objectives were focused on pool formation in different areas and the logjams were designed to increase the number of wood-formed pools, increase the quantity of complex wood cover in secondary pools in low-flow channel, and target four pools in cool water refuge areas (Table 81).

Figure 98: Downstream of Hutchinson Project logjams.

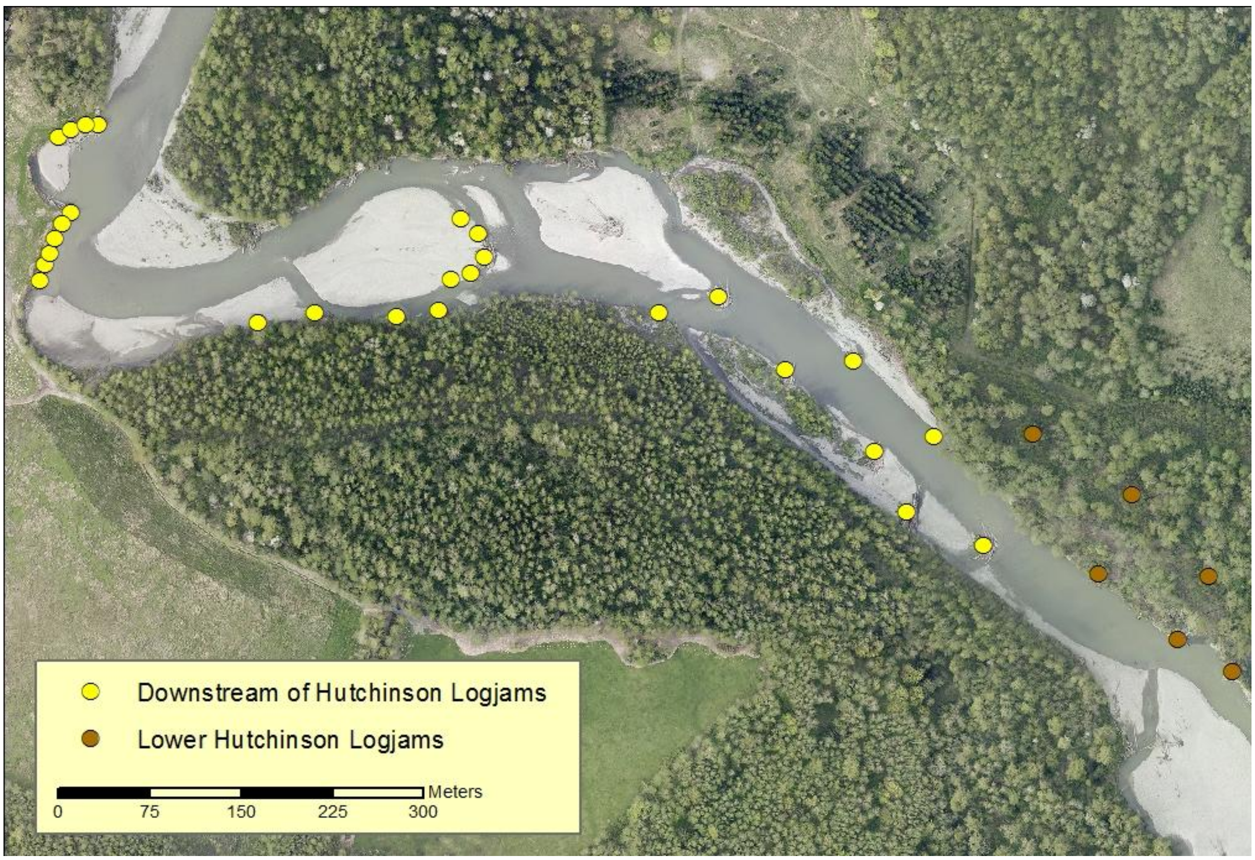


Table 81: Downstream of Hutchinson project objectives (NNR 2014 Project Design Report covering phase 1, 2 and 2a).

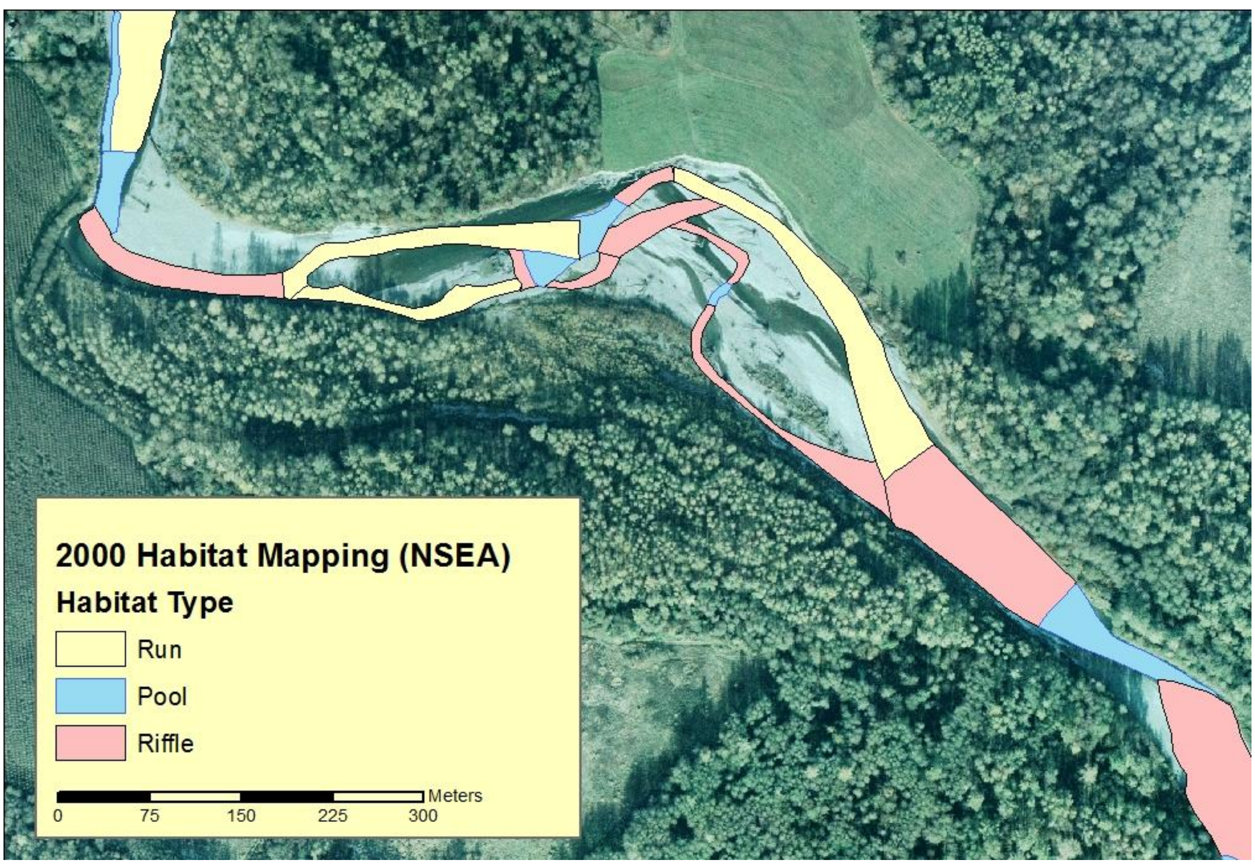
Stated Project Objectives	Objective Group	Limiting Habitat Factors
Create 6 wood-formed primary pools	Pool formation	Lack of Key Habitat
Create low flow cover in 11 secondary pools	Instream cover	Low habitat diversity
Create low flow cover in 4 secondary pools in cool water refuge areas	Thermal refuge creation	Elevated summer water temperature

Project Objectives

Pool Formation

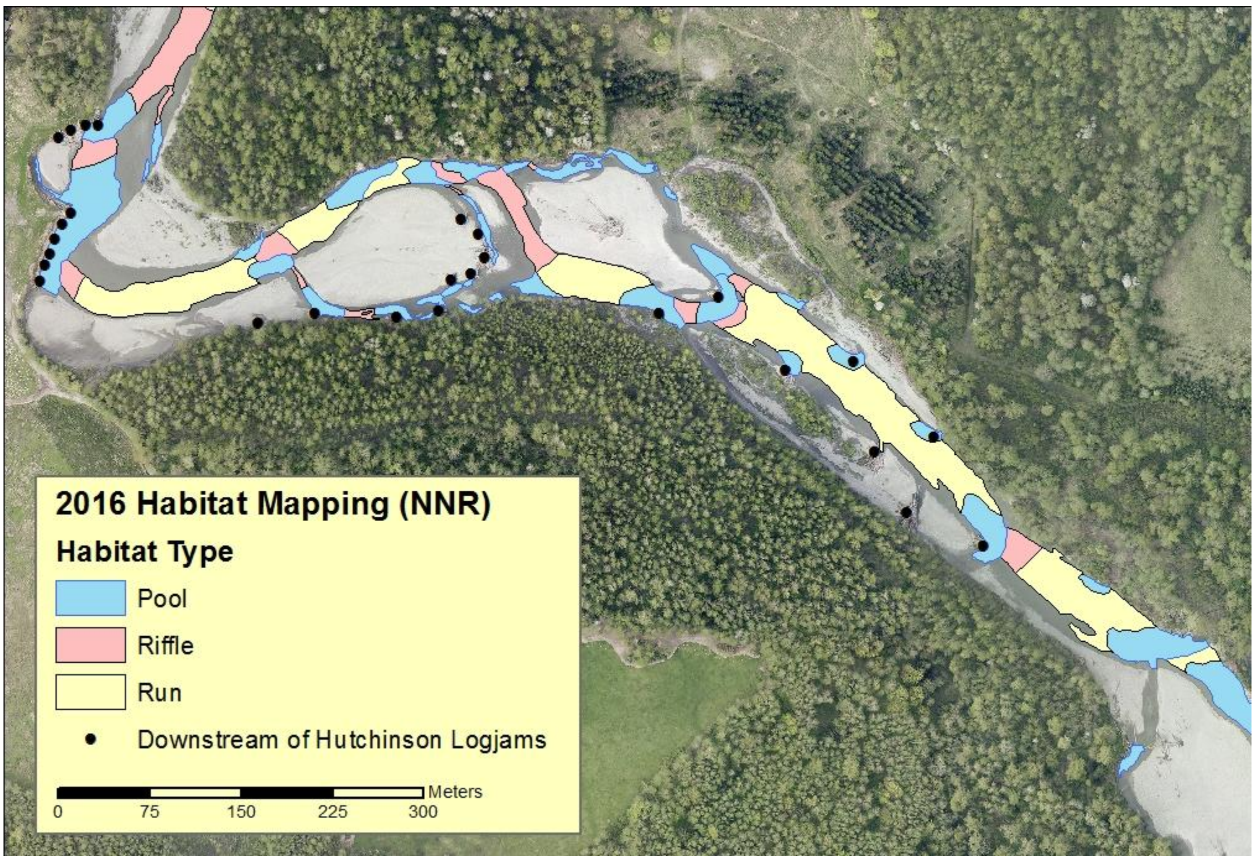
The project had the goal of creating six wood-formed primary pools in the project reach. Pre-project mapping of the reach was conducted in 2000 (NSEA data) and 2003 (Ecotrust data). In 2000, there were five pools in the project reach: two primary and three secondary habitat pools (Figure 99). One of the pools was formed by wood. In 2003 there was no change in primary pools- two pools, with one pool formed by wood. The channel was not braided in 2003 as it was in 2000 and there were no secondary pools mapped.

Figure 99: Baseline habitat mapping in the Downstream of Hutchinson project reach.



Post project monitoring of the reach in 2016 found that the logjams have been effective in creating pools (Figure 100). The project reach has 26 pools in the low flow channel: 10 primary pools in the main channel and 16 secondary pools in sloughs or along the edges of the main channel. Of the ten primary pools in the reach, five were formed by the engineered logjams, three by natural wood accumulations, and two by flow convergence. Further, the engineered logjams have formed three secondary pools in the main channel that all exceeded the 1m residual depth threshold for a deep pool. Together the engineered logjams were responsible for 16 of the 26 pools present in the reach. The project met the objective of six wood-formed primary pools in the reach. Baseline conditions showed one wood-formed primary pool and the reach now contains eight wood-formed primary pools. Engineered logjams are responsible for forming five of the eight pools.

Figure 100: Habitat mapping in 2016 of the Downstream of Hutchinson project (NNR data).



Instream Cover

The objective of the project was to provide wood cover for 11 secondary pools in the reach. Baseline mapping 2000 found three secondary pools in the project reach, two having wood as the dominant cover type. Mapping in 2016 found that the project included 16 pools in the low flow channel area. Of these 16 pools, wood was the dominant form of cover in 13 of them and engineered logjams were providing cover in nine of the pools. While the engineered logjams were associated with just over half of the secondary pools, they dominated the woody cover area in secondary pools. The engineered structures were providing approximately 96% of the 207 m^2 of wood cover that was present in secondary pool units. The project met the objective by increasing the number of pools with wood cover in the reach from two to thirteen, with engineered logjams providing cover in nine of the thirteen.

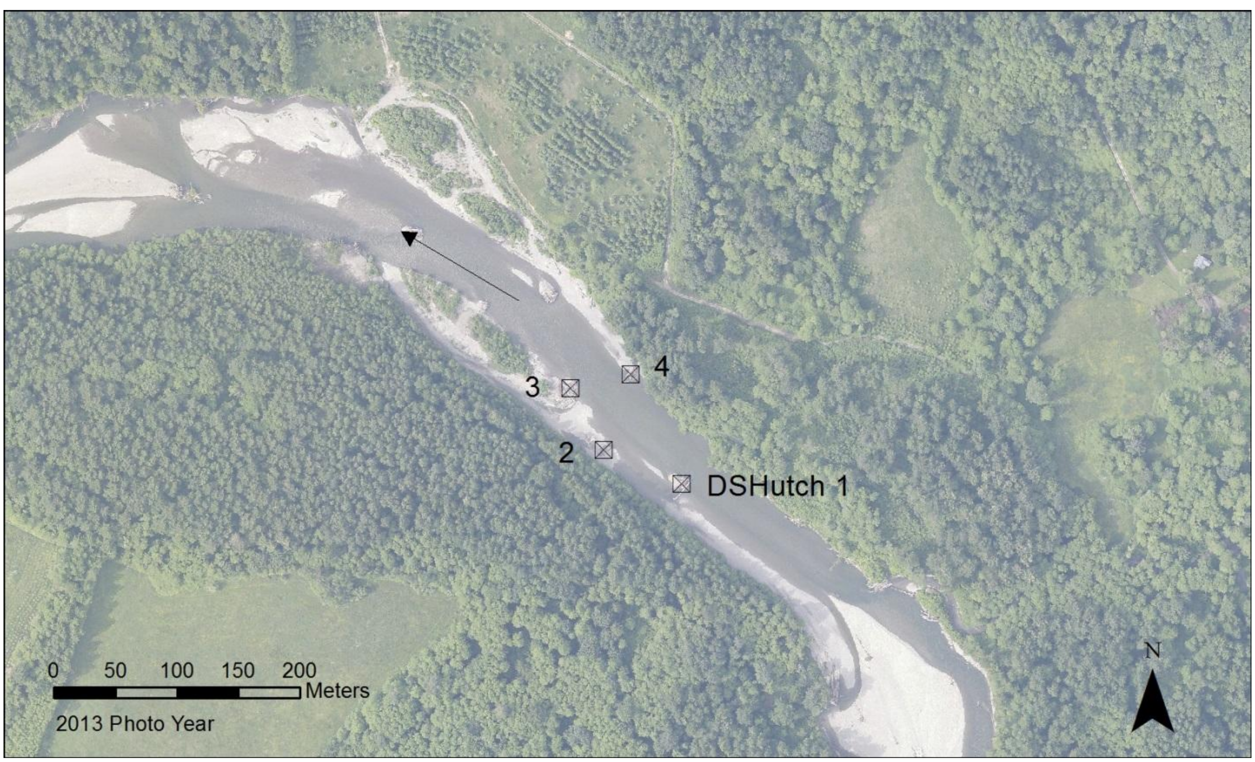
Thermal Refuge Creation

Thermal refuge mapping in the reach used a combination of scanning pools to map refuge areas and a distributed temperature sensor cable that was deployed in the reach. Refuge mapping was conducted on August 18, when mean daily flow was 89 cfs and the South Fork temperature ranged between 22.2 and 22.5 °C during the survey of the upstream portion of this project reach (Figure 101). Monitoring found that two of the four engineered logjams that were monitored were both associated with thermal anomalies (Table 82).

Table 82: Temperature and depth associated with habitat structures in the Downstream of Hutchinson Reach, bolding shows cooler water areas (NNR data).

Site ID	Minimum Temperature (°C)	Average SF Temperature (°C)	Depth at Minimum Temperature (m)
DSHutch 1	**19.2**	**22.2**	**0.8**
DSHutch 2	N/A	N/A	N/A
DSHutch 3	**18.8**	**22.5**	**0.25**
DSHutch 4	21.6	22.5	1.7

Figure 101: Downstream of Hutchinson Project Area that was monitored for the refuge mapping.



The DSHutch1 structure formed a deep primary scour pool in the main channel of the river. A portion of the pool was a backwater environment around the front of the logjam. This backwater area had a minimum temperature of 19.2 °C at a depth of 0.8m, compared to 22.2 °C. The refuge area was approximately 42 m^2 in area (Figure 102). Juvenile fish were abundant in the refuge area, with a variety of species and sizes present (Figure 103). A second small (>1m^2) refuge areas was found near DSHutch3, where there was a 0.25 m-deep isolated pool was associated with the structure. The minimum temperature measured in the pool was 18.8 °C, compared to 22.5 °C in the South Fork. No fish were noted in the isolated pool.

Figure 102: Refuge area associated with the DS Hutch1 structure- at the time of survey the flow was lower than the photo and the refuge area was a backwater of the river.

Figure 103: Fish present in the DSHutch 1 refuge area.

A second method of evaluating stream temperature was used in the project reach that allows both a picture of the spatial distribution of temperature and how it changes through time (Gendaszek 2014). The distributed temperature sensor (DTS) is a fiber optic cable that is placed along the bed of the river that can record a continuous temperature profile along its length. The cable was installed so that it captured the areas adjacent to four of the logjams as well as the river between the sites (Figure 104). The cable recorded temperature for approximately a week during August of 2013 and found that there was one location where there was a cooler water anomaly, at approximately 320 m along the temperature profile (Figure 105). Habitat mapping in the reach in 2013 showed that most of the area that was monitored was a large, shallow riffle habitat, with secondary pools near four of the structures and a fifth pool at a natural woody debris pile (Figure 106). The site of the anomaly was a 1.2 m deep secondary pool associated one of the engineered logjams. The other pools associated with the logjams that were monitored showed no cooling in spite of also being similar habitat types and having similar depths.

Figure 104: Digital temperature sensor cable lay-out in the Downstream of Hutchinson Project reach. Green point shows location of anomaly at 320m shown in Figure 105 (Gendaszek 2014).

Figure 105: Thermal profile of the Downstream of Hutchinson Project in August of 2013. Note the thermal anomaly at ~320m showing ~2°C temperature difference during the warm part of the day (Gendaszek 2014).

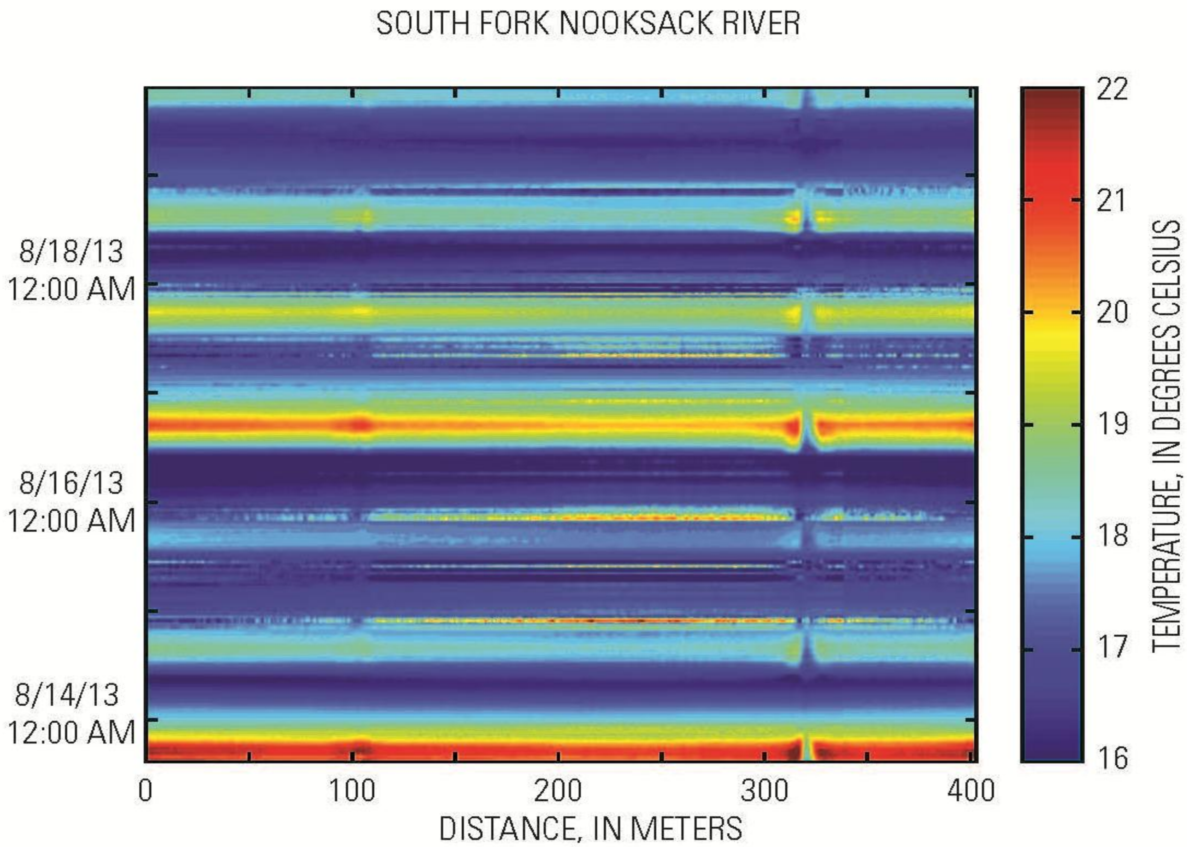
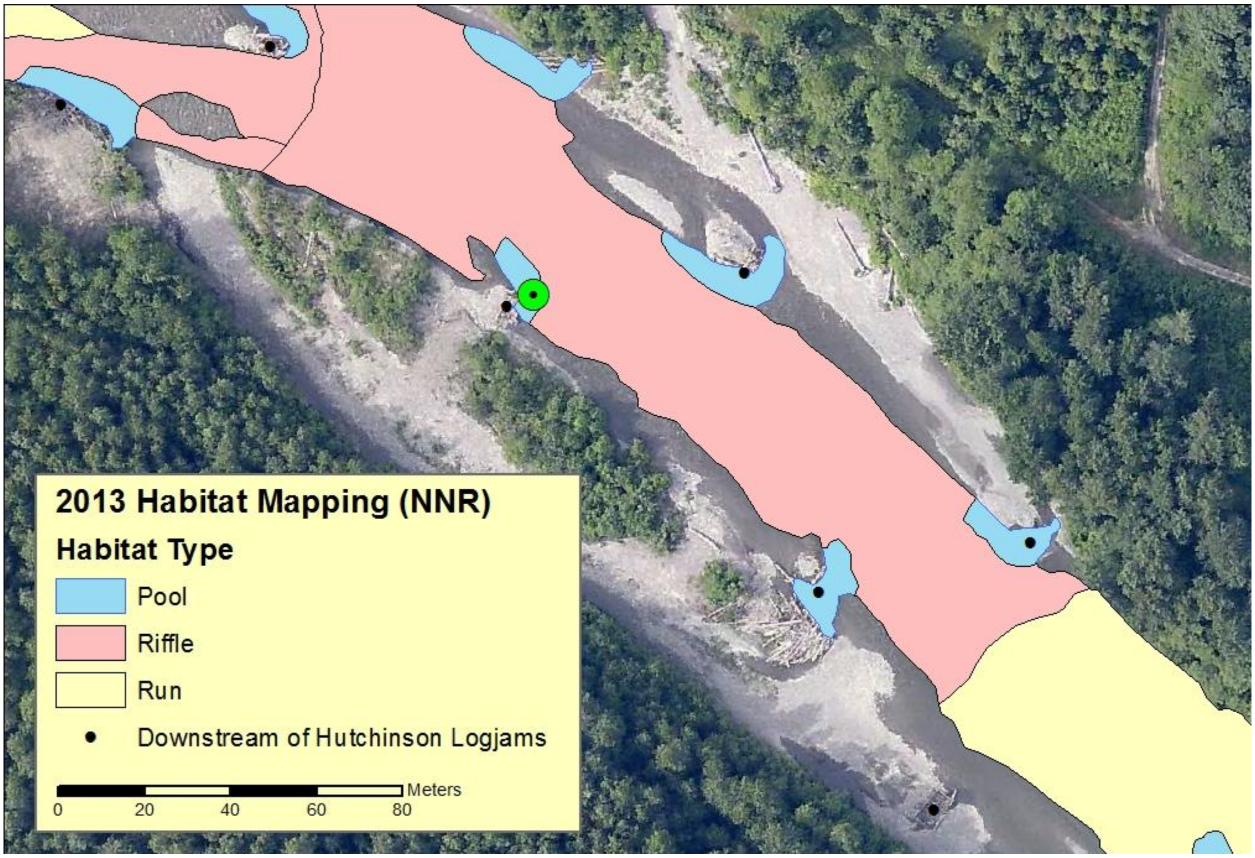


Figure 106: 2013 habitat mapping in the Downstream of Hutchinson reach showing location of the DTS thermal anomaly (NNR data).



Based on the temperature monitoring that has been done, several of the structures are associated with ground water seeps that are forming potential thermal refuges. Continuous temperature probes have been deployed in several of the logjams to evaluate changes in temperature with depth, but these have found little difference in the well mixed pools associated with the main channel. Continued monitoring of the pool habitats will help identify cooler water anomalies and assess how the project is interacting with these areas.

Conclusions and Recommendations

The Downstream of Hutchinson Project has generally met its project objectives (Table 83). The project has increased primary and secondary pools over the baseline line conditions and improved cover in these pools. The engineered logjams have been largely responsible for the reach meeting the project objectives, although natural wood is providing some additional function. Potential thermal refuge areas have been identified in the reach, but additional surveys will be needed to determine whether the project has been successful in meeting the objectives.

Table 83: Downstream of Hutchinson project objectives (NNR 2014 Project Design Report covering phase 1, 2 and 2a).

Stated Project Objectives	Objective Group	Objective Success
Create 6 wood-formed primary pools	Pool formation	**Met**- the project reach included 8 wood-formed pools; 5 formed by engineered logjams.
Create low flow cover in 11 secondary pools	Instream cover	**Met-** the project had low flow wood cover in 13 of the 16 secondary pools, with engineered logjams counting for 9 of these.
Create low flow cover in 4 secondary pools in cool water refuge areas	Thermal refuge creation	**Uncertain**- temperature monitoring of portions of the reach has identified three potential refuges.

Acme Early Chinook Project

Project Description

The Acme Project was built over two years (2009 and 2010) and included five groups of structures in the South Fork Nooksack and several smaller habitat structures in the Landingstrip Creek side channel (Figure 107). The Acme Project was designed to integrate flood management and salmon habitat and included increasing bank resistance to erosion as a project objective, along with pool scour and increased wood cover at a range of flow elevations along with enhanced flow into the Landingstrip Creek side channel (Table 84).

Figure 107: Acme Project structure groups.

Table 84: Acme project objectives (from SRFB proposal #07-1790).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Restore South Fork in-channel habitat and complexity by creating multiple complex pools	Pool formation	Lack of Key Habitat
Provide thermal refuge through complex pool creation in a zone of cool groundwater emergence and hyporheic flow.	Thermal refuge creation	Elevated summer water temperature
Meter and encourage flow into lower Landingstrip Creek to enhance juvenile rearing opportunities, floodplain connectivity and reduce mainstem volumes and velocities during high flow events.	Secondary channel length	Low habitat diversity
Remove approximately 150’ of existing left bank riprap to allow for more natural bank deformation and evolution of channel form and riparian forest recovery.	Edge habitat improvement	Low habitat diversity
Improve in-channel habitat complexity and diversity in lower Landingstrip Creek for rearing early chinook, steelhead, and coho through placement of complex wood structure(s).	Habitat unit diversity	Low habitat diversity
Reduce potential for adverse flood effects on community of Acme and SR 9 bridge.	Bank protection	N/A

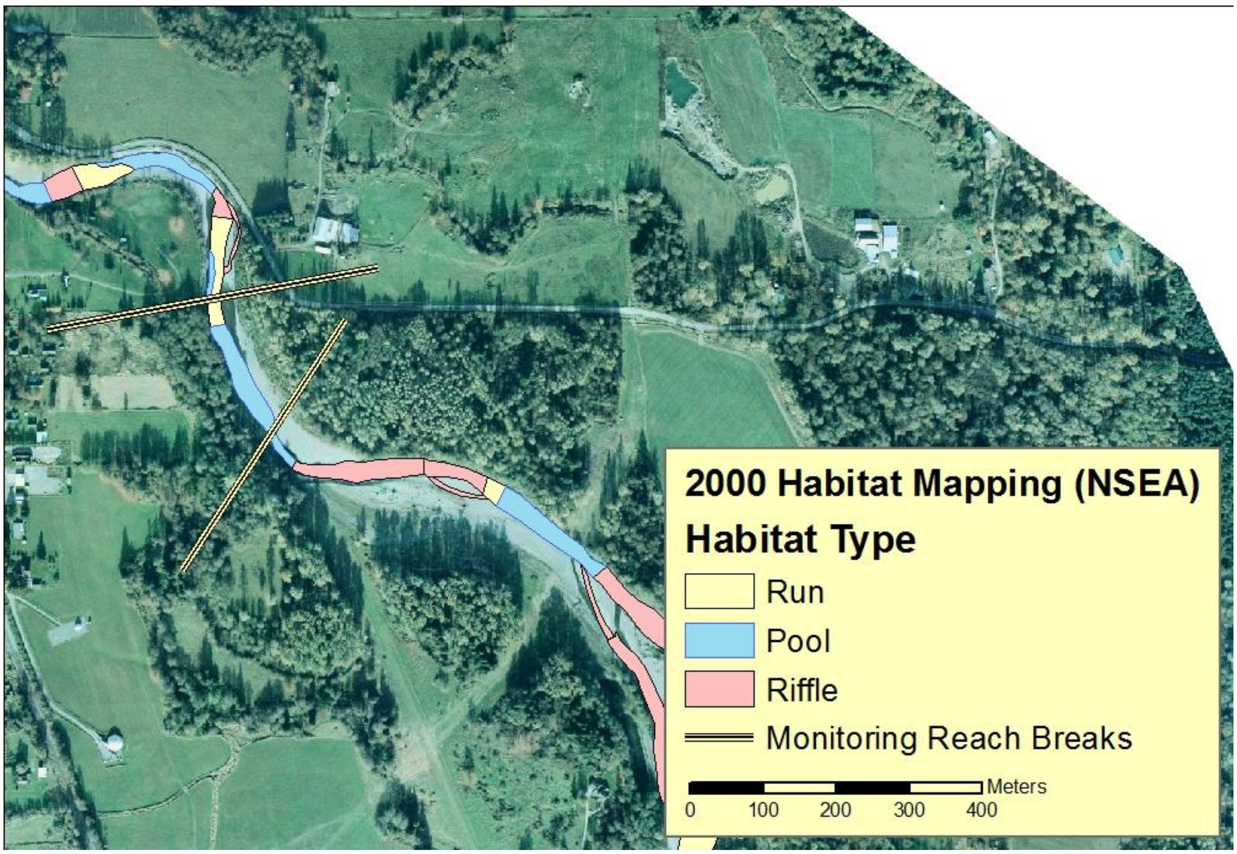
Project Objectives

Pool formation

Baseline mapping of the project reach from 2000 and 2003 showed that the project area was one large, deep pool. In 2000, the pool was formed by riprap 2.55 m deep and 4,500 m^2 in area with LWD as the dominant cover type (Figure 108). Mapping in the summer of 2003 showed little change in the habitat. Snorkel surveys at that time showed an abundance of juvenile salmonids (~1,325 coho, 970 steelhead/ rainbow trout and 145 chinook) present in the riprap and wood cover of the pool.

Post construction monitoring in 2016 showed that there was little change in the habitat units in the reach (NNR data). The project reach was again mapped as one large pool. The riprap removal and installation of the engineered logjams led to a change in the pool-forming feature from riprap to wood and an increase in wood cover area in the pool. The maximum pool depth increased from between 1.9m and 2.55 m in the pre-project mapping to 3.66 m following the construction of the project. Snorkeling associated with 2016 mapping found a relative abundance of coho and steelhead/ rainbow, with a most (79%) of the fish found in pool associated with the engineered logjams rather than in the bar edge, natural bank or middle of the channel (USFS and NNR survey data). Since the project reach is essentially one pool long, the pool spacing in the reach and habitat unit diversity haven't changed as a result of the project.

Figure 108: Baseline habitat mapping (Nooksack Salmon Enhancement Association 2000).



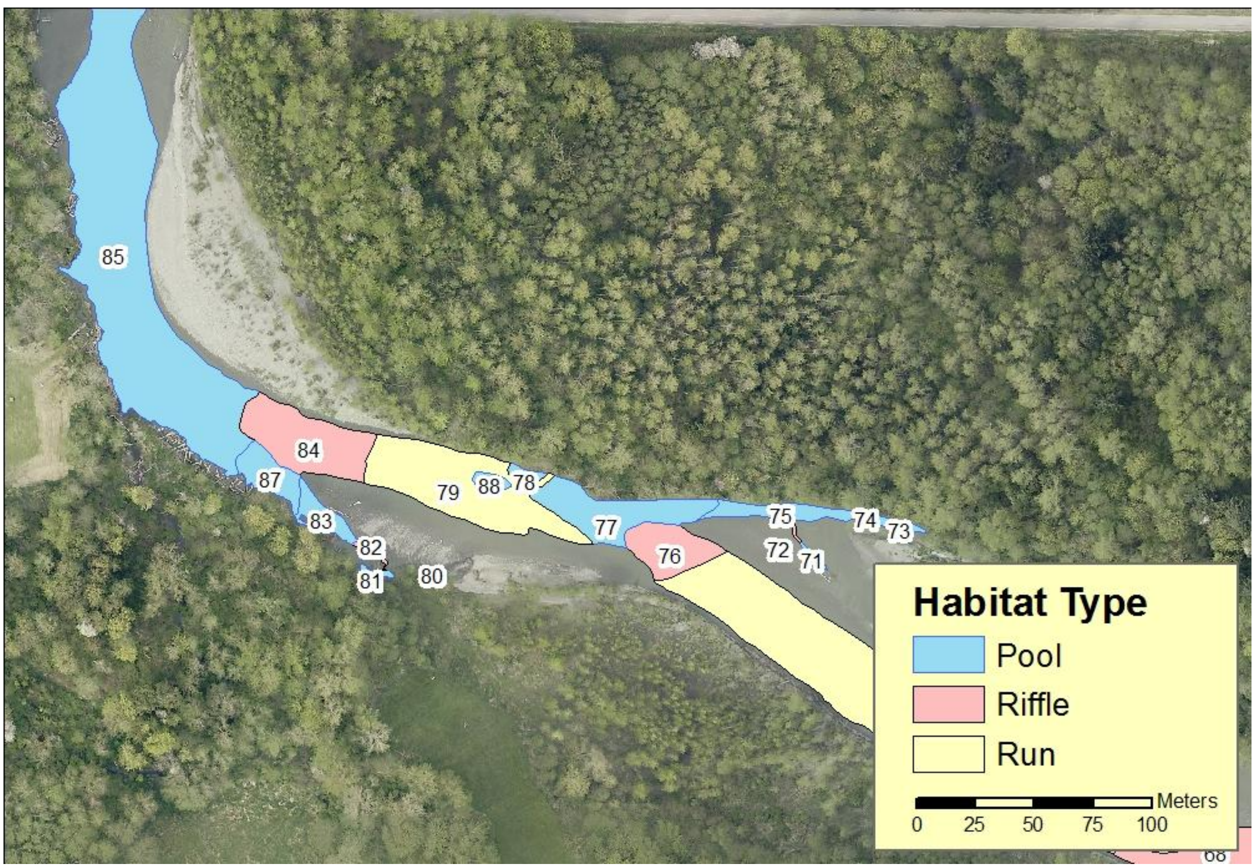
Thermal Refuge Creation

Temperature monitoring of the habitat in the project reach found no difference in temperature in the logjam-formed pools. Scanning of the habitat units immediately upstream of the project found several groundwater seeps that were contributing cooler water to the South Fork, reflecting the groundwater emergence area referred to in the project objectives. Five of the backwater and isolated pool units along the bank were found to be temperature refuges (>2 °C cooler than the adjacent channel), but all five had a dissolved oxygen less than 5.0 mg/L and were considered oxygen limited for juvenile salmonids (various authors, cited from Bjornn and Reiser 1991) (Table 85). While the project did increase the pool depth in an area of groundwater emergence, this did not lead to measurably cooler water pools associate with the structures.

Table 85: Thermal refuge monitoring in the Acme Project reach (August 25, 2016). Unit numbers are from mapping shown in Figure 109.

Unit No.	Min. Temp (°C)	SF Temp (°C)	Temp Diff (°C)	DO (mg/L)	Refuge (Y/N)	DO Limited (Y/N)
80	12.9	18.5	5.6	2.50	Y	Y
81	11.7	18.5	6.8	0.50	Y	Y
82	13.8	18.5	4.7	2.51	Y	Y
83	13.7	18.5	4.8	1.85	Y	Y
84	18.7	18.8	0.1	10.51	N	N
87	16.6	19.1	2.5	2.95	Y	Y

Figure 109: 2016 habitat mapping in the Acme project reach (NNR data).



Secondary Channel Length

Metering flow into the Landingstrip Creek channel has not been monitored. Channel migration in the project reach between the 2003 mapping and the project construction eroded the floodplain separating the main channel from the Landingstrip Creek channel and likely increased the high flow connectivity of the floodplain channel. The channel is not connected during the low flow period, but is likely available to juvenile salmon during the winter rearing period and as a high flow refuge area. It is unclear if the amount of flow into the side channel is metered by the project, although there are no indications that the side channel is enlarging due to increased flow.

Edge Habitat Improvement

The project removed edge habitat in the project reach by removing the riprap and increasing the amount of engineered logjam edge. In the 2003 habitat survey the reach had approximately 45m of riprap, 125 m of natural bank and 390 m of bar edge. By the 2016 survey, the low flow edges were approximately 120 m of natural bank, 190 m of engineered logjams, and 300 m of gravel bar edge. The overall increase in edge length in the 2016 survey reflects the bank deformation due to migration through the reach.

Habitat Unit Diversity

The project sought to increase habitat diversity in lower Landingstrip Creek to provide rearing habitat for juvenile salmon. During the 2016 mapping, the channel was not connected at low flow and habitat mapping has not been done at other flow levels.

Bank Protection

No hydraulic modeling has been done to evaluate the flood benefits to the community of Acme or the State Route 9 bridge.

Conclusions and Recommendations

Overall, the Acme Project has increased the amount of complex woody cover and the pool depth in the project reach (Table 86). The structures have not scoured individual pools and increased the habitat diversity in the reach as was expected. The project improved edge habitat in the reach by removing riprap, installing engineered logjams and allowing for bank deformation. The main channel pool in the reach was not found to be measurably cooler than the average temperature of the South Fork in an August survey, although several cooler water seeps were identified in the project reach that may be providing a local refuge area. The low dissolved oxygen associated with groundwater likely limits the amount of fish use in these areas. The objectives related to floodplain connection- metering floe and reducing potential adverse flood impacts were not monitored. Instream habitat in the side channel areas was also not monitored.

Table 86: Acme Project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
Restore South Fork in-channel habitat and complexity by creating multiple complex pools	Pool formation	**Not Met**- the project increased pool depth and improved wood cover, but did not create multiple pools.
Provide thermal refuge through complex pool creation in a zone of cool groundwater emergence and hyporheic flow.	Thermal refuge creation	**Not Met**- groundwater emergence was noted in the project reach, although the pool habitat was not found to be cooler.
Meter and encourage flow into lower Landingstrip Creek to enhance juvenile rearing opportunities, floodplain connectivity and reduce mainstem volumes and velocities during high flow events.	Secondary channel length	**Uncertain**- there has likely been an increase in high flow connectivity of the side channel.
Remove approximately 150' of existing left bank riprap to allow for more natural bank deformation and evolution of channel form and riparian forest recovery.	Edge habitat improvement	**Met**- the project removed bank armoring and increased natural and engineered logjam edges.
Improve in-channel habitat complexity and diversity in lower Landingstrip Creek for rearing early chinook, steelhead, and coho through placement of complex wood structure(s).	Habitat unit diversity	**Uncertain**- habitat in the Landingstrip Creek has not been monitored.
Reduce potential for adverse flood effects on community of Acme and SR 9 bridge.	Bank protection	**Uncertain**- hydraulic modeling to show flood impacts has not been done.

Kalsbeek Project

Project Description

The Kalsbeek Project was completed in 2007 and includes three logjams, six bank structures, and a series of small habitat structures placed in a side channel of the South Fork Nooksack. The original design called for additional upstream structures on the opposite bank to encourage flow toward the side channel, but these were dropped due to a lack of landowner cooperation. The logjams and bank structures consist of pilings and interwoven logs stacked-up from below the scour depth to above the 100-year flood elevation. The bank structures are built into the margin of the floodplain surface, while the logjams are designed to function with flow around them. The habitat objectives of the project were to reconnect a side channel and create deep scour pools with complex woody cover (Table 87).

Figure 110: Kalsbeek Project logjam locations.

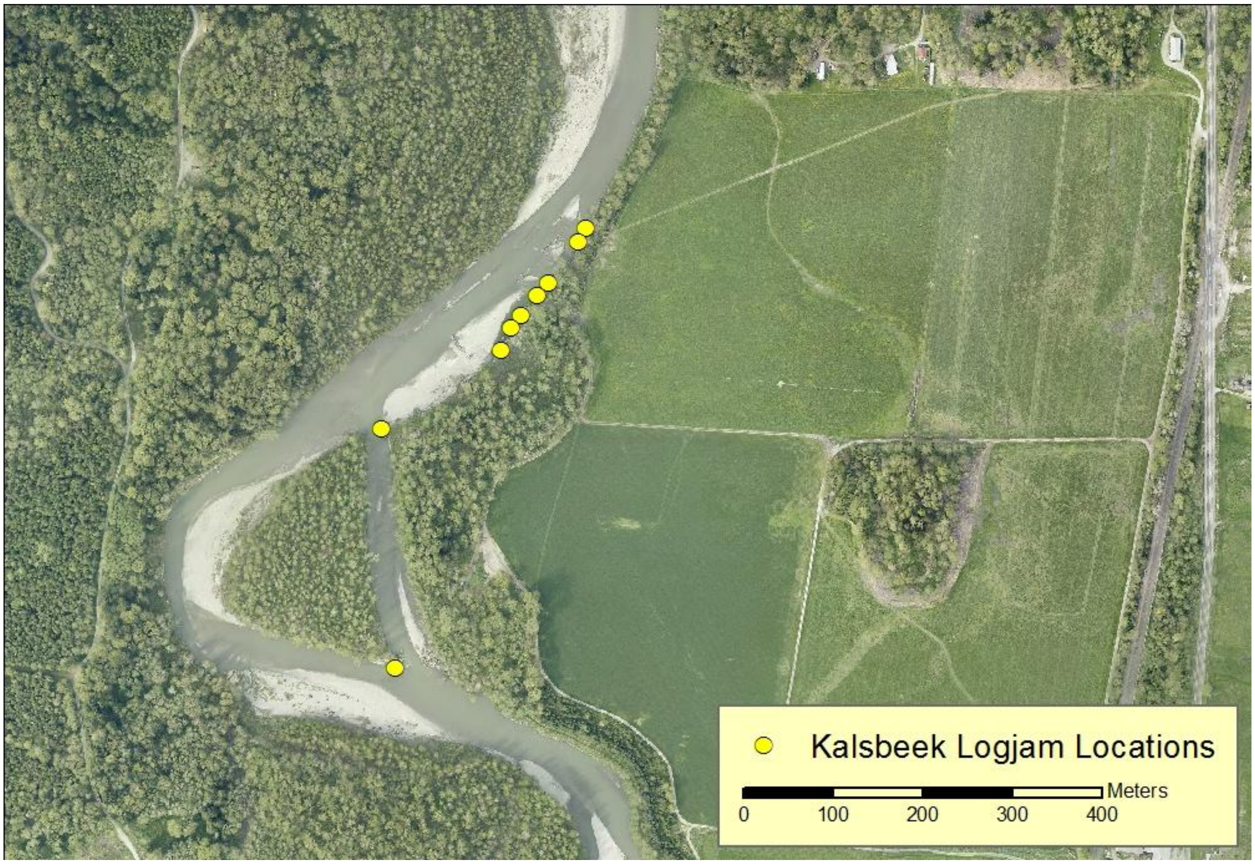


Table 87: Kalsbeek project objectives (summarized from NNR 2010 monitoring report).

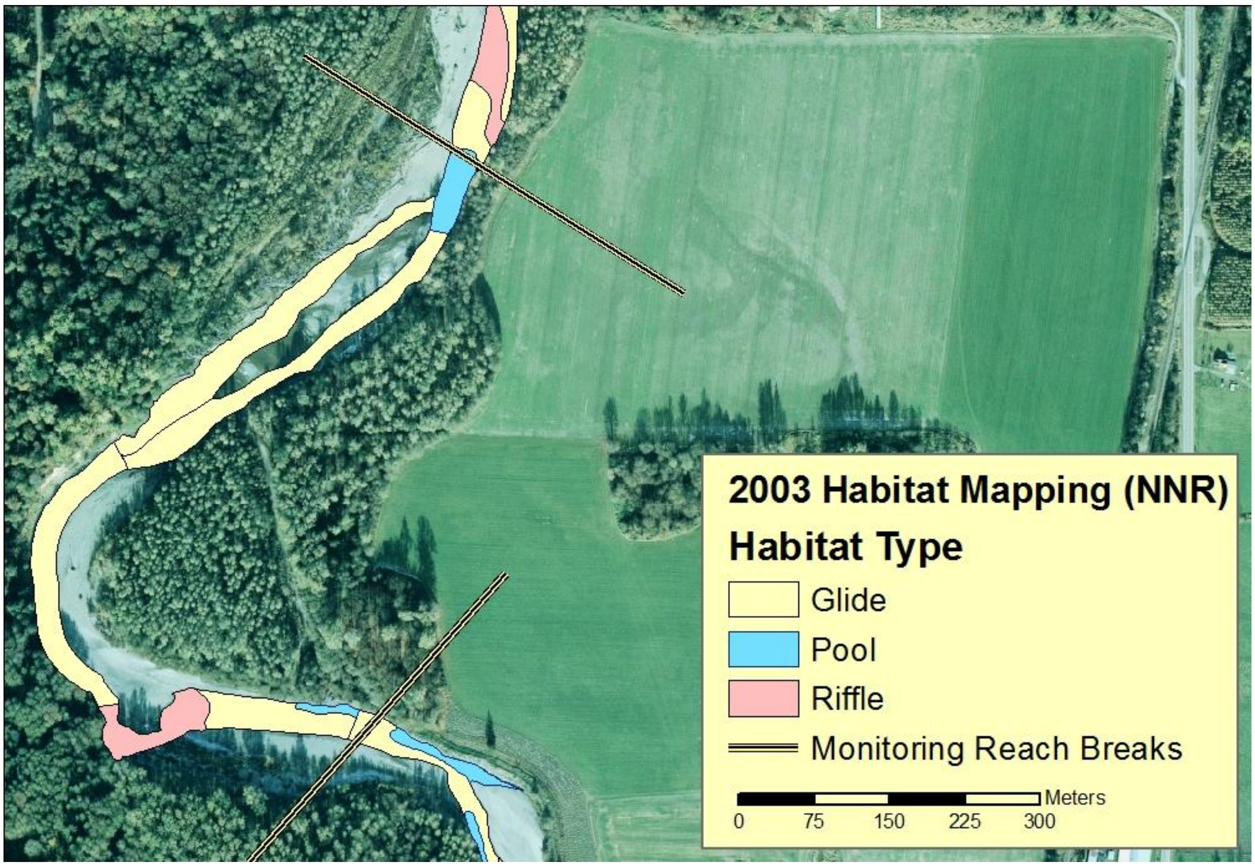
Stated Project Objectives	Objective Group	Limiting Habitat Factors
Develop main channel scour pools at each engineered logjam.	Pool formation	Lack of Key Habitat
Encourage flow into existing side channel.	Secondary channel length	Low habitat diversity
Mimic forested eroding bank to increase diversity and instream cover	Instream cover	Low habitat diversity
Provide roughness and increase habitat diversity and availability of wood cover in the side channel, as well as reduce the velocity of floodwaters and encourage fine sediment deposition on the adjacent floodplain.	Floodplain reconnection	N/A

Project Objectives

Pool Formation

Baseline mapping conducted in 2003 for the Acme to Confluence Assessment (Soicher et al. 2006) showed that the reach was dominated by glide habitat. There was one primary pool and one secondary pool in the project reach, and the glides each contained pool-like habitat, although it was not dominant. The primary pool was formed by flow convergence with wood cover and the secondary pool formed by wood (Figure 111). The primary pool had a residual pool depth of 1.95 m and the secondary pool had a residual depth 1.5 m- both qualifying as deep pools. The pre-project pool spacing was 2.5 channel widths per pool.

Figure 111: 2003 baseline instream habitat in the Kalsbeek reach.



In 2009 the habitat was remapped to assess the effectiveness of the instream structures in meeting their stated objectives (NNR data). The mapping found two primary pools; both formed by lateral scour associated with wood (Figure 112). One of the pools was formed by recently recruited natural wood, and one formed along the series of bank logjams. Three secondary pools and two backwaters were also mapped in the reach, for a total of seven pools. Five of these pools exceeded the 1 m residual depth threshold, leading to a reduction in pool spacing to meet the 1.0 channel widths per pool to meet the threshold for “Very Good”. Three of the seven pools in the reach were formed by engineered logjams.

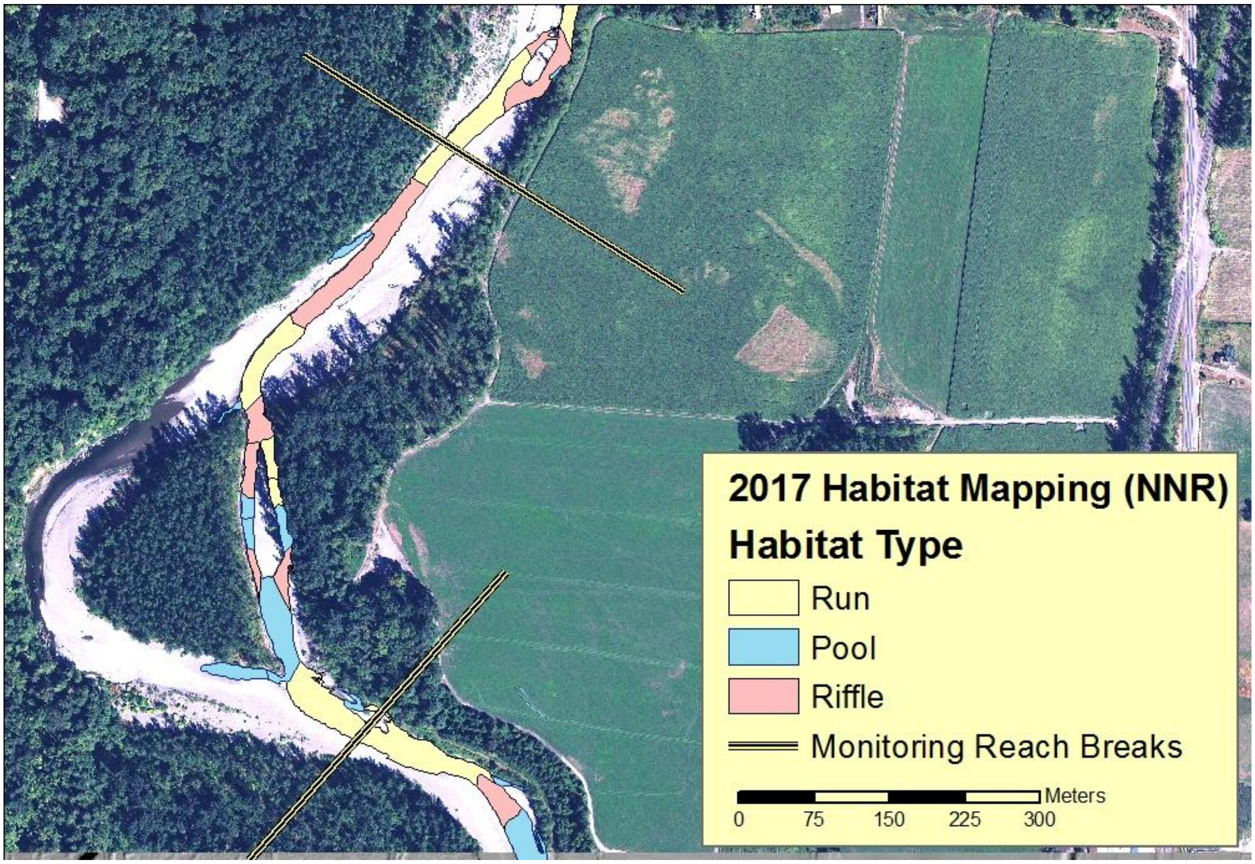
In 2014, each individual structure was visited and any pool formation or instream cover was measured. At that time, none of the three large engineered logjams were forming a pool in the low flow channel. The seven bank structures were all associated with secondary pool formation in a long glide along the bank. Of the six pools associated with the bank structures, two met the minimum residual depth target of 1 m.

Figure 112: 2009 habitat mapping in the Kalsbeek Project reach showing primary and secondary pools.

In the winter of 2015-2016 there was a channel avulsion in the project reach that occupied the former side channel across the forested point bar in the reach. The project sought to maintain low flow connectivity of this channel, but discourage an avulsion. The channel change had a profound impact on the channel by reducing the channel length through the reach and increasing the habitat diversity as the channel adjusts to occupying the former side channel area (Figure 113). Following the avulsion, the pool count increased to four primary pools, one secondary pool, and three backwater pools. Of these eight pools, three meet the 1 m minimum residual depth, yielding a pool spacing of 1.6 channel widths per pool. Only one of the pools was formed by engineered logjam.

Over the ten years of monitoring the Kalsbeek project, the reach has increased the number of pools in the reach and has intermittently met the target for pool spacing. While engineered logjams increased the number of pools in the reach, consistently forming pools, the goal of a pool formed by each logjam was not met in any of the monitoring years.

Figure 113: 2017 instream habitat in the Kalsbeek reach.



Secondary Channel Length

The project had the goal of encouraging flow into a ~300 m side channel in the project reach. The channel was connected at higher flow when the project was completed, and the goal was to improve connectivity at lower flow. Based on field observations at the time, it was estimated that the channel was only flowing at a discharge greater than 2000 cfs. It is likely that connectivity changed through time following the construction of the project. Wood accumulated on the upstream-most logjam and closed off much of the head of the channel. This led to the formation of a new connection around the wood accumulation slightly upstream at a pool and may have increased the connectivity of the side channel. This condition persisted until the avulsion in 2016.

Following the avulsion, the low flow channel occupied the former side channel and abandoned the old main channel except during higher flow. The avulsion led to an increase in high flow secondary channel length (from ~300 m to ~600 m), but a decrease in low flow channel length of the same magnitude (Figure 113). NNR will continue to monitor the side channel connectivity as the channel continues to respond to the recent channel avulsion. It is possible that the channel shortening could lead to a head-cut that reduces the connectivity of the high flow side channel.

Instream Cover

Monitoring of cover will focus on characterizing the cover types associate with habitat units. The goal will be to show an increase in the area of habitat units with complex LWD cover types. Monitoring of the amount of wood interacting with the low-flow channel will also be used to assess changes in the quantity of complex wood cover.

Wood mapping of logjams and key-sized pieces (>9 m^3) through the reach in 2003 found four logjams and two key-sized pieces of wood, neither of which were associated with the logjams (Lummi Natural Resources 2007a). One of the logjams was located on the outside of a meander bend where the channel had migrated into a forest floodplain; the other three were deposited in a row on top of a lateral bar that has subsequently vegetated with young deciduous trees. Three of the logjams were interacting with the low flow channel, although only one showed signs of stability. Of the two key-sized pieces in the reach, one was an unknown conifer (too decayed to identify the species) and the other was a black cottonwood. In 2009, there was both an increase in the number of logjams in the reach and the stability of those accumulations due to the engineered logjams.

Another objective was to increase the amount of complex wood cover in the low-flow and high flow channel of the reach. To this end, several small LWD clusters were placed along the side channel to provide cover during high flow periods. By 2009, most of these structures were transported out of the side channel and by 2017 none remained (Figure 114).

In the 2003 habitat surveys, three of the seven mapped habitat units had woody debris as a dominant cover type. These units were two pools and a glide. The glide is associated with a slope failure that has brought a large amount of wood into the channel. One of the pools is associated with a wood accumulation that was identified in the 2003 habitat mapping, but not in the LWD mapping, while the other is woody cover associated with recent wood recruitment along failing riprap. The failing riprap was replaced with a bank roughness logjam as a part of the Kalsbeek Project.

In 2009, wood was characterized as a cover type in the habitat units in the project reach and woody debris accumulations were mapped. Twelve of the 19 habitat units that were mapped during the low flow period included some form of wood as a cover type: 6 debris piles (or logjams), 3 engineered logjams and 3 single logs. All seven of the primary and secondary pools mapped had a woody cover component.

Figure 114: Side channel LWD clusters present in 2007 and transported by 2009, looking upstream.

Subsequent structure-scale mapping found that all but one of the engineered logjams was interacting with the wetted channel- providing ~300 m^2 of woody cover. Mapping from 2017 showed a similar distribution of wood cover types as the 2009 mapping. Eleven of the seventeen habitat units contained wood cover- 2 engineered logjams, 6 natural debris piles and 3 single logs.

Together these changes in wood through the reach between 2003 and 2017 showed an increase in stable wood structures, increase in wood as a dominant cover type, and an increase in the pool forming function of wood in the reach. All of these reflect the project objectives of increasing the quantity of complex wood cover in the low-flow and high-flow channels.

Floodplain Reconnection

Floodplain connectivity was not directly measured. There was an increase in habitat diversity and flow obstruction in the side channel due to the installation of the side channel structures until these were washed-out. Fine sediment deposition was observed on the adjacent floodplain, but changes in the connectivity of the surface were not monitored.

Conclusions

The Kalsbeek project has increased wood-formed pool and increased the amount of wood cover in the reach (Table 88). The project has continued to function and provide habitat benefits even after the avulsion relocated the low flow channel. The secondary channel objective was not met by the project and the channel avulsion through the side channel has likely changed the opportunities for side channel reconnection.

Table 88: Kalsbeek Project objectives and success.

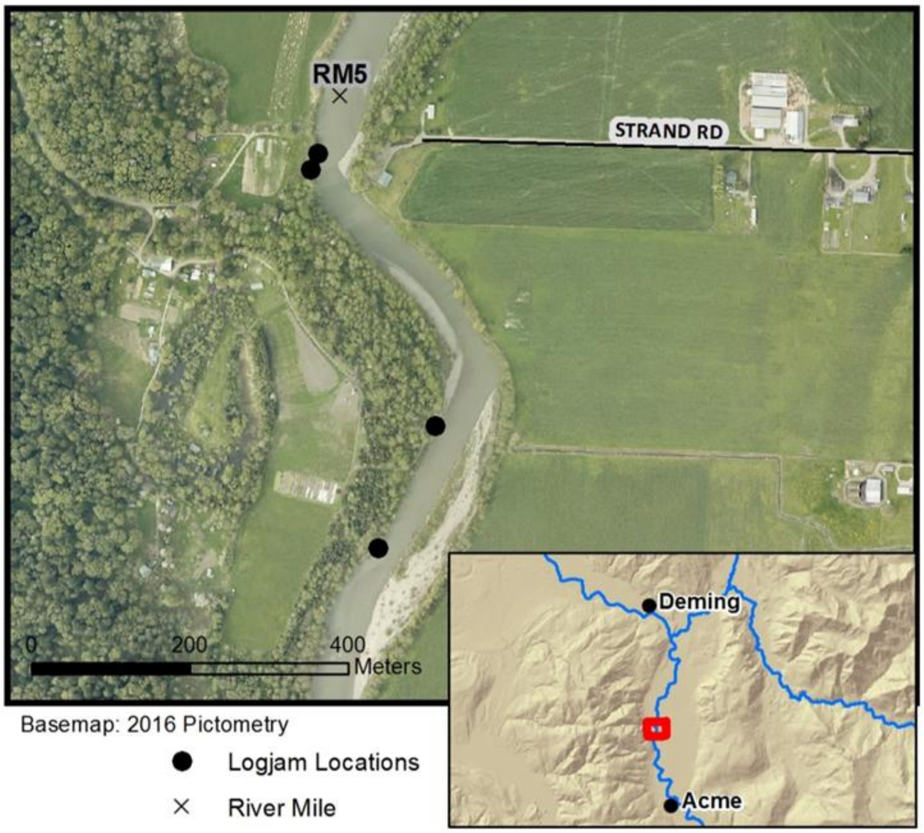
Stated Project Objectives	Objective Group	Objective Success
Develop a main channel scour pools at each engineered logjam.	Pool formation	**Partially Met**- there has been an increase in wood-formed pools in the reach (meeting the “Very Good” target in 2009), but the objective of all structures forming pools was not met.
Encourage flow into existing side channel.	Secondary channel length	**Not Met**- avulsion into target side channel and no increase in side channel length.
Mimic forested eroding bank to increase diversity and instream cover	Instream cover	**Met**- there was an increase in wood as a cover component and an increase in habitat unit diversity.
Provide roughness and increase habitat diversity and availability of wood cover in the side channel, as well as reduce the velocity of floodwaters and encourage fine sediment deposition on the adjacent floodplain.	Floodplain reconnection	**Uncertain**- floodplain connectivity was observed but not monitored. Side channel habitat diversity and availability did not increase.

Hardscrabble and River Farm Projects

Project Description

The Hardscrabble and River Farm (Oak Park Creek) projects both came out of the Hardscrabble Reach restoration design project, but were implemented by different agencies. The design project assessed restoration opportunities between river mile 4.8 and 5.4 of the South Fork and resulted in several concepts. A lack of landowner support led to focusing the implementation on two separate locations. The Hardscrabble Project was completed in 2012 near RM 5 of the South Fork (Figure 115) by the Nooksack Tribe. The River Farm Project followed in 2014 and was completed by the Evergreen Land Trust and the Whatcom Conservation District.

Figure 115: Hardscrabble (northern two structures at the end of Strand Road) and River Farm (southern two structures) project locations.



The projects were constructed to address habitat limitations of the lower reaches of the South Fork Nooksack identified in the Acme-Confluence Reach Assessment (Soicher et al. 2006). These limitations include elevated summer water temperature, a loss of habitat diversity, and a loss of key habitat quantity for the holding and rearing life stages (pools with complex woody cover). High quality holding habitat is widely spaced in the lower South Fork, so these projects sought to provide additional holding habitat between the Kalsbeek and Todd projects located at RM 3.8 and 6.5. In both cases, there was an opportunity to reduce bank armoring in the reach and replace the riprap with engineered logjams. The Hardscrabble project consists of 2 engineered logjams built at the edge of the channel near the confluence of Hardscrabble Creek, which was identified as a cooler water influence area (Figure 116). The project included removing riprap behind and adjacent to the structures. The original design proposal scoped one structure and the project objectives are based on that scope. The structures are designed to address limiting factors of low habitat diversity (spacing of holding habitat), lack of deep pools with cover, and elevated summer water temperature in the reach (Table 89). The River Farm Project is 2 engineered logjams built along the bank between river miles 5.4-5.5. Project objectives were not presented for the project, but likely were focused on pool-formation, increased habitat unit diversity and increased wood cover, as described in the Hardscrabble design proposal.

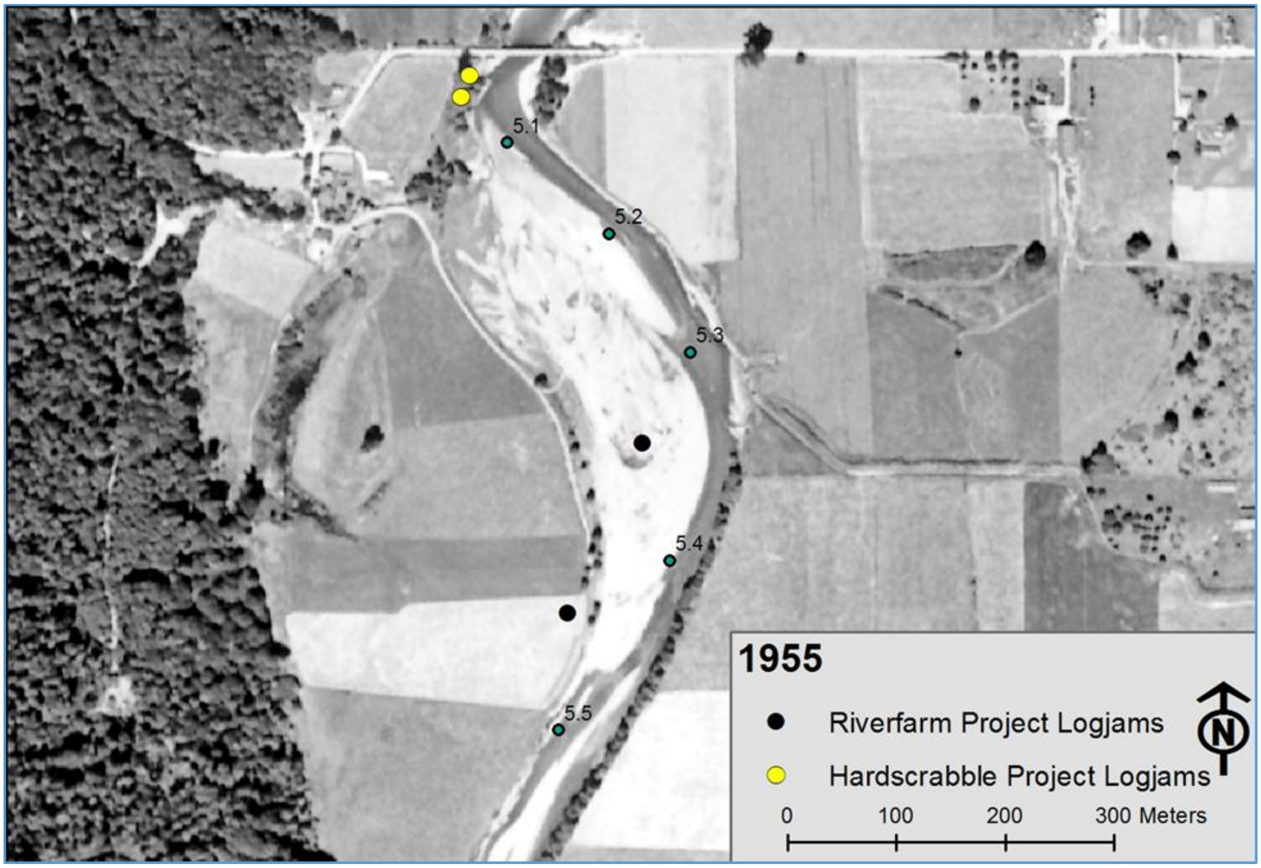
Table 89: Project objectives of the Hardscrabble and River Farm projects.

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Reduce pool spacing	Pool formation	Lack of Key Habitat
Provide complex cover in the low-flow wetted channel	Instream cover	Low habitat diversity
Create a pool in the cool water influence area of Hardscrabble Creek.	Thermal refuge creation	Elevated summer water temperature

Figure 116: Hardscrabble logjams build into an existing riprapped bank.

The Hardscrabble Reach has seen a modest change through the historic photo record defined by migration of the channel to the east upstream of Strand Road and the stabilization and forest growth on the opposite point bar. The lack of substantial channel movement may be related in part to early bank protection associated with the Strand Road Bridge over the South Fork that was in place from the earliest photos in 1933 until the late 1950s or early 1960s. The majority of the channel migration occurred before the 1955 photo when riprap along the east bank through the project reach can be seen in the aerial photos (Figure 117). By 1976, the low flow channel has moved slightly toward the west and an armored levee had been extended downstream along the left bank connecting the two future River Farm logjam locations shown in the figure. The open bar shown in the 1955 photo had largely reforested by the mid-1970s. The channel has remained virtually unchanged through the project reach over the last 40 years (Figure 115).

Figure 117: The Hardscrabble reach in 1955 showing recent migration to the northeast downstream of the Strand Road bridge.



Project Objectives

Pool Formation

The Hardscrabble and River Farm projects both had the objective of increasing pool number and depth in the reach. The project reach was included in the Acme-Confluence Assessment (Soicher et al. 2006) and was first mapped in 2003. The combined project reach had three pools mapped at that time, with two formed by riprap bank armor and one formed by wood (Figure 118). Both of the riprap-formed pools met the minimum <1 m residual depth criterion, while wood-formed pool did not. The pool located at the end of Strand Road, where the Hardscrabble project would be built, had a maximum depth of 2.5 m and was noted as having heavy recreational use. Surveys in 2010 found a similar depth at that location. Prior to construction of the River Farm Project, the section was dominated by long, homogenous runs and riffles. There were no pools identified in the project reach in either the 2003 or 2010 mapping.

Figure 118: Habitat in the Hardscrabble and River Farm project reach in 2003 (NNR data).

Following construction, mapping in 2018 found that the pool area expanded in the Hardscrabble project area and a new pool was formed at the upstream logjam in the River Farm project (Figure 119). The pool spacing had not improved between the mapping years, but the dominant pool-forming feature had changed from riprap to wood.

Structure-scale monitoring of the Hardscrabble logjams between the 2003 and 2018 surveys shows how the habitat changed through time in response to the project (Table 90). Prior to construction the riprap-formed pool averaged 2.23 m in residual depth, following construction the average residual pool depth increased slightly to 2.56 m, reaching the deepest residual depth in 2017. The pool area also appears to have increased following construction, although locating the tail-out when the pool transitions to a glide can be difficult. The greatest change in the pool is the increase in wood cover from 0m^2 to ~100 m^2. Given the history of heavy recreational use at this location, this provides important cover for migrating adult rearing juvenile salmon.

Table 90: Pool depth and cover associated with Hardscrabble project site 2003-2018 (NNR data).

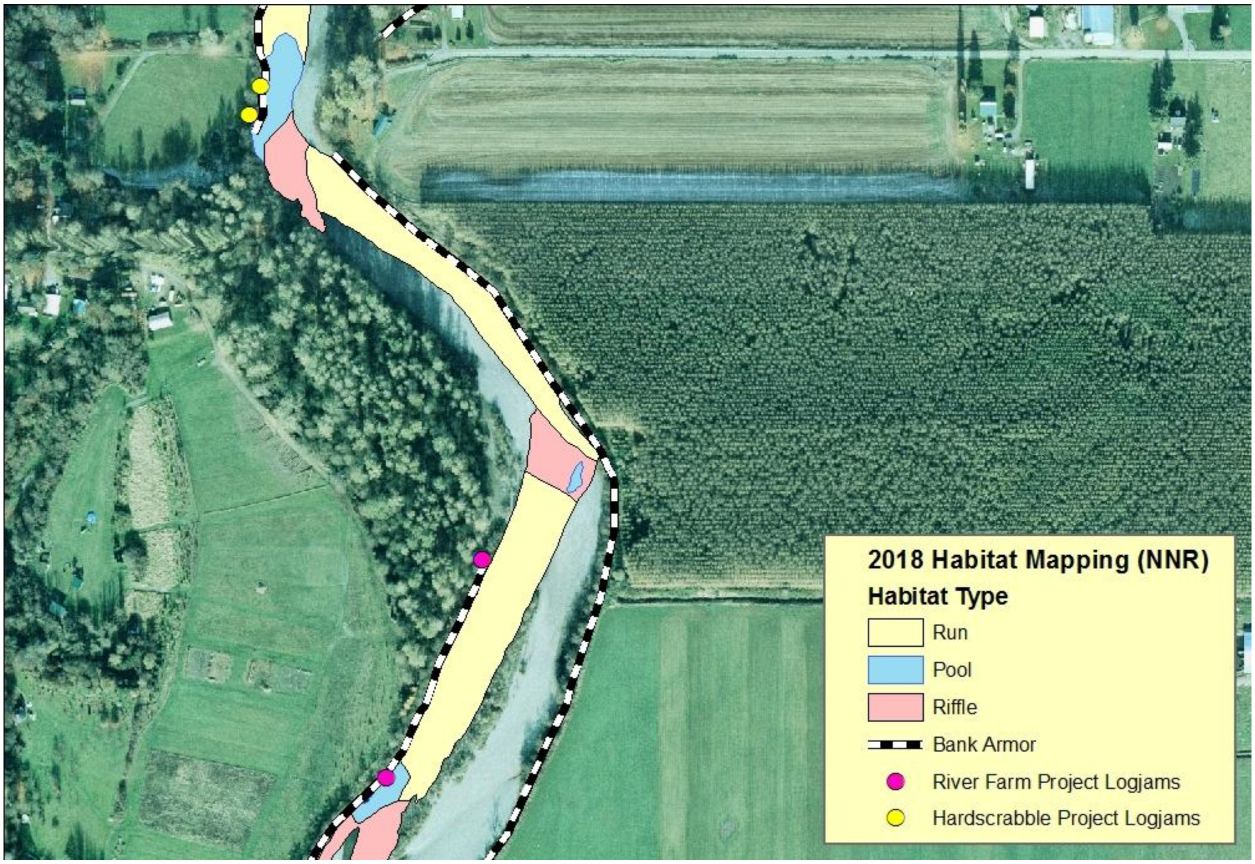
Year	Max Depth (m)	Residual Depth (m)	Pool Area (m^2)	Pool-forming Feature	Wood Cover Area (m^2)
2003	2.50	2.25	1,300	Riprap	0
2010	3.10	2.20	875	Riprap	0
2012	3.50	2.67	2,765	Eng. Logjam	101
2017	3.45	2.75	2,555	Eng. Logjam	80
2018	3.24	2.25	1,710	Eng. Logjam	100

The River Farm Project has also led to an increase in holding habitat. The pool associated with the upstream structure has developed from a riffle in 2010, to a secondary pool in 2017, to a deep primary pool in 2018. The pool area has increase and the amount of cover this structure provides has increased (Table 91). As of 2018, the downstream structure has not resulted in local scour and has provided less than 15m^2 of cover to the wetted channel.

Table 91: Pool depth and cover associated with the River Farm project (NNR data).

Year	Max Depth (m)	Residual Depth (m)	Pool Area (m^2)	Pool-forming Feature	Wood Cover Area (m^2)
2003	Glide		N/A	N/A	N/A
2010	Riffle		N/A	N/A	N/A
2017	2.10	0.80	125	Eng. Logjam	30
2018	1.90	1.35	710	Eng. Logjam	50

Figure 119: Instream habitat in the Hardscrabble and River Farm project reach in 2018 (NNR data).



Surveys of holding fish in the Hardscrabble and River Farm have found consistent use of these structures by a variety of species through the summer holding period. Snorkel surveys of the South Fork between Acme and the Potter Bridge in mid-August of 2010 found several adult chinook in the project reach. One was located tucked into the riprap in the riffle near where the upstream River Farm structure would be built. Two more adult chinook were found in the glide along the riprap between the two projects. Two more adults and one steelhead were found in the pool where the Hardscrabble project would be built. Following construction, repeated surveys were conducted in the summer of 2017 (Table 92). These surveys showed that the structures provided holding habitat throughout the summer, with the complex wood at the Hardscrabble project providing cover for adult salmon even though the site is heavily used for recreation. The survey in mid-September followed a rain event where the discharge rose and the stream temperature dropped, possibly encourage fish to move upstream in the South Fork. The 250 chinook were among several hundreds of pink salmon that were present in the Hardscrabble pool (Ian Smith pers. comm. Sept 2017). A follow-up survey in 2018 of the lower river again found adult chinook (5) in the Hardscrabble pool. This was the second highest count in the lower river.

Table 92: 2017 adult chinook holding surveys of the Hardscrabble and River Farm projects.

Pool	Survey Date and Chinook Count			
	July 15, 2017	July 28, 2017	August 20, 2017	Sept 11, 2017
Hardscrabble	7	6	11	250
River Farm Upstream	2	3	2	3

Instream Cover

The project had the goal of increasing the instream cover in the project reach. In 2003, only one of the seven primary habitat units mapped in the reach had wood cover associated with it (Table 93). In 2010, the wood-formed pool from 2010 was gone and none of the habitat units noted complex wood as a cover component. The pool at Hardscrabble contained some pilings associated with the bank protection project, but these were not a prevalent cover type.

Following construction of the Hardscrabble project, wood cover area increased to 125m^2 in the 700m reach centering on the Hardscrabble project. Of this 125 m^2, 100 m^2 was associated with the two engineered logjams and 25 m^2 was a natural woody debris pile downstream of the project. In 2017, wood cover area increased to 160 m^2, with engineered logjams accounting for 125 m^2 of the wood cover. Mapping in 2018 saw a continue increase in engineered logjam cover as the channel interacted more strongly with the structures.

Table 93: Wood cover changes in the project reach through time (NNR data).

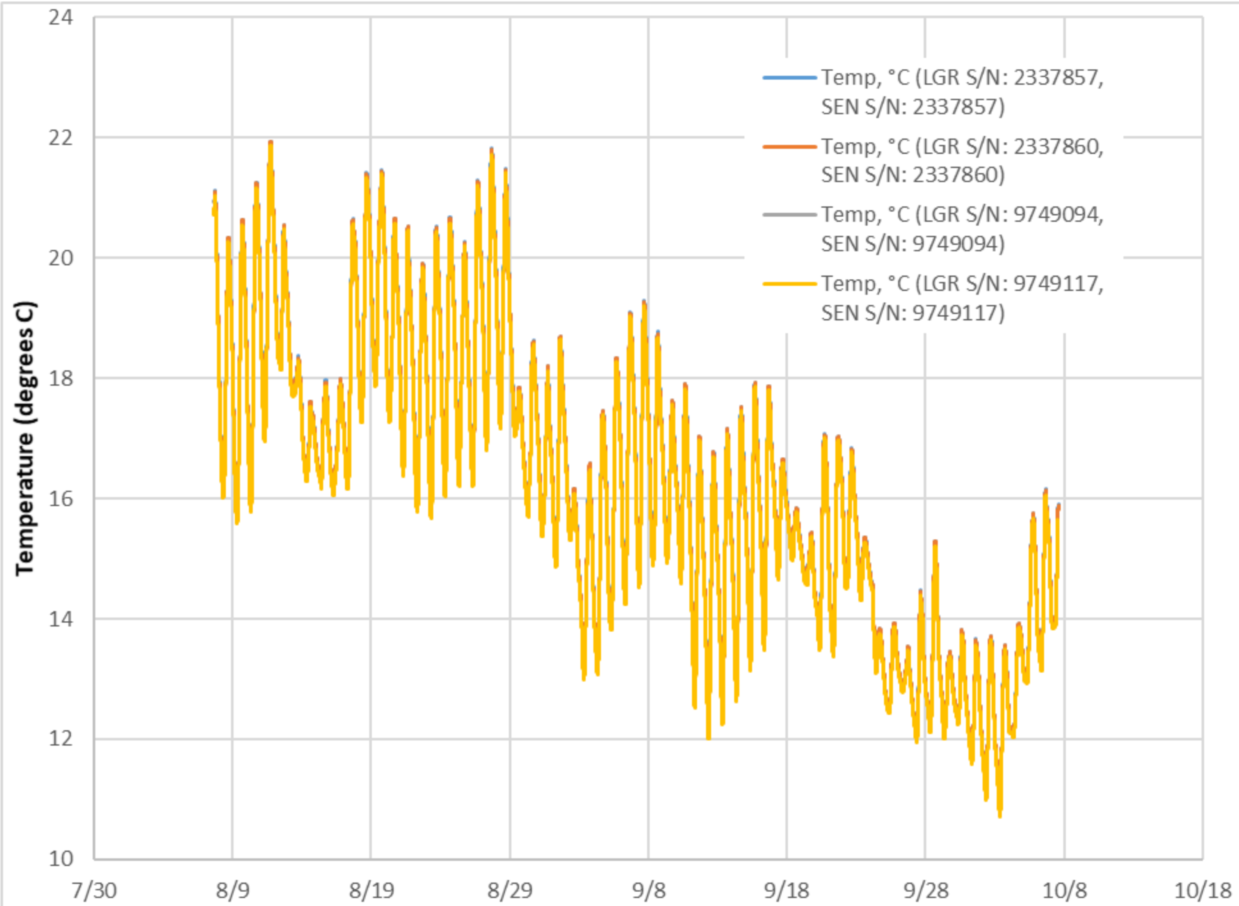
Wood Cover Type	**Wood Cover (m^2) Area by Year**				
	2003	**2010**	**2012***	**2017**	**2018**
Natural Wood	Present in 1 unit	0	25	35	0
Engineered Logjam	0	0	100	125	150

*2012 did not include the River Farm project area

Thermal Refuge

Continuous temperature probes were placed around the two engineered logjams in the Hardscrabble Project in the summer of 2014. For each logjam, temperature probes were placed at the surface and at depth to identify any thermal stratification associated with the pools. For the four temperature probes in the Hardscrabble pool, there was little difference between the temperature at the surface of the pool and the temperature at depth (Figure 120). At the peak temperature of the day, the difference between surface and depth was consistently less than .025 °C cooler at the deeper probe.

Figure 120: Continuous temperature monitoring of the two logjams in the Hardscrabble Project (probe: 7857 and 9094 are surface temperature and 7860 and 9117 are at depth).



Hardscrabble Creek is dry during the warmest months, so there is no cool surface water source to the reach and there has been no instantaneous monitoring of temperature in the project reach to determine if there are cool water seeps that could provide a temperature benefit.

Conclusions and Recommendations

The four structures built as a part of the Hardscrabble and River Farm projects have not met the pool-formation and temperature refuge objectives (Table 94). The total number of primary pools in the reach has decreased from three in 2003 to two and one secondary pool in 2018. The reach had 2 pools greater than 1m residual depth throughout the monitoring period in 2003, 2010, 2017 and 2018. In both reaches, the pools associated with the engineered logjams were deeper than the pre-construction conditions. The percentage of wood-formed pools increased following construction. In 2003 both deep pools were associated with riprap. In 2017 all the deep pools were associated with wood. The area of logjam cover increased considerably between 2003 and 2018, from zero to 150 m^2. The potential for an increase in pools in the Hardscrabble reach was limited because both structures were constructed in an existing riprap-formed pool area.

Cooler water refuge areas (more than 2 °C cooler than the main channel) were not associated with the engineered logjams in the Hardscrabble project and no continuous temperature monitoring occurred in the River Farm Project. Temperature monitoring focused on identifying thermal stratification in the large pool formed by the Hardscrabble Project, rather than identifying cool water seeps through the project reach. Identifying the cool water sources should be done to better evaluate this objective.

Table 94: Hardscrabble and River Farm project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
Reduce pool spacing	Pool formation	**Not met**- while 3 of the 4 engineered logjams are associated with pools, the reach has not seen an increase in the number of pools.
Provide complex cover in the low-flow wetted channel	Instream cover	**Met**- the project has increased the amount of wood cover in the reach and increased the number of wood-formed pools.
Create a pool in the cool water influence area of Hardscrabble Creek.	Thermal refuge creation	**Uncertain**- the project has not resulted in thermally stratified pools in the reach. Detailed monitoring of groundwater seeps has not been done to identify potential cool water sources.

Todd and Sygitowicz Projects

Project Description

The Todd Project was constructed in 2008 at RM 3.8 (Figure 121). The project includes six bank logjams, one bar-apex logjam, and the stabilization of an existing debris pile. The goal of the project was to create deep, thermally stratified pools with complex woody cover for migrating and holding habitat. The structures were built around piles driven to below the scour depth. Logs were then stacked and interwoven between the pilings to form the structures. The existing accumulation was stabilized with pilings driven through it and the wood placed around the pilings. The Sygitowicz phase of the Todd Project, built in 2010 and 2011, consists of seven engineered logjam structures and the removal of ~150 m of riprap bank protection at RM 3.9 of the South Fork Nooksack. The objectives of the project were to create deep, thermally stratified pools with cover and to encourage secondary channel flow toward the left bank structures built as a part of the Todd Project (Table 95). The Sygitowicz design included 5 logjams built into the high bank of the Sygitowicz Creek and Todd Creek alluvial fans and two structures built to split flow around them. Like the Skookum Project, the Sygitowicz design compensated for potential flooding issues by setting the bank structures deeply into the bank. After 2010, it was evident that the bank excavation for the structures left the logjams sitting in a backwater and not likely to form the pools that were a project objective. Additional large pieces of wood were added to three of the bank structures in 2011, so that they projected further into the wetted channel (Figure 122). One of these extensions was subsequently lost.

Figure 121: Todd/ Sygitowicz project location.

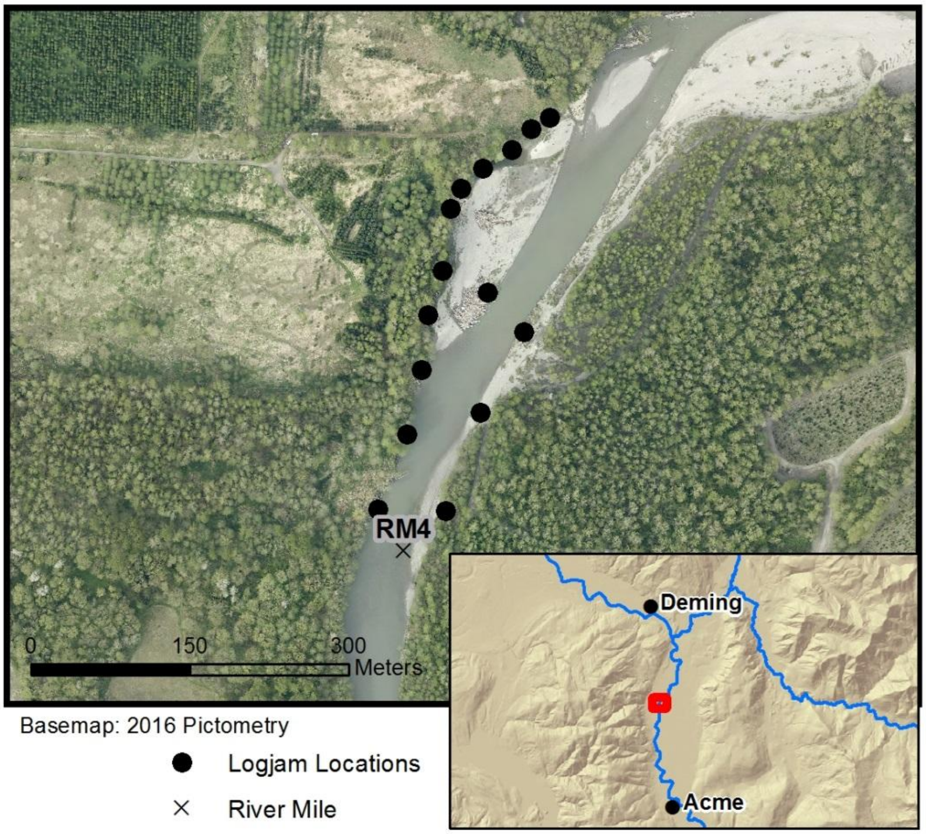


Table 95: The Todd/ Sygitowicz project objectives

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase number, area and depth of pools	Pool formation	Lack of Key Habitat
Increased secondary channel development	Secondary channel length	Low habitat diversity
Increase woody cover abundance	Instream cover	Low habitat diversity
Create cool water refuge areas	Thermal refuge creation	Elevated summer water temperature

Figure 122: A Sygitowicz Project recessed logjam showing the added log with rootwad that projects further into the low flow channel for structures #3, #4, and #5 in the plans.

Project Objectives

Pool Formation

The project had the goal of increasing the number, area and depth of pools in the reach. Habitat mapping conducted in 2003 as a part of the Acme to Confluence Assessment (Soicher et al. 2006) found 1 main channel pool and two backwater areas present in the Todd/Sygitowicz project reach (Figure 123). This is approximately 5 channel widths per pool for the project reach, which was considered Poor for pool spacing. The one main channel pool was formed by riprap and contained wood as the dominant cover type (Table 96). The residual pool depth (maximum depth minus the tail-out depth) of the primary pool was 1.95 m and the main channel pool area in the project reach was ~760 m^2, the backwaters provided an additional ~930 m^2 of slow water habitat area. There was no habitat mapping that documented the as-built conditions of the project.

Table 96: Baseline Todd/ Sygitowicz Reach pool statistics (2003).

Habitat Type	Primary/ Secondary	Area (m^2)	Maximum Depth (m)	Tail-out Depth (m)	Forming Feature	Main Cover Type
Pool	Primary	758	2.1	0.2	Riprap	LWD
Backwater	Secondary	773	n/a	n/a	Riprap	LWD
Backwater	Secondary	154	n/a	n/a	n/a	LWD

The first effectiveness monitoring of the Todd Project occurred in the summer of 2009, following the January 2009 flood that caused the channel to avulse to the east side of the project area (NNR data). The avulsion left 6 of the 8 structures in a deep backwater that was the primary pool of the pre-avulsion channel mapped in 2003. In 2009, no primary pools were mapped in the project reach (Figure 124). There were three qualifying secondary pools- including the large backwater left by the avulsion and a new scour pool associated with the mid-channel structure (ELJ #7). The third secondary pool was associated with a stump in the mid channel. A fourth secondary pool was mapped associated with the stabilized natural wood, but the residual depth was too shallow to qualify as a pool (Coe 2013). The pools were all formed by wood (engineered logjams and rootwads), rather than riprap as was the case in 2003 (Table 97). Reflecting the deep primary pool mapped in 2003, the backwater area was still the deepest pool in the reach with a residual depth of 2.3 m. The new scour pool along the mid-channel engineered logjam was approximately 0.5 m deep and barely met the depth criteria for inclusion as a secondary pool. Pool area did increase in the reach from ~1,685 m^2 to ~2,725 m^2, mostly due to the extent of the backwater pool. This change in area represents an increase in pool area from 9% in 2003 to 13% in 2009. Some of the improvement may be related to slightly different mapping techniques used in 2003 and 2009, although efforts were made to use a similar minimum unit size and have similar unit types. The 2009 mapping used a greater level of description and sought to map secondary units within primary units, rather than call-out a percent of the primary unit that the secondary unit represented.

Figure 123: Primary habitat units in the Todd Creek Reach (August 2003, photo 2003).

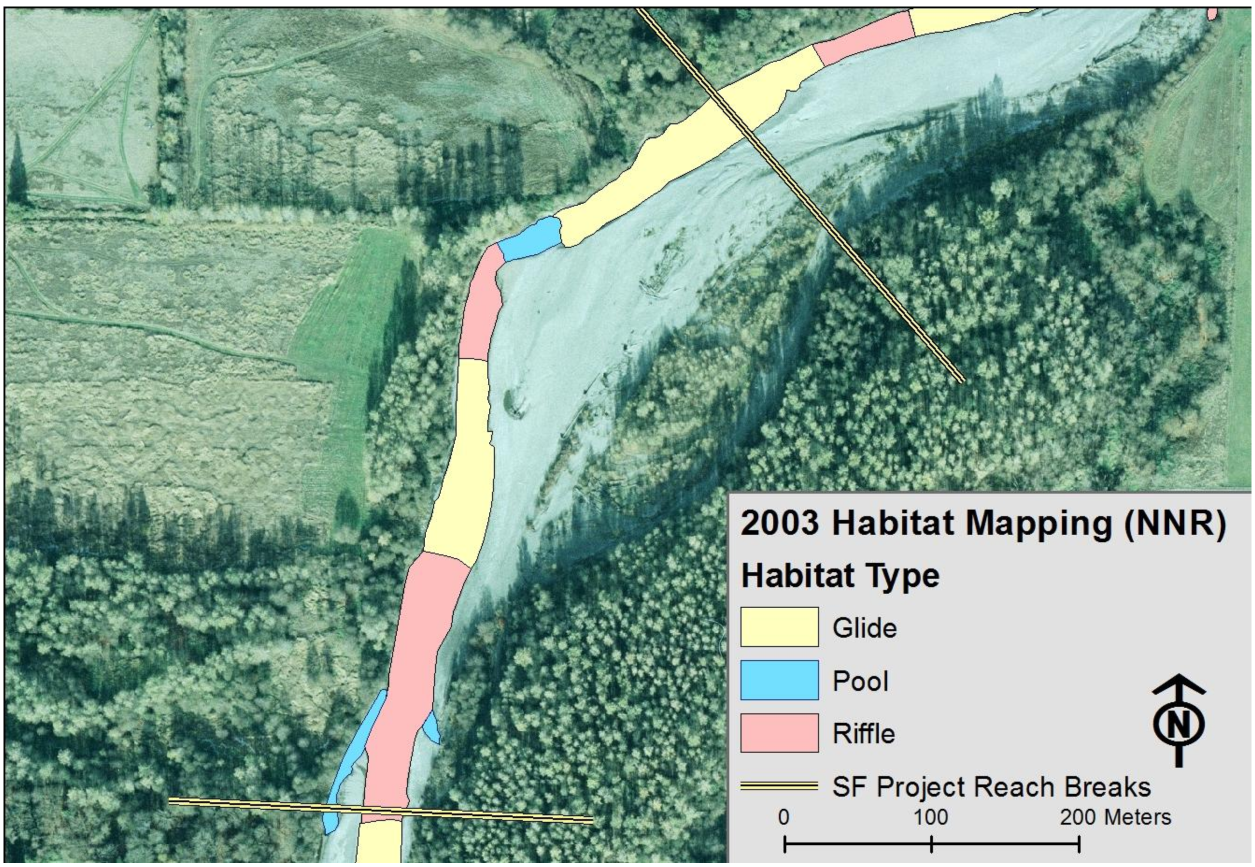
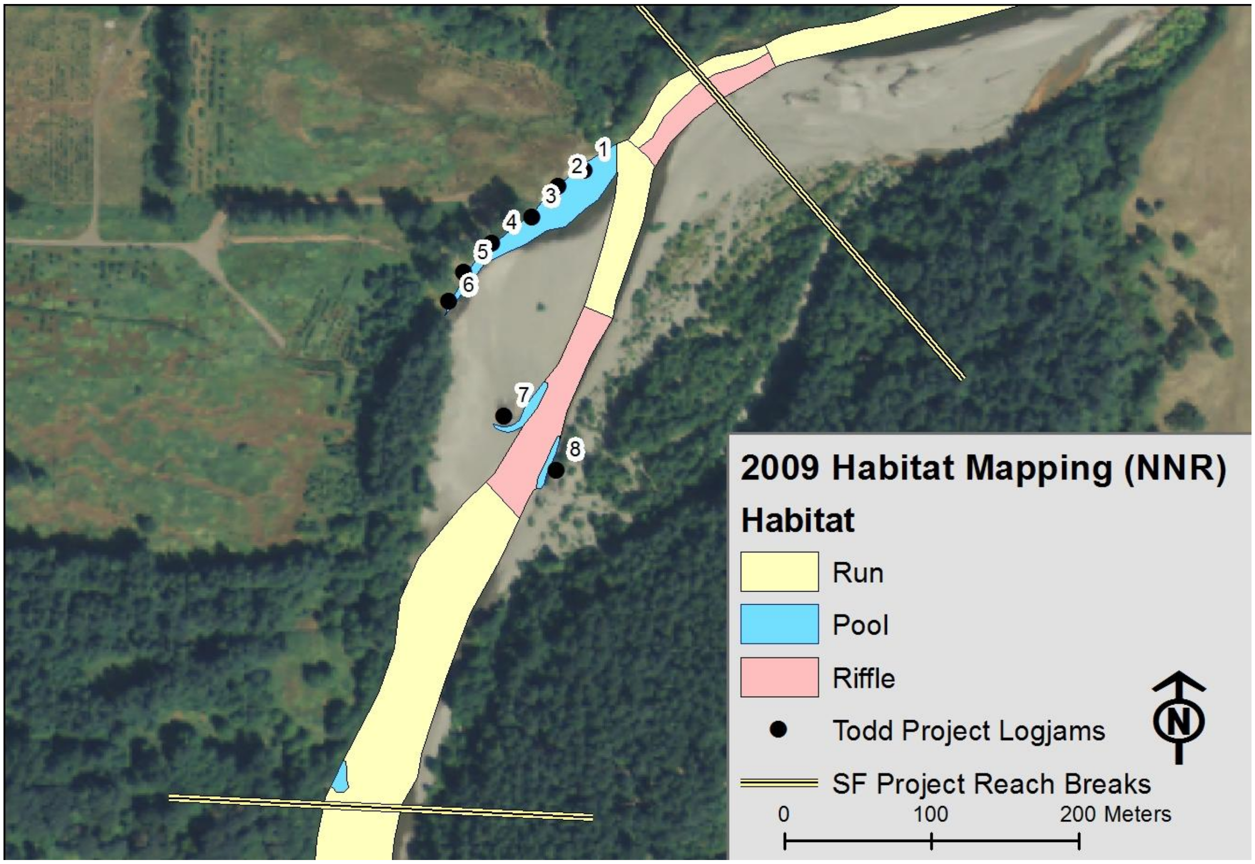


Table 97: Todd/ Sygitowicz Reach pool statistics 2009.

Unit Type	Primary Unit Type	Area (m^2)	Maximum Depth (m)	Tail-out Depth (m)	Forming Feature	Main Cover Type
Scour Pool	Glide	221	2.0	0.5	Rootwad	LWD
Scour Pool	Riffle	212	0.5	0.2	Eng. Logjam #7	LWD
Backwater	n/a	2295	2.9	0.6	Eng. Logjam	LWD

Figure 124: Habitat mapping in the Todd Creek Reach, showing all primary habitat units and any secondary pools (October 2009, photo 2009). The channel has avulsed, leaving many of the Todd structures in a deep backwater area.



Following the avulsion and the construction and enhancement of the Sygitowicz Project the reach was mapped several more times, including two structure-scale effectiveness surveys (2011 and 2014) and two adult holding count surveys (2010 and 2018). These surveys show a slow evolution of the habitat as the channel interacts more strongly with the mid-channel logjam and migrates further from the bank structures in the Todd Project.

Mapping in 2010 associated with an adult chinook holding survey showed a modest change in the project reach from the 2009 survey. A deep wood-formed primary pool was identified on the bend downstream of the Todd Project where the channel was actively migrating into the forested bank. The deep backwater was still connected to the main channel, and a third pool was present along the riprap in the Sygitowicz project reach. This riprap was being removed and a logjam constructed in its location during the surveys. The small secondary pools mapped in 2009 along logjams #7 and #8 were not present. The only location that an adult chinook was found holding in the reach was the riprap-formed pool, although abundant juvenile salmonids were present in the backwater pool. The natural wood-formed pool could not be snorkeled due to high turbidity from the eroding bank.

Structure-scale monitoring is used to document the localized habitat functions of each individual logjam (pool-formation and wood cover) and does not include mapping of the other habitat within the project reach (Coe 2013). Structure-scale mapping in 2011 showed that three (Todd #7, Syg #4 and Syg #7) of the fifteen structures were associated with a secondary pool that would meet minimum depth and area for inclusion in the reach-scale mapping. In 2014 the same three structures provided pools, with the addition of one more secondary pool (Syg#5). Two of these secondary pools were associated with the added large logs in the Sygitowicz project. ELJ Todd #7 showed a marked increase in residual pool depth from (0.3 m to 1.2 m) and pool area (212 m^2 to 388 m^2) between 2009 and 2014.

Habitat was again mapped in 2017 and 2018 associated with adult chinook holding surveys in the lower South Fork. In 2017, four secondary pools were mapped in the reach- two were associated with structures #7 and #8 in the Todd Project. The other two pools were associated scour along a remnant of riprap on the bank. An engineered logjam (Syg #5) provided a small amount of cover (~1.5 m^2) in the backwater pool (Table 98). These four pools represented about 11% of the overall habitat area.

Table 98: Pools identified in reach-scale habitat mapping in the Todd/ Sygitowicz reach in 2017 and 2018.

Year	Unit Type	Primary Unit Type	Area (m^2)	Maximum Depth (m)	Tail-out Depth (m)	Forming Feature	Main Cover Type
2017	Scour Pool	Riffle	645	1.7	0.5	ELJ Todd #7	LWD
	Backwater	n/a	604	1.9	1.9	Riprap	Riprap
	Scour Pool	Riffle	371	1.9	0.5	Riprap	Riprap
	Backwater	n/a	185	0.7	0.4	ELJ Todd #8	LWD
2018	Scour Pool	Pool	1461	2.55	0.66	ELJ Todd #7	LWD

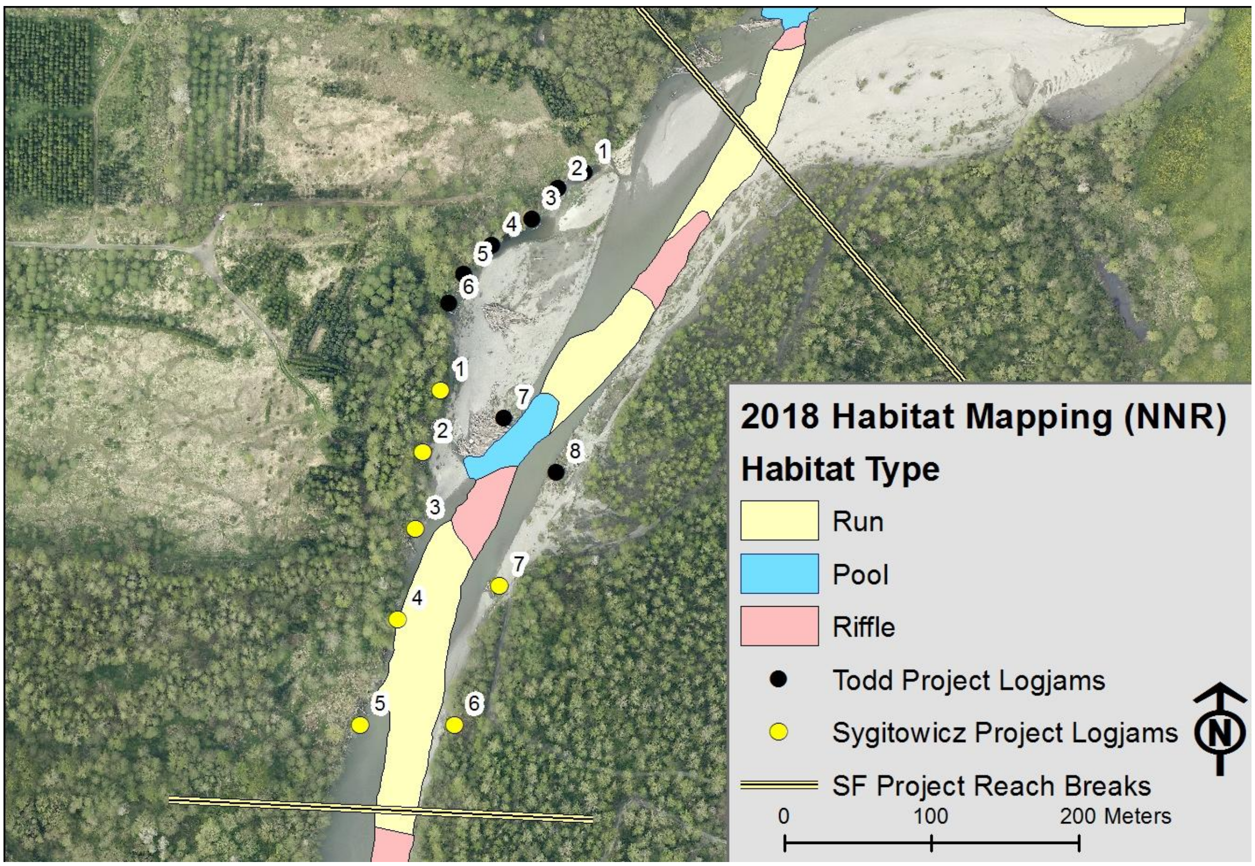
The major changes in the reach-scale habitat was the disconnection of the deep backwater area associated with the bank structures, and the continued development of the lateral scour pool associated with the mid-channel structure (#7) in the Todd Project (Table 99). While the depth did not change for the pool between 2011 and 2017, the area of the logjam-formed pool increased from less than 400 m^2 to nearly 650 m^2 in 2017. Mapping in 2018 showed that the pool formed by the Todd #7 structure had become a channel-spanning pool with an area of ~1,460 m^2 and a residual depth of 1.9 m. It was the only pool mapped in the project reach (Figure 125). Snorkeling of the reach in 2018 identified holding adult chinook using the pool and subsequent spawning surveys found 18 chinook redds in ~425 m^2 of the upstream riffle associated with this structure. This was the highest spawning density in the lower 14 miles of the South Fork Nooksack and likely reflects the importance of high-quality holding habitat in this reach. Monitoring of the Sygitowicz enhanced structures in 2017 and 2018 showed that the projecting log had been lost from ELJ #4 and neither of the remaining enhanced structures formed pools that were large enough to map as a part of the reach-scale mapping.

Table 99: Changes in the habitat associated with ELJ#7 in the Todd Reach.

Year	Max Depth (m)	Residual Depth (m)	Pool Area (m^2)	Cover Area (m^2)
2009	0.5	0.3	212	50
2011	1.7	1.0	390	58
2014	1.9	1.2	388	139
2017	1.7	1.2	645	213
2018	2.6	1.9	1461	300

Between 2003 and 2018, the reach has seen a modest change in pool depth, pool spacing and pool area. Primary pool count has fluctuated between zero and one for the five years of reach-scale mapping. In 2003, the one primary pool was formed by riprap. In 2010, the one primary pool was formed by channel migration into the forested floodplain. In 2018, the primary pool was formed by an engineered logjam. Forming primary pools is the focus of restoration in the lower South Fork Nooksack because these have the potential to provide the deepest, largest and most complex holding habitat for adult chinook. Secondary pool counts in the reach ranged between four pools in 2017 and zero in 2018. The percentage of pools formed by wood also varies, with the project reach meeting targets in 2009 and 2018- both years with very low pool counts. Overall, these values are considerably lower than the target of <1.0 channel widths per pool with 70% formed by wood.

Figure 125: Habitat mapping in the Todd Creek Reach, showing all primary habitat units and any secondary pools (August 2018, photo 2016). Continued migration to the east has isolated much of the Todd Project.



Secondary Channel Length

Another objective of the Todd Creek Reach Project was to split flow and increase the low-flow secondary channel length. Secondary channel was mapped as side channel if it was split from the main channel by persistent woody vegetation, braided if it was split by an unvegetated bar and a slough if it was a backwater area that was only connected at the downstream end.

Habitat mapping in 2003 showed 65 meters secondary channel length during the low-flow period (Table 100). This was a backwater area associated with scour along the riprap at the upstream end of the Sygitowicz project reach. Habitat mapping in 2009 found 155 m of slough channel type that was associated with the backwater area and Todd project bank structures left by the avulsion of the channel in January 2009. It was hoped that this avulsion would lead to a wetted low-flow side channel around the mid channel logjam (Todd #7) that flowed along the west bank (Figure 126, Figure 127). One of the objectives of the Sygitowicz project was to create local areas of scour and encourage more flow along the western bank and maintain a side channel in this area. As of 2018, wood and sediment deposition has continued to disconnect the upstream portion of this channel and channel change associated with continued migration into the forested floodplain downstream of the project reach has disconnected the downstream of the channel leaving no secondary channel length in the project reach (Figure 128). During higher flow events, flow does occupy this area and maintains isolated pools along the Todd project bank structures.

Table 100: Secondary channel lengths in 2003 and 2009.

Secondary Channel Type	2003 Length (m)	2009 Length (m)	2018 Length (m)
Side Channel	0	0	0
Slough Channel	65	155	0
Braided Chanel	0	0	0
Main Channel	575	550	529

Figure 126: Channel change in the project between 2006 and 2009 showing avulsion associated with ELJ #1.

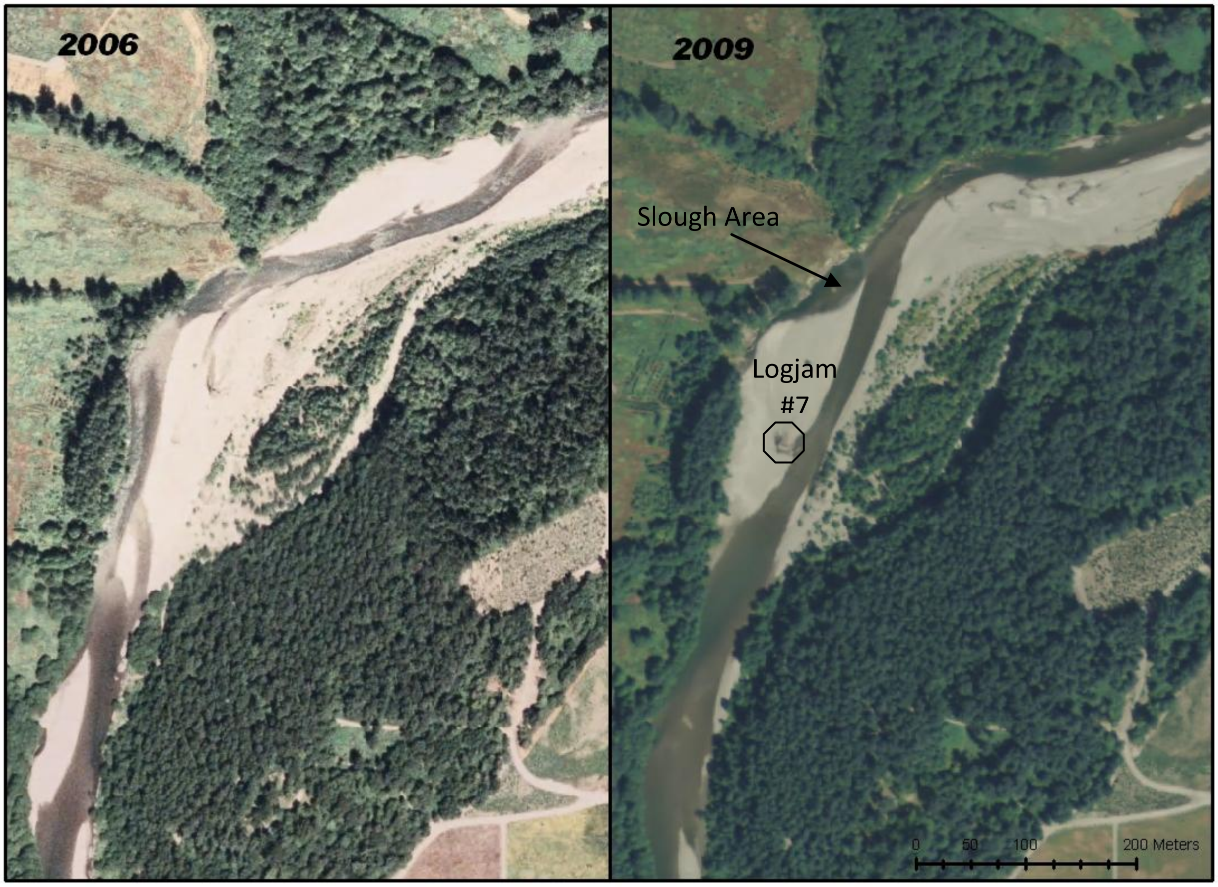
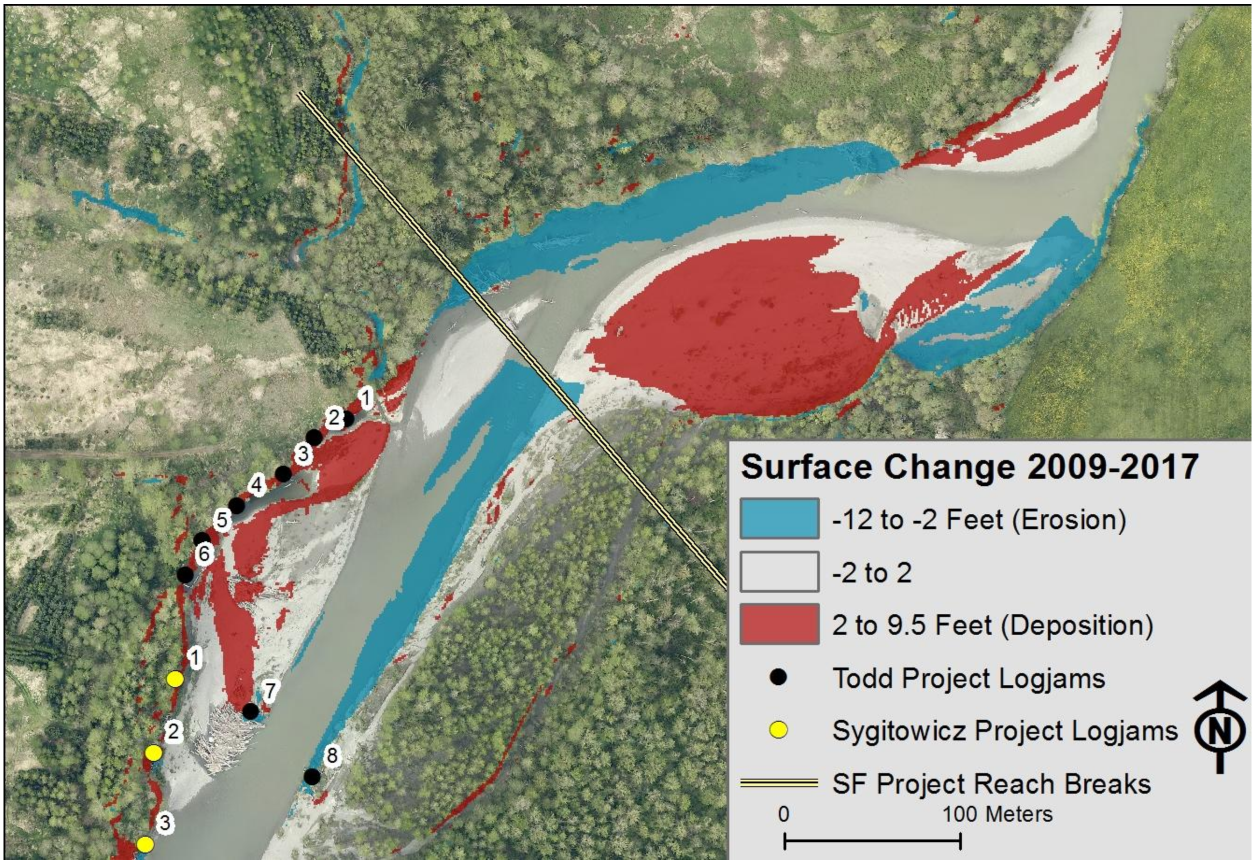


Figure 127: Looking downstream at the slough area before (left) and after (right) channel change.

Figure 128: Surface change between 2009 and 2017 based on lidar-derived DEM subtraction.



Instream Cover

Another goal of the Todd Creek Reach Project was to increase the habitat diversity by increasing the amount of woody cover in the low-flow channel. Instream cover was noted in the 2003 surveys, although not classified for each habitat unit. In subsequent mapping, cover was classified, measured and rated for complexity for each habitat unit. While detailed comparison is difficult, it is possible to compare the number of habitat units where wood is a noted cover component.

In the summer of 2003, the Lummi Natural Resources Department mapped logjams and key-sized pieces of wood throughout the South Fork Nooksack (LNR 2007a). At that time, there was one logjam and no key-sized (>9 m^3) pieces identified in the project reach. The logjam was associated with the primary pool that was mapped in the 2003 habitat mapping. While the pool was formed by failing riprap, the mapping indicates that wood was the dominant cover type. From the wood mapping the cover area for the pool is estimated to be approximately 450 m^2.

Mapping in 2009 provided a more detailed look at instream cover. Five of the nine units (including secondary units) mapped contained some woody cover. The most common and abundant type of cover was debris pile, which increase from 450 to 712 m^2 following construction (Table 101). Subsequent mapping in 2017 showed a decrease in wood cover area, particularly in the amount of debris piles. This was due largely to the migration of the channel away from the Todd project bank structures and the isolation of the backwater habitat that they were associated with. Nearly all the debris pile cover mapped in 2017 was associated with the mid-channel structure in the Todd Project (ELJ#7).

Table 101: The 2009 and 2017 cover types, number of habitat units with that cover type and cumulative area.

Cover Type		Count of Units	Area (m^2)
2009 Cover Types and Area			
Wood	Debris Pile	4	712
	Single Log	1	12
	Rootwad	1	44
Artificial Bank	Riprap	1	85
2017 Cover Types and Area			
Wood	Debris Pile	2	214
	Single Log	3	13
	Rootwad	0	0
Artificial Bank	Riprap	2	33

Another important measure of habitat diversity is distribution of different edge types in the project reach. For the purposes of effectiveness monitoring, four edge classes were used: artificial bank (riprap), natural bank, bar, and engineered logjam. For the Todd and Sygitowicz projects, edge types were classified using the low flow wetted edge of the channel as mapped in 2003 as a part of the Acme-Confluence assessment. The wetted edge type was then determined from a 2003 aerial photo. In the 2017 effectiveness monitoring the edges were mapped and classified in the field.

Comparing the two data sets shows a decrease in riprap edge due to channel movement and associated riprap removal and engineered logjam construction between 2003 and 2017 (Table 102). The 2009 channel avulsion away from the edge of the floodplain and toward the middle of the active channel area is also reflected in the decrease in natural bank and riprap and increase in bar edge habitat. The modest increase in engineered logjam edge is due to the channel avulsing away from many of the Todd project structures and the recession of the Sygitowicz structures into the bank out of the low flow channel. If the 2017 conditions were compared to an estimate of the 2017 conditions without the project then the increase in engineered logjam and natural bank edges due to the project is evident (Table 103).

Table 102: Edge types associated with the low flow wetted channel in 2003 and 2017.

Year	Length (m) of Edge Type				Total Length (m)
	Riprap	Natural Bank	Bar	Eng. Logjam	
2003	210	387	742	N/A	1339
2017	111	37	1096	56	1300

Table 103: Comparison of the existing 2013 edge types with an estimate of the 2013 conditions without the project.

Year	Length (m) of Edge Type				Total Length (m)
	Riprap	Natural Bank	Bar	Eng. Logjam	
2017	111	37	1096	56	1300

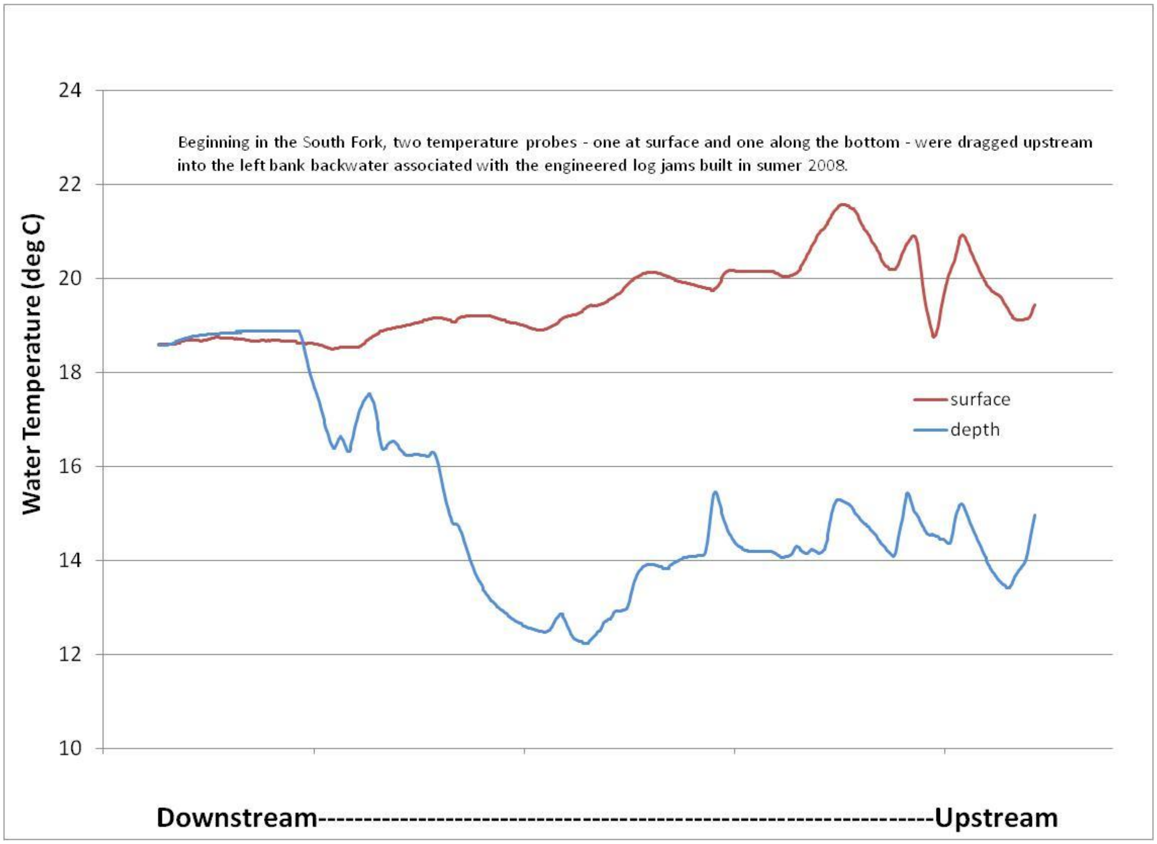
2017 (*w/o Project)*	148	0	1152	0	1300

The Todd Creek Reach project saw an increase in the area of wood cover and the habitat units that included wood as a dominant cover type between 2003 and 2009. The number of stable logjams increased in the reach leading to an increase wood-formed pools and wood as dominant cover type in pools. Between 2009 and 2017 there was a reduction in both the number of units that included wood cover and the area of wood cover in the project reach because of the disconnection of the large backwater area in the Todd project. This change is also reflected in the edge mapping, with the loss of natural bank edge and increase in bar edge between 2003 and 2017.

Thermal Refuge

Temperature monitoring of the backwater pools associated with the engineered logjam projects showed a marked decrease in the water temperature with depth (NR data). Temperature was monitored in summer of 2009 in the large backwater pool that formed against the bank roughness structures following the channel moving to the east of the mid-channel engineered logjam during January 2009. The summer of 2009 was a typical year for water temperature in the South Fork Nooksack, with daily maximum temperatures exceeding 20 ˚C during the warmest period. During July 2009, two temperature probes were moved through the pool from the main channel of the South Fork Nooksack, one at depth and one at the surface. As the probes entered the backwater area, where the flow was not being actively mixed by the flowing water, the temperatures diverged and the deeper water was up to 6 ˚C cooler than the surface (Figure 129). Monitoring of other pools in the reach showed no measurable thermal stratification. It is likely that the stratification of the pool occurred because there was no surface flow through the pool to mix and dilute the groundwater. Subsequent monitoring found that the cooler water backwater area was disconnected from the main channel during the summer low flow period when it could provide a cool water refuge for salmonids.

Figure 129: Temperature measurements in Todd Creek backwater 7/16/09



Conclusions and Recommendations

The fifteen structures built as a part of the Todd and Sygitowicz projects have not met most of their project objectives (Table 104). The total number of pools in the reach has increased from three in 2003 to four in 2017, but subsequently dropped to one pool in 2018. The number of pools greater than 1m residual depth increased from one in 2003 to three in 2010 before dropping to one in 2018. The percentage of wood-formed pools increased following construction. In 2003 all three of the pools were associated with riprap. In 2009 all three pools were associated with wood. Like the changes in pool count, the area of logjam cover increased considerably between 2003 and 2009, from 450 m^2 to 712 m^2 only to fall in 2018 to 214 m^2. The retrofit of the Sygitowicz structures provided a modest increase in wood cover and localize scour, but never reached a scale that was evident in the reach-scale habitat mapping. By 2017, one of the enhanced structures had lost the projecting log and another was isolated from the channel.

Pool formation was likely limited because most of the structures were built at the farthest western extent of the historic migration area. In the case of the Sygitowicz project the bank structures were recessed into the terrace limiting the interaction with the low flow channel. As the channel moved back toward the center of the historic channel migration area, many of the Todd project structures were first left in a backwater area and then abandoned, leaving only two structures interacting with the low flow channel. These two structures have consistently provided pool habitat and cover since the channel movement.

Changes in the edge habitat in the reach also reflect the channel avulsion in 2009 and the lack of interaction between the recessed logjams and low flow channel. The project resulted in a decrease in riprap has an edge type as the riprap that was present in 2003 was removed or replaced with engineered logjams. The fifteen logjams that were constructed resulted in only 56m of edge habitat due to the channel moving away from most of the structures and the limited interaction of the recessed structures with the low flow channel. The avulsion further led to an increase in bar edge and a decrease in natural bank edge as the channel moved away from the terrace and back toward the center of the historic migration area.

Secondary channel development has not occurred in the reach, aside from backwater areas, and efforts to increase flow toward the western margin of the channel and re-engage the lower Todd project structures have not been successful. It is likely that the Sygitowicz structures were built too far into the bank to create the local scour that would encourage flow along the western edge of the channel.

Cooler water refuge areas (more than 2 °C cooler than the main channel) were not generally associated with the engineered logjams in the project. One thermal refuge area was identified in the deep backwater pool that was likely heavily influenced by local groundwater emergence. In the 2010 snorkeling survey, the cool backwater held abundant juvenile fish including chinook. This pool remained connected during the low flow period until approximately 2014, when channel migration away from the western bank isolated the pool. The habitat is now an isolated pool that is only connected during high flow events.

Table 104: Todd/ Sygitowicz Project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
Increase number, area and depth of pools	Pool formation	**Not met**- The total number of pools in the reach has increased from three in 2003 to four in 2017, but subsequently dropped to one pool in 2018. Current pool spacing (1.7 CW/ pool) is below the target level.
Increased secondary channel development	Secondary channel length	**Not met**- the project has not resulted in the reconnection of the left bank channel through the Todd project extent.
Increase woody cover abundance	Instream cover	**Met**- the project has seen a modest increase in woody cover through most of the reach. The main channel structure has seen a substantial increase in wood cover.
Create cool water refuge areas	Thermal refuge creation	**Partially met**- the project formed a backwater pool that was thermally stratified. The pool persisted from 2009 to 2014 before becoming isolated from the low flow channel. No other refuge areas have been

		identified.

Van Zandt Project

Project Description

The Van Zandt Project was constructed in 2010 between river mile 1.0 and 1.3 and includes 14 engineered logjams and the stabilization of a large cottonwood tree that is keying a natural logjam (Figure 130, Figure 131). One of the structures has subsequently washed-out. The goal of the Van Zandt Project was to scour deep, thermally stratified pools with complex wood cover for migrating and holding habitat. The project also protects an old landfill from channel migration and avulsion, although this was not a stated objective of the habitat project. The specific project objectives are presented in Table 105.

Figure 130: Van Zandt project location.

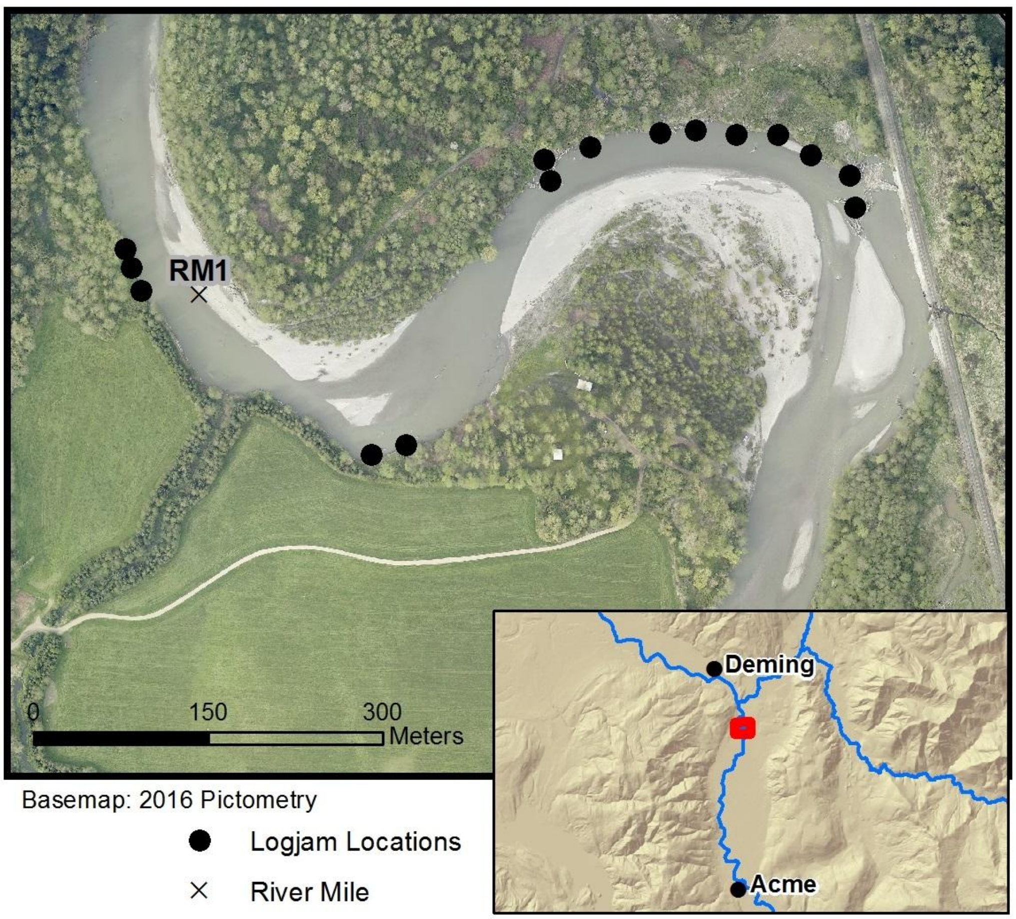


Figure 131: Looking downstream at the Van Zandt Project (structures 1-7) from the BNSF railroad right-of-way (January 2012).

Table 105: Van Zandt project objectives (cited from NNR 2017 monitoring report).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase key habitat quantity (increase number and depth of pools for holding and rearing, number of pool tail-outs for spawning)	Pool formation	Lack of Key Habitat
Increase habitat diversity (i.e. increase quantity of complex wood cover in low-flow and high-flow channels, increase habitat unit diversity	Habitat unit diversity	Low habitat diversity
Increase availability of summer temperature refugia by encouraging formation of deep, thermally-stratified pools in groundwater discharge and tributary confluence areas.	Thermal refuge creation	Elevated summer water temperature

Monitoring data for the Van Zandt project comes from three sources: baseline habitat mapping conducted by the Nooksack Tribe's Natural Resources Department (NNR) in 2003 as a part of the Acme to Confluence Habitat Assessment (Soicher et al. 2006), structure-scale effectiveness monitoring for engineered logjam projects in the South Fork Nooksack (Maudlin and Coe 2012), and reach-scale project effectiveness monitoring of the Van Zandt project reach in 2013. The reach-scale monitoring assessed habitat throughout the project reach, while the structure-scale mapping focused on the habitat functions provided by individual habitat enhancement structures as describe in the *Quality Assurance Project Plan for Implementation and Effectiveness Monitoring of Nooksack River Watershed Habitat Restoration Projects* (Coe 2013). All of these monitoring efforts occurred during the late summer low flow period for the river, although the flow at the site was likely substantially lower in late August of 2003 (~90 cfs measured near Wickersham) than on September 6, 2011 or September 9, 2013 (175 cfs and 176 cfs respectively measured at Saxon Bridge). The USGS relocated the stream gage for the South Fork Nooksack downstream between 2003 and 2011 making direct comparison of the flow difficult.

Project Objectives

Pool Formation

The project has the objective of increasing the number and depth of pools and the number of pool tail-outs. Baseline habitat mapping in 2003 found nine main channel habitat units in the project reach (Figure 132). Of these nine units, three were classified as channel-spanning primary pools (Table 106). Rather than mapping smaller secondary pools within the primary units, the survey estimated the percent of the unit area that was pool-like (deeper, with relatively slower velocity). The area given in Table 106 is the unit area multiplied by the estimated percent pool area, rather than the area of an individual secondary pool.

Figure 132: Pre-project habitat mapping in the Van Zandt project reach (NNR 2003, aerial photo from 2003)

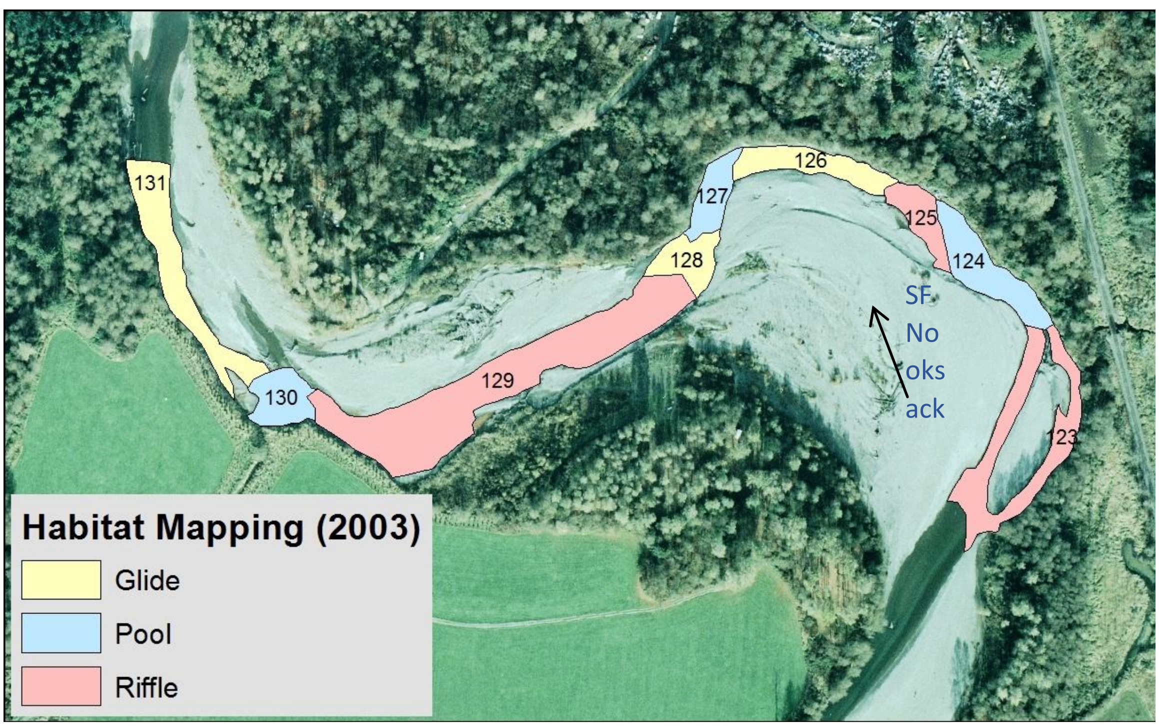


Table 106: Pre-project pool measurements in the Van Zandt Reach (NNR 2003).

Unit #	Unit Type	Area (m^2)	Maximum Depth (m)	Tail-out Depth (m)	Forming Feature	Main Cover Type
123	Secondary	620	1.1	0.2	-	Wood
124	Primary	2160	2.2	0.35*	Debris Pile	Wood
125	Secondary	200	-	-	-	Wood
126	Secondary	700	2.2	-	-	Wood
127	Primary	1,295	2.6	0.8*	Meander	Wood
128	Secondary	280	-	-	-	-
130	Primary	1,560	2.1	0.4	Riprap	Riprap
131	Secondary	370	2.0	-	-	Wood

*Estimated from adjacent unit average depth

Of the three primary pools mapped in 2003, one was formed by wood and one was formed by riprap bank armoring. The third pool was formed by the outside of the meander bend as it migrated northward into the floodplain forest. While only the pool-forming feature of the primary pools was noted in the 2003 surveys, it is likely (based on the field notes and instream cover descriptions) that a large portion of the secondary pool habitat area was formed by woody debris.

The average residual pool depth (maximum depth subtracting the tail-out depth to account for changes in the river stage) of the three primary pools was 1.8 m. The total primary pool area in the project reach was 5,015 m^2. Five riffles or glides were mapped containing a percentage of pool habitat area in 2003. This secondary pool habitat accounted for an additional 2,170 m^2 of pool area. Overall, pool habitat represented 26.3% of the reach area in 2003, while riffles accounted for 52.6% and glides made up 21.1% of the channel area.

The project was completed in 2010 and structure-scale monitoring was completed in 2011 and reach-scale effectiveness monitoring was done in 2013. The 2013 mapping showed that the project reach still contained the same number (nine) of primary habitat units, but there was a substantial increase in the number of secondary units- most notably large backwater areas (Figure 133). In 2003, the reach contained 3 riffles, 3 pools and 3 glides. In 2013, the channel-spanning units were 4 riffles, 1 pool and 4 glides. The three pools that were mapped in 2003 were still present in 2013, although two of the three were considered secondary pools. In spite of the loss of two primary pools, overall percentage of the channel that was classified as pool was similar: 26.3% in 2003 and 23.7% in 2013 (Table 107). The wetted channel area increased 45% from 27,325 m^2 in 2003 to 39,720 m^2 in 2013 and the total pool area increased from 7,190 m^2 to 9,430 m^2. This 45% increase in wetted area likely is a result of increased flow during the 2013 monitoring period, although there is also an increase in backwater areas that accounts for nearly a third of this increase.

Figure 133: Post-project habitat mapping in the Van Zandt project reach (NNR 2013, aerial photo from 2013)

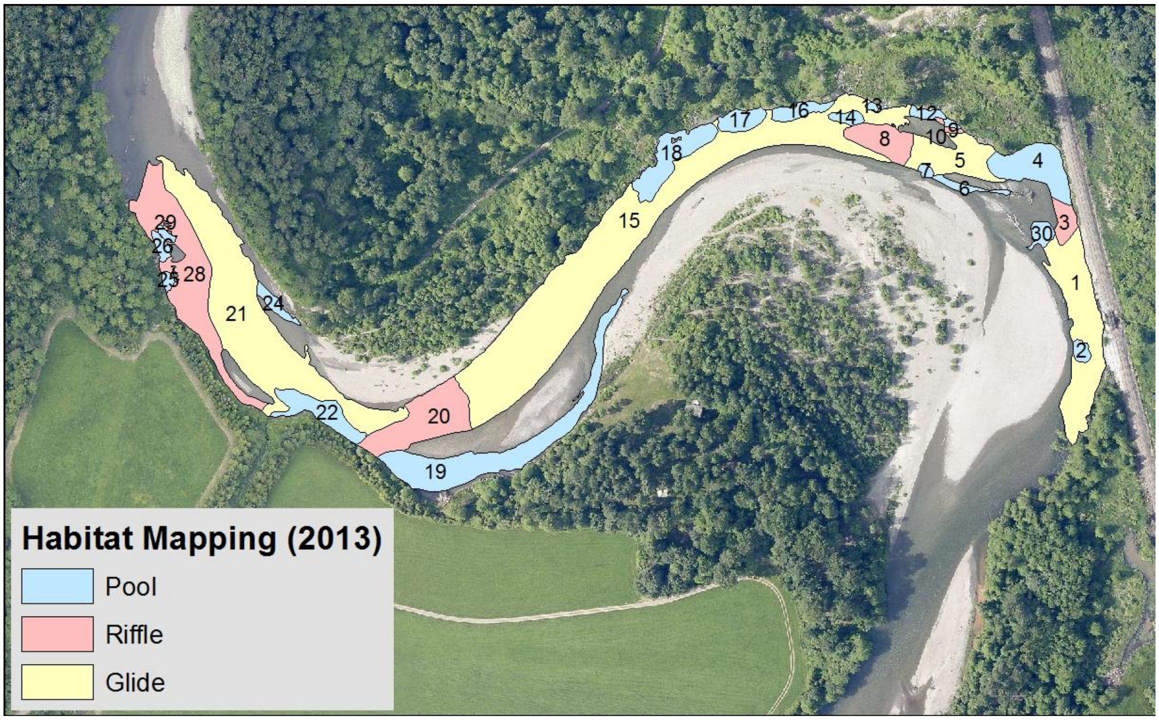


Table 107: Main Channel Habitat Type Area Comparison 2003 and 2013.

Habitat Type	2003 Area (Percentage)	2013 Area (Percentage)
Glide or Run	5,755 m^2 (21.1%)	23,185 m^2 (58.4%)
Riffle	14,380 m^2 (52.6%)	7,105 m^2 (17.9%)
Pool	7,190 m^2 (26.3%)	9,430 m^2 (23.7%)
Total:	*27,325 m^2*	*39,720 m^2*

The more detailed mapping of secondary habitat units in 2013 yielded an increase in the number of smaller and shallower pools than were individually mapped in 2003. The higher level of detail allowed for a closer look at the pool-forming features in the reach. Engineered logjams and natural debris piles were the dominant pool-forming features in the reach following construction. Of the 18 pools mapped the project reach in 2013, seven were formed by the constructed logjams (Table 108). These logjam-formed pools represented 40% of the pool area in the reach.

The detailed mapping also led to a decrease in average depth of the non-backwater pools from 1.8 m in 2003 to 1.4 m in 2013 because a greater number of smaller pools were mapped. If the comparison is isolated to the three pool areas that were measured in 2003 (units #4, #18, and #22 in 2013), then the average depth of the pools increased from 1.8 m to 2.5 m. Two of these three sites are now associated with engineered logjams and the depth of those logjam-formed pools increased dramatically from 1.9 m and 1.8 m to 2.4 m and 3.1 m respectively. The remaining pool, which was formed by riprap increased slightly in residual depth from 1.7 m to 1.9 m.

Table 108: 2013 pool measurements from reach-scale habitat mapping in the Van Zandt Reach (NNR 2013)

Unit #	Unit Type	Area (m^2)	Maximum Depth (m)	Tail-out Depth (m)	Forming Feature	Main Cover Type
2	Secondary	165	2.1	0.4	Debris Pile	Wood
4	Primary	1440	3.1	0.7	Eng. Logjam	Wood
6	Secondary	225	0.5	0.15	Eng. Logjam Backwater	Wood
7	Secondary	80	1.0	0.45	Single Log	Wood
10	Secondary	55	0.8	0.4	Debris Pile	Wood
12	Secondary	160	1.1	0.5	Eng. Logjam	Wood
13	Secondary	45	2.1	1.2	Eng. Logjam	Wood
14	Secondary	185	2.2	0.4	Single Log	-
16	Secondary	370	2.7	1.4	Eng. Logjam	Wood
17	Secondary	450	3.2	1.4	Debris Pile	Wood
18	Secondary	1235	4.3	1.2	Eng. Logjam	Wood
19	Secondary	3215	1.6	1.6	Bank Backwater	Wood
22	Secondary	200	2.9	1.0	Riprap	Riprap
24	Secondary	255	0.4	0.2	Debris Pile Backwater	Wood
25	Secondary	95	1.4	0.8	Eng. Logjam	Wood
26	Secondary	170	1.6	0.4	Riprap	Wood
29	Secondary	85	1.4	0.3	-	-
30	Secondary	260	0.4	0.4	Backwater	Wood

Pool formation at each engineered logjam was monitored in 2011 as a part of a structure-scale effectiveness study of projects throughout the South Fork Nooksack (Maudlin and Coe 2012). The results show that nine of the fifteen structures (including the stabilized cottonwood) created local scour pools (Table 109). At the time of that survey, three of the logjam-formed pools were primary pools. While it is difficult to directly compare the structure-scale results to the reach-scale mapping, it is evident from the 2011 and 2013 mapping that the engineered logjams are a dominant pool-forming feature in the project reach (Figure 134).

Figure 134: Aerial view of pool-formation associated with engineered logjams (#8 and #9) (June 2014).

The target for pool spacing is less than 1.0 channel widths between each pool. The Acme-Confluence Assessment (Soicher et al. 2006) identified a target of 50% for pool surface area for the reach and the target for pool quality is pools deeper than 1 meter with complex wood cover. In 2003 the pool frequency was 2.3 channel widths per pool. In 2013, the spacing of pools greater than one meter deep decreased to 0.9 channel widths per pool, exceeding the target. The estimated percent of the surface area comprised of pools was 26.3% in 2003 and 23.7% in 2013- both well below the target value. Habitat surveys that covered the lower 8.5 miles of the South Fork Nooksack in 2003 found an average value of 11%, so this reach is considerably higher than the overall average.

Table 109: Van Zandt Project habitat functions for individual structures mapped in 2011.

Structure Number	Habitat Functions					
	Pool-formation					Cover
	Pool Type	Max Depth (m)	Tail-out Depth (m)	Residual Depth (m)	Pool Area (m^2)	Logjam Cover Area (m^2)
1	None	N/A	N/A	N/A	N/A	0
2	None	N/A	N/A	N/A	N/A	0
3	Secondary	1.6	1.3	0.3	265	2
4	Primary	1.8	1.1	0.7	435	4
5	None	N/A	N/A	N/A	N/A	8
6	Primary	3.1	0.5	2.6	645	18
7	None	N/A	N/A	N/A	N/A	0
8	Secondary	2.8	2.1	0.7	290	65
9	Primary	2.5	1.0	1.5	665	33
10	None	N/A	N/A	N/A	N/A	0
11	Secondary	2.7	1.0	1.7	250	32
12	Secondary	0.7	0.4	0.3	10	13
13	Secondary	1.4	0.4	1.0	70	42
14	None	N/A	N/A	N/A	N/A	18
15	Secondary	1.5	0.5	1.0	165	105

Habitat Unit Diversity

The second objective of the Van Zandt project was to increase the habitat diversity in the project reach. Habitat diversity was characterized as the quantity of complex wood cover in low-flow channel and the number of habitat units per mile. Instream cover was noted in the 2003 surveys, although not classified for each habitat unit. In 2013, cover was classified and measured for each habitat unit. The 2011 structure-scale monitoring measured only the amount of cover provided by each engineered logjam. While detailed comparison is difficult, it is possible to compare the number of habitat units where wood is noted as a cover component and the role of the engineered logjams in providing instream cover.

In the 2003 habitat surveys, six of the nine (67%) habitat units were characterized as having large woody debris as a dominant cover component. These units were two glides, two riffles and two pools. Five of these units were located on a meander bend, where the channel was actively migrating into a forested terrace (Figure 132). The sixth unit was a riprapped bank protecting a forested terrace. One unit had riprap as the cover type listed and two had no instream cover observations.

Structure-scale effectiveness mapping in 2011 focused on the amount of wood cover each engineered logjam was providing (Table 109). Eleven of the 15 structures were providing complex cover to the channel. Cumulatively, the 11 structures were providing approximately 340 m^2 of woody cover to the channel- mostly associated with deeper, slower water habitats.

Mapping in 2013 provided a more detailed look at instream cover. Twenty-one of the 28 units (75%) (including secondary units) mapped contained some woody debris cover and several contained multiple categories. The most common type of cover was debris pile, with engineered logjams providing cover in ten habitat units (Table 110). Engineered logjams provided a similar amount of woody cover area in 2013 as was mapped in 2011, which was the majority of the woody cover area in the reach.

Table 110: 2013 Wood cover types and area.

Cover Type		Count of Units	Area (m^2)
LWD	Debris Pile	12	245
	Single Log	4	15
	Engineered Logjam	10	310

There were nine primary habitat units mapped in 2003 and five of these included secondary pools. These fourteen units in the 1.0-kilometer reach equated to 14 units per kilometer. In 2013, there were still nine primary habitat units in the reach, but the count of secondary pools increased from five to nineteen units. This increase is partly a result of the mapping methods, but also likely reflects the local scour associated with the engineered logjams. The 2013 habitat unit diversity was 28 units per kilometer, twice the pre-project diversity.

A second measure of habitat diversity is distribution of different edge types in the project reach. For the purposes of effectiveness monitoring, four edge classes were used: artificial bank (riprap), natural bank, bar, and engineered logjam (Table 111). For the Van Zandt project, edge types were classified using the low flow wetted edge of the channel as mapped in 2003 as a part of the Acme-Confluence assessment. The wetted edge type was then determined from a 2003 aerial photo. In the 2013 effectiveness monitoring mapping the edges were classified in the field and this information was used to check classes that were identified in the 2013 aerial photo. Comparing the two data sets shows an increase in all the edge classes that were mapped due to channel migration and braiding that occurred between the two periods. Three of the engineered logjams were built to replace existing bank armoring, which decreased the amount of riprap present in the reach, but this was more than offset by additional riprap placed by the BNSF railroad to protect the rail line from channel migration. If the 2013 conditions were compared to an estimate of the 2013 conditions without the project then the reduction in artificial bank is evident (Table 112).

Table 111: Edge types associated with the low flow wetted channel in 2003 and 2013.

Year	Length (m) of Edge Type				Total Length (m)
	Riprap	Natural Bank	Bar	Eng. Logjam	
2003	254	466	1,216	N/A	1,936
2013	306	720	1,982	147	3,155

Table 112: Comparison of the existing 2013 edge types with an estimate of the 2013 conditions without the project.

Year	Length (m) of Edge Type				Total Length (m)
	Riprap	Natural Bank	Bar	Eng. Logjam	
2013	306	720	1,982	147	3,155
2013 (*w/o Project)*	353	821	1,982	N/A	3,155

Thermal Refuge Creation

Temperature effectiveness monitoring occurred during August of 2015 (NNR data). Using a temperature probe the area around each engineered logjam was scanned and the minimum temperature was compared to the temperature in a well-mixed area of the adjacent main channel of the South Fork Nooksack (Coe 2013). A thermal refuge area was defined as a location that was more than 2 °C cooler than the average South Fork temperature. The results show that only one of the structures (VZ10) was associated with a cooler water refuge area (Table 113). This refuge was a groundwater seep that flowed underneath the logjam and provided a refuge area that was ~14 m^2 in size (Figure 135). None of the deep primary pools showed greater than 2 °C difference in temperature, likely due to the amount of warm mainstem flow through the pools, rapidly diluting any cooler groundwater inflow.

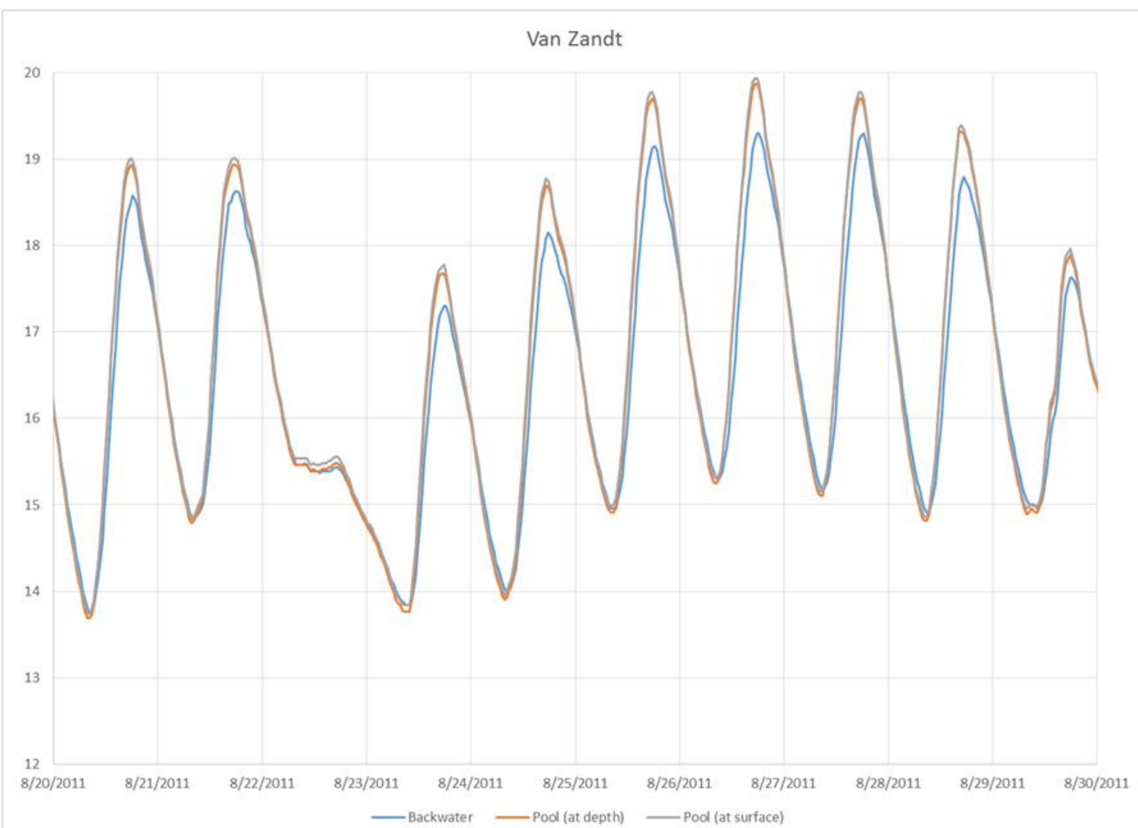
Table 113: Thermal refuge monitoring of Van Zandt Logjams August 19, 2015- fish presence estimated. Italics show refuge area.

Site ID	Min Temperature (°C)	SF Avg Temperature (°C)	Depth (m)	Habitat Type	Temperature Difference (°C)	Fish Presence
VZ 10	*11.4*	*22.6*	*0.5*	*Side channel pool*	*-11.2*	*0*
VZ 15	20.2	21.4	0.8	Braided channel pool	-1.2	10
VZ 07	20.8	21.8	1.5	Primary Pool	-1.0	10
VZ 11	21.9	22.6	0.1	Side channel pool	-0.7	20
VZ 12	22.3	22.6	1.2	Primary pool	-0.3	0
VZ 13	22.3	22.6	1.4	Primary pool	-0.3	0
VZ 09	21.8	22	2.8	Primary pool	-0.2	0
VZ 01	20.7	20.8	3.65	Primary pool	-0.1	50
VZ 05	21.5	21.6	1.75	Primary pool	-0.1	0
VZ 08	21.7	21.8	2.7	Primary pool	-0.1	0
VZ 04	21.6	21.6	2.4	Primary pool	0.0	0
VZ 06	21.6	21.6	2	Primary pool	0.0	0
VZ 14	22.6	22.6	1.7	Primary pool	0.0	10
VZ 03	21.6	21.5	0.2	Isolated Pool	0.1	0
VZ 02	22.1	21.5	0.25	Braided channel pool	0.6	10

Continuous temperature monitoring during late August in 2011 did show a slight difference in the maximum daily temperature and a lag in the warming water through the day in different habitat types (Figure 136). Temperature probes were placed in various habitat types and suspended in deep pools at the water surface and near the channel bed to identify areas of thermal stratification. As found with the 2015 pool scanning, there was little difference in water temperature at depth in the pools and the pool temperature was nearly the same temperature as the adjacent main channel control areas. However, a backwater area associated with the stabilized cottonwood tree was consistently >0.5 °C cooler at the time of the maximum temperature. The site also warmed more slowly than the adjacent part of the pool. It is unclear whether the backwater was influenced by ground water emergence, or if the backwater maintained the cooler water from the previous evening for longer than the better mixed areas of the channel. The channel changed prior to the 2015 temperature monitoring and the pool and the backwater pool was replaced with a secondary pool in a braided channel. Scanning of the habitat adjacent to the cottonwood still showed the site was 1.2 °C cooler than the average main channel temperature at the coolest point location.

Figure 135: Refuge area associated with the Van Zandt 10 structure- at the time of survey the refuge area was a small side channel of the river.

Figure 136: Continuous temperature monitoring in the pool associated with the stabilized cottonwood (Structure #15) showing temperature at the surface and bottom of the pool and in a backwater area (NNR data from 2011).



Conclusions and Recommendations

The Van Zandt project has met the majority of its project objectives (Table 114). Between 2003 and 2013, the reach saw an increase in total count of pools from eight to eighteen and an increase in wood as a pool-forming feature. The increased number of pools also represented an increase in total pool area, although the percent of surface area composed of pools fell slightly. The majority (9 of 15) of the engineered structures had measurable scour associated with them. The reach also saw a decline in average residual depth through the reach, but an increase in the range of the depth. This equates to more frequent pools, with a wider range of depth.

The project reach is also more diverse, with an increase in the number of habitat units per mile and an increase in woody cover. While the number of channel-spanning habitat units didn't change between the pre-project and post-project monitoring, the amount of secondary habitat units increased dramatically from five to nineteen units, reflecting the local scour associated with the engineered logjams. Habitat units that contained woody cover increased from 66% of the units in 2003 to 75% of the units (including smaller secondary units) in 2013. Engineered logjams provided the largest source of woody cover area in 2013.

Changes in the edge types through the reach between 2003 and 2013 largely showed the influence of individual engineered logjams and the armoring of the railroad grade on habitat. Continued slow channel migration to the north increased the interaction of the logjams built along the waste disposal site. Migration to the east reached the railroad and riprap was added to protect the tracks. The channel continued to migrate northward along the railroad grade with the railroad continuing to add riprap as the channel migrated. This led to a net increase in the riprap edge type of approximately 50 meters, in spite of the restoration project removing some riprap and replacing the rock with engineered logjams.

Cooler water refuge areas (more than 2 °C cooler than the main channel) were not generally associated with the engineered logjams. One thermal refuge area was identified in a side channel pool and was heavily influenced by local groundwater emergence. While minimum point temperatures associated with the structures were often slightly cooler than the average main channel temperature, these points did not represent large areas of cool water. In all but one case, the minimum temperature still exceeded 20°C. Continuous monitoring did show that there can be differences by habitat type in the rate of warming and cooling in addition to the difference in maximum temperature. The backwater pool stayed cooler longer than the adjacent scour pool and had a lower daily maximum temperature. While a modest difference, it does indicate that habitat diversity (side channel pools and backwaters) could be an important component for providing thermal refuge areas.

Table 114: Van Zandt Project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
Increase key habitat quantity (increase number and depth of pools for holding and rearing, number of pool tail-outs for spawning)	Pool formation	**Partially met**- an increase in the number of pools in the reach, but a decrease in average pool depth. Pools spacing met <1.0 channel widths per pool.
Increase habitat diversity (i.e. increase quantity of complex wood cover in low-flow and high-flow channels, increase habitat unit diversity	Habitat unit diversity	**Partially met**- an increase in the number of secondary habitat units per mile and an increase in woody cover. Primary habitat unit count remained unchanged.
Increase availability of summer temperature refugia by encouraging formation of deep, thermally-stratified pools in groundwater discharge and tributary confluence areas.	Thermal refuge creation	**Not met-** No pool stratification was observed. A thermal refuge area was found associated with a groundwater seep. Minimum point temperature associated with structures was generally less than the average reach temperature.

Middle Fork Projects

This section evaluates the stated objectives for both of the instream habitat restoration projects that have been constructed in the Middle Fork Nooksack Watershed. Similar to the other forks, objectives were identified from grant proposals. The stated objectives were then generalized into objective groups for comparison across the watershed and linked to the habitat limiting factors from the WRIA 1 Salmonid Recovery Plan (WRIA Salmon Recovery Board 2005).

Project-scale monitoring generally followed methods presented in the *Quality Assurance Project Plan* (QAPP) *for Implementation and Effectiveness Monitoring of Nooksack River Watershed Habitat Restoration Projects* (Coe 2013). There are 2 instream habitat projects that have been completed in the Middle Fork watershed, both within the same project area (Figure 53). The MF LWD Stabilization Project is a combination of a 2004 project and a 2010 project that used a similar approach to improve side channel habitat. For each of the projects below, the project objectives will be presented and evaluated for success using available monitoring data. We will provide an opinion on whether the objective was met, partially met, or not met. In some cases, it will be inconclusive. Data that informs the reach-scale habitat indicators will also be presented for each project.

Figure 137: Middle Fork Nooksack Project Locations

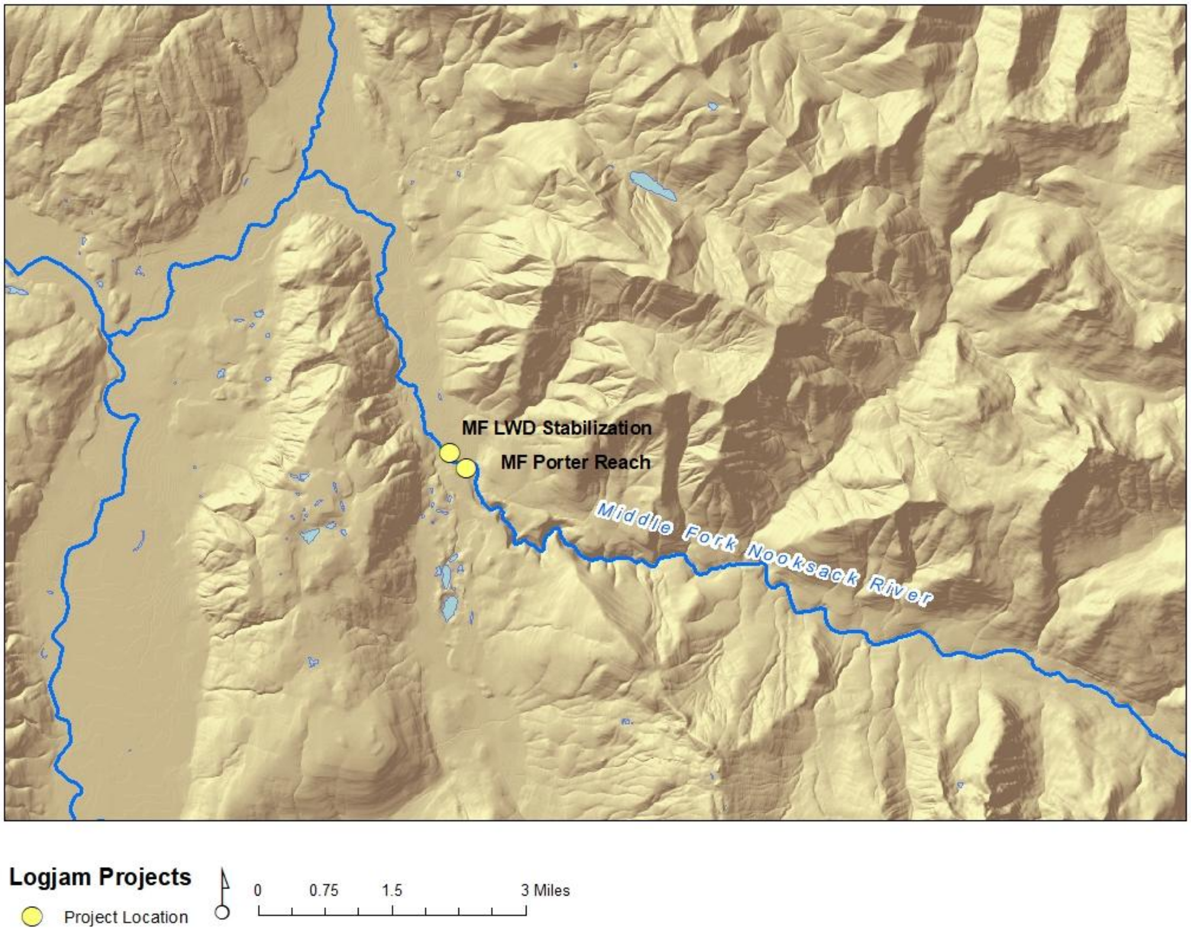


Table 115: Middle Fork restoration projects

Project Name	River Mile	Year	Lead Sponsor
MF LWD Stabilization	4.2	2004/ 2010	Nooksack Salmon Enhancement Association
MF Porter Reach	4.2	2017	Lummi Nation

Porter Creek Reach Project

The Middle Fork Porter Creek Reach In-stream Restoration Project is multi-phased engineered logjam project located between river miles 3.9 and 4.8 on the main stem of the Middle Fork Nooksack (Figure 138). The goal of this project is to restore salmonid spawning, rearing and holding habitat by addressing the limiting factors of temperature, channel stability, and habitat diversity and key habitat quantity in the reach (Table 116). Two phases of the project (23 engineered log jams) were completed in 2017 and 2018.

Figure 138: Phases 1 and 4 Middle Fork Porter Reach logjam locations.

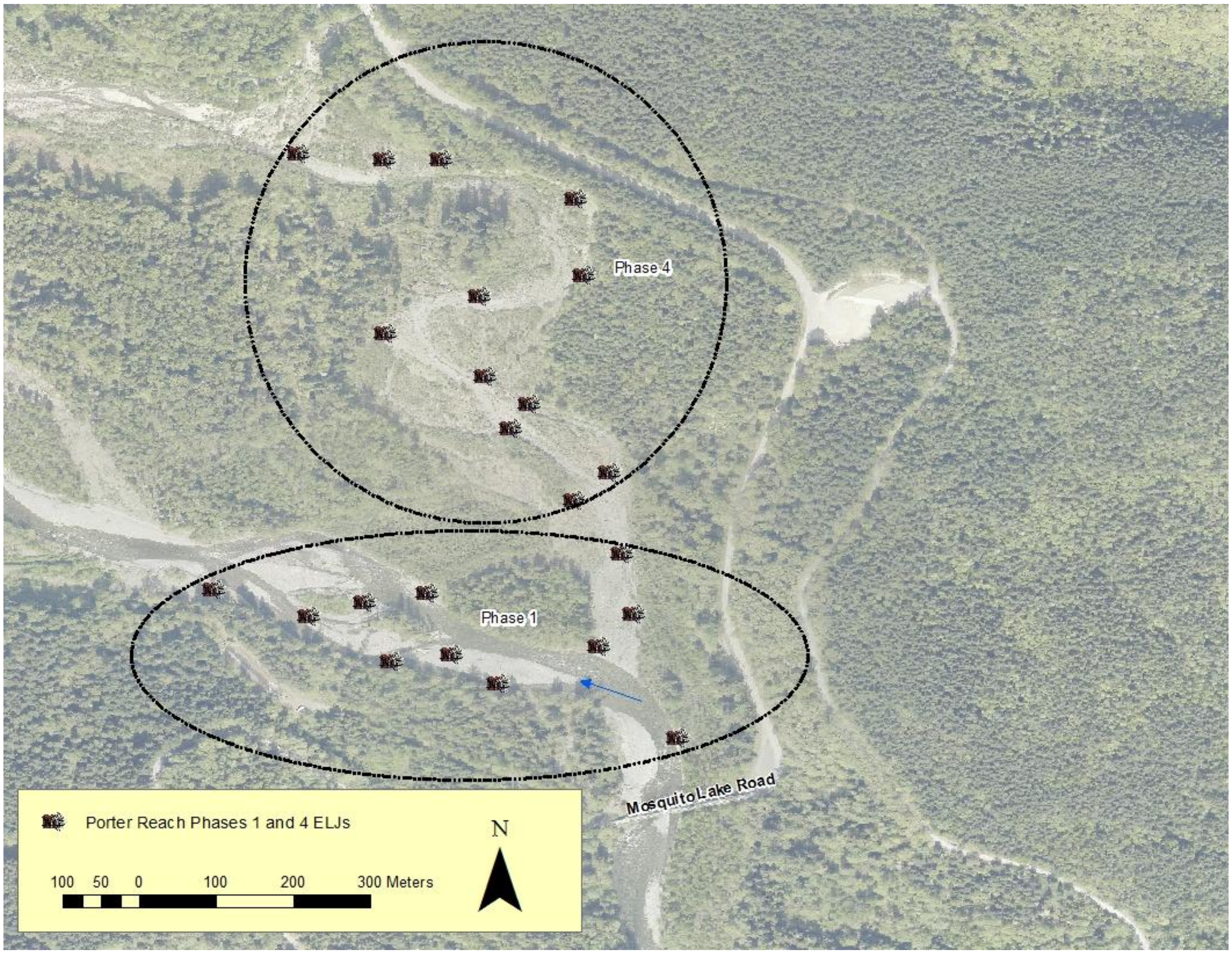


Table 116: Porter Creek Reach project objectives (cited from multiple LNR SRFB proposals).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
To provide a higher rate of egg survival, dissipate high streamflow energies by adding roughness, disrupting flow patterns, and partitioning flow more evenly into the left and right channels downstream of the flow divide from RM 3.9 to 4.8 within five years, leading to increased channel stability over time.	Secondary channel length	Low habitat diversity
Increase thermal refugia for salmonid species by creating secondary pool habitat units with cover within five years through the placement of ELJs.	Thermal refuge creation	Elevated summer water temperature
Increase the frequency of stable spawning habitat by partitioning shear stress in the channel, reducing average grain size to more suitable spawning sized gravels.	Redd scour	Channel stability
Trap mobile LWD to further obstruct flow and provide additional habitat with pool and edge cover benefits, and maximize residence time of large trees within the project reach susceptible to recruitment as the channel adjusts to the ELJs within two years.	LWD Loading	Low habitat diversity

Project Objectives

Secondary Channel Length

The channel has not avulsed to the right side (northern) channel as of this writing. A LiDAR analysis was conducted at the main stem adjacent to the secondary channel. The analysis between 2013 and 2017 found a general degrading pattern. The lateral bar across the bank from the channel split was assessed for elevation change. The bar was degrading between 2013 and 2017. This suggests that the restoration efforts are not causing the aggradation needed to split flows into the secondary channel. The objectives are to occur within five years; this time allotment permits placemen t of large wood to influence riverine processes.

Thermal refuge creation

Scour pools were formed as part of ELJ implementation. Eight scour pools were mapped following Phase 1 implementation. The pools were about 800 square meters during implementation surveys, remaining about 800 square meters during 2018 effectiveness monitoring surveys. Observations since 2018 indicate that the pool area has increased (A. Levell, project manager, pers. comm.).

Redd scour

This objective has not been evaluated since project implementation.

LWD Loading

The two phases of the Porter Reach had the objective of installing 23 stable logjams. Implementation and effectiveness monitoring of the projects found all of the structures remained stable by 2018. The two phases added over 6,200 square meters of wood to the reach. There was about 3,500 square meters of wood in the project area prior to implementation.

Conclusion and Recommendations

The Porter Creek Project has increased the amount of wood in the channel and been effective at forming secondary pools (Table 117). The project has not met the objective of increased secondary channel length. A lack of monitoring data made it difficult to assess success relative to the stream temperature refuge and spawning gravel scour objectives.

Table 117: Porter Creek project objectives and assessment of success.

Stated Project Objectives	Objective Group	Objective Success
To provide a higher rate of egg survival, dissipate high streamflow energies by adding roughness, disrupting flow patterns, and partitioning flow more evenly into the left and right channels downstream of the flow divide from RM 3.9 to 4.8 within five years, leading to increased channel stability over time.	Secondary channel length	**Uncertain**- There has not been an avulsion. The channel has occupied the side channel during high flow events.
Increase thermal refugia for salmonid species by creating secondary pool habitat units with cover within five years through the placement of ELJs.	Thermal refuge creation	**Uncertain**- ELJs installed in Phases 1 and 4 have scour pools, but monitoring of temperature has not occurred.
Increase the frequency of stable spawning habitat by partitioning shear stress in the channel, reducing average grain size to more suitable spawning sized gravels.	Redd scour	**Uncertain**- There have not yet been pebble counts or sediment monitoring.
Trap mobile LWD to further obstruct flow and provide additional habitat with pool and edge cover benefits, and maximize residence time of large trees within the project reach susceptible to recruitment as the channel adjusts to the ELJs within two years.	LWD Loading	**Met**- Wood has nearly doubled in area since project implementation.

Middle Fork LWD Placement

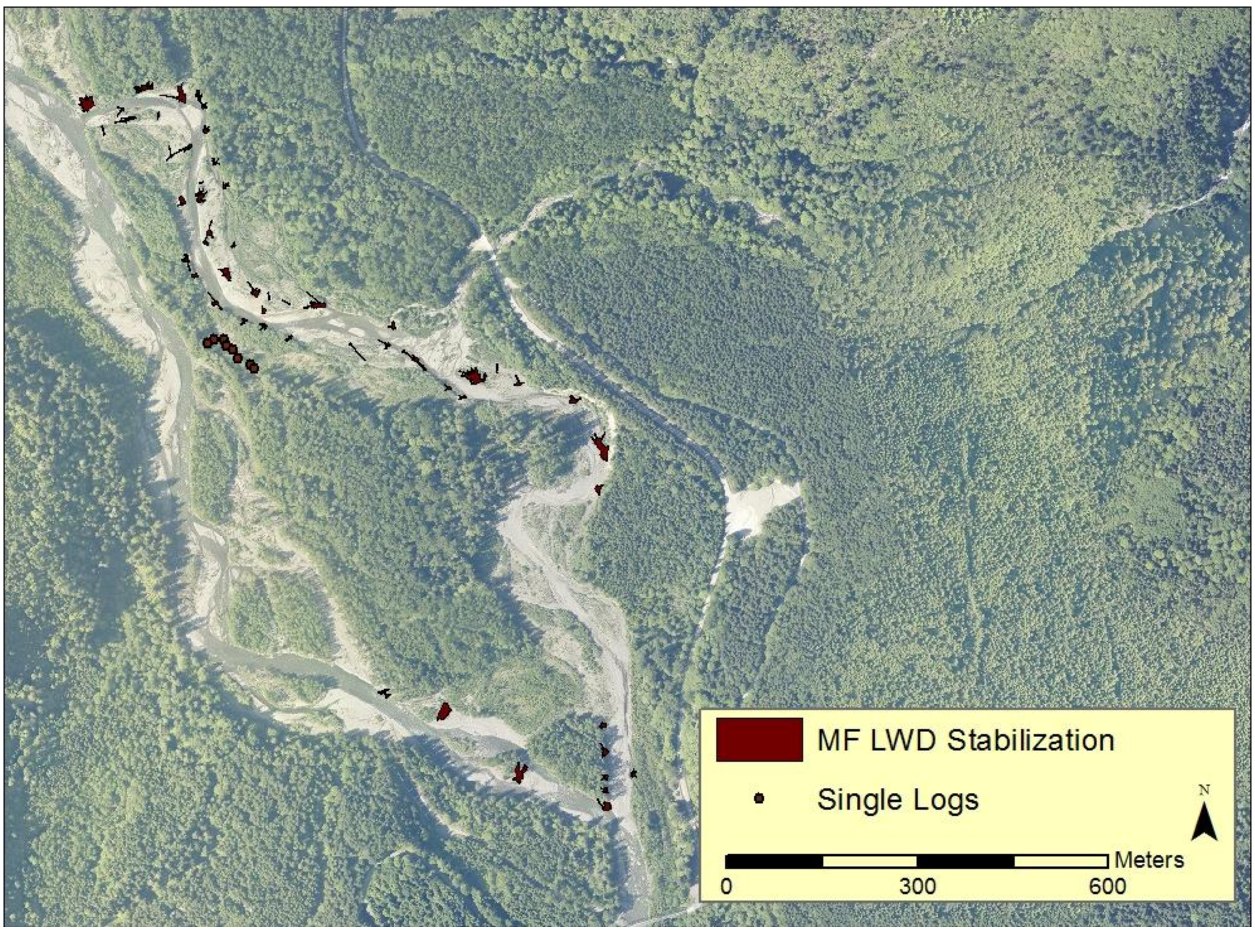
Project Description

The Middle Fork LWD Placement project is similar to the other projects that used non-engineered approaches to increase the stability of the existing wood in the channel. Similar to the Nesset's LWD Stabilization project in the South Fork Nooksack and the North Fork Island project in the North Fork, this project consisted of stabilizing existing and added woody debris with piles driven with an excavator. The objective of the Nooksack Middle Fork LWD project was to augment existing LWD accumulations by adding several large key pieces secured with pilings. The project proposal had no specific objectives presented, but the goal in the project overview was to increase the longevity and ability of these LWD accumulations to form forested islands, sort and store sediments, create pools and provide cover along a one mile (1.6 km) reach of the Middle Fork Nooksack between RM 3.9 and 4.9 (Table 118). The project encompasses two projects: a 2004 project that was built in a side channel, that became the main channel following the start of an avulsion to the south in ~2006. At the time of the baseline monitoring in 2008, there was little evidence of the original project remaining. The second project was constructed in 2010 and includes 48 individual accumulations or individual large pieces of wood, mostly constructed in the abandoned mainstem channel to the north (Figure 139).

Table 118: Middle Fork LWD project objectives (cited from project description SRFB #09-1670).

Stated Project Objectives	Objective Group	Limiting Habitat Factors
Increase the longevity and ability of these LWD accumulations to form mid-channel forest islands, sort and store sediments, create pools and provide cover.	LWD Loading	Channel stability Habitat diversity Key habitat quantity

Figure 139: NSEA Middle Fork Nooksack LWD stabilization sites



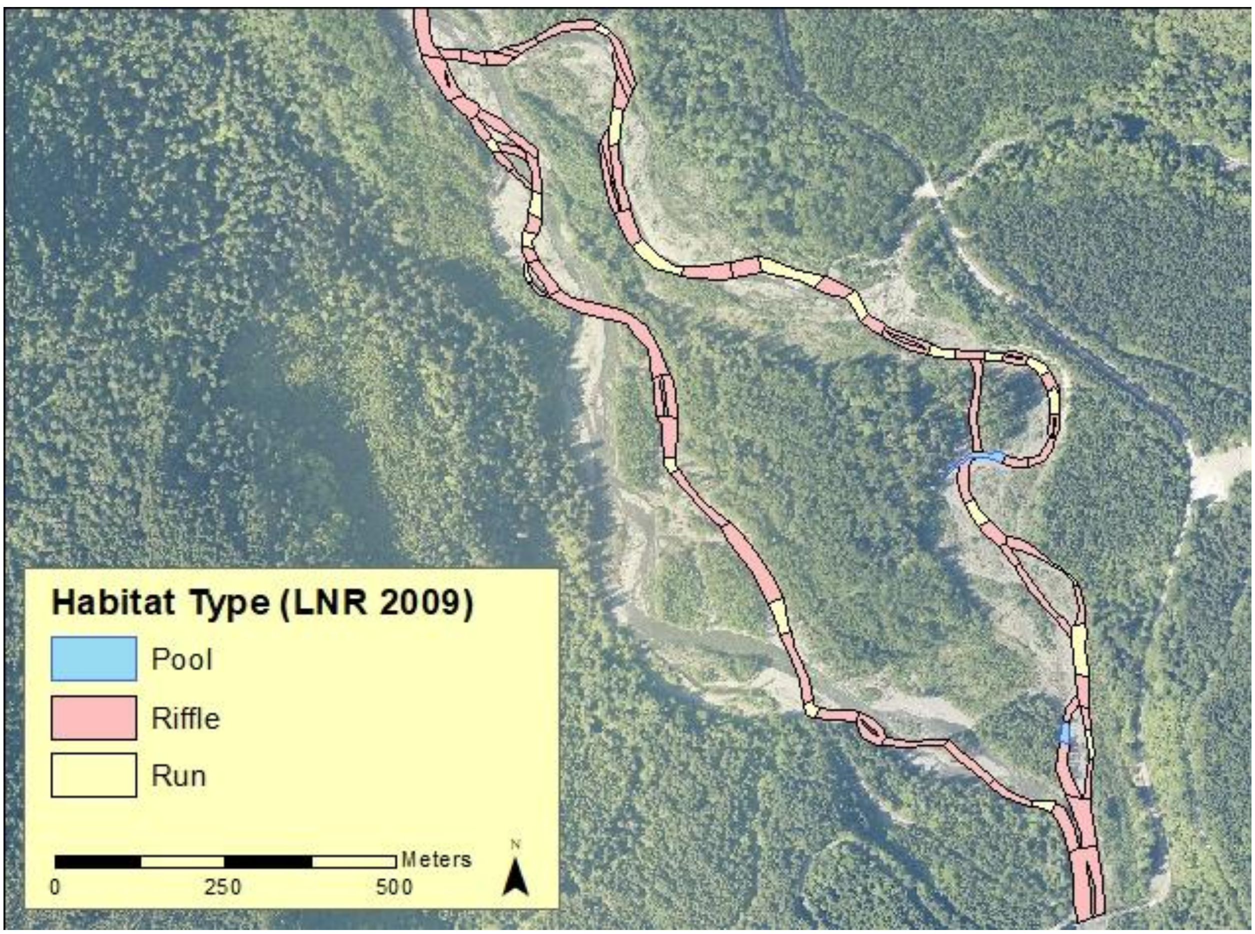
Project Objectives

Large Woody Debris Loading

Baseline monitoring of the project reach occurred in 2008 and 2009 as a part of the Middle Fork habitat assessment (LNR 2011) and effectiveness monitoring occurred in 2012. In both of these years, the low flow channel was split around a large (22.8 hectare) forest island (Figure 140). The 2008 mapping found that the project reach was dominated by riffle and run habitat with 12 pools present in the reach. Eleven of these were formed by wood, but only three met the 1 m residual depth requirement to be considered “deep”. Mapping in 2009 found similar results, but with only two pools mapped in the project reach. Both were wood-formed and exceeded the 1 m residual depth criteria. Wood cover was not mapped in 2008, but was common in the 2009 mapping of the reach. Thirty of the 95 habitat units contained wood cover elements. Surveyors estimated 1,500 m^2 of complex wood cover in the reach.

Between the time of the 2009 mapping and the 2012 structure-scale monitoring, the main channel fully avulsed into the western channel, leaving the area to the northeast as a high flow channel. The large forest island that was present in the baseline mapping became considered a part of the floodplain rather than an island when the secondary low flow channel was lost. The high flow channel has continued to narrow and revegetate since the avulsion, indicating that the channel is becoming less well connected to the main channel of the river. In 2017, the Porter Reach project was begun in the project area and included the goal of encouraging more flow into the northeastern channel.

Figure 140: Habitat mapping in the MF LWD placement reach.



The stabilized sites were surveyed in October 2012 to map the location and assess the habitat functions provided by each stabilized site. Of the 51 sites that were visited, 20 of the structures were not providing obvious habitat functions. Of the remaining 31 structures, only one was interacting with the low flow channel. The 30 other structures were providing high flow functions, such as increased bank resistance at the edge of the high flow channel, or floodplain roughness, where the structure showed signs of splitting the high flow channel. Only two of these structures had appeared to accumulate wood that was moving through the reach. It will require longer-term monitoring to determine if the increased high flow bank resistance will split flow and increase the formation of forested islands in the reach. In spite of limited interaction with the flow, six of these structures showed signs of settling or damage from the floodplain flow.

One of the structures (the furthest to the southeast in Figure 140) was providing low flow habitat at the time of the survey. The structure had formed a pool that was 2.1 m deep and had a residual pool depth of 1.75 m. The structure was providing 200 m^2 of woody cover at the time of the survey. Sediment sorting and storage was not noted for this structure. The structure appeared to have been damaged by the flow at the time of the survey and has since been largely washed-out by the river.

Subsequent site visits have found that the flow from Porter Creek and the groundwater that is intercepted in the high flow channel do interact with the structures in the northern active channel area. Several of these sites provide seasonal instream cover and small pool areas for juvenile fish and the adult steelhead that spawn in the flow of Porter Creek. The amount of seasonal or high flow habitat has not been measured to date.

Conclusions and Recommendations

The project has not met the near-term objectives of pool formation, wood accumulation or sediment storage (Table 119). The project has not been associated with increases in the wood loading through the project reach, aside from the wood that was added as a part of the project. The one structure that was interacting with the main channel of the Middle Fork at the time of the survey has been washed-out, limiting the overall effectiveness of the project. The structures that are in the northern high flow channel have not interacted with the main channel to date and were only providing high flow functions. Flow from Porter Creek combined with groundwater emergence has interacted with the structures and several are providing low flow cover and some local pool formation.

The longer-term objective of island formation will require continued monitoring to determine if high flow functions form additional islands. This will be difficult to separate from the effects of the more recent Porter Reach project that was completed in the reach. This project has been designed and partially constructed in the reach and uses an engineered design to improve structure stability. The newer project was focused on many of the same objectives as the LWD stabilization project.

Table 119: MF LWD Project objectives and success.

Stated Project Objectives	Objective Group	Objective Success
Increase the longevity and ability of these LWD accumulations to form channel Islands, sort and store sediments, create pools and provide cover	LWD Loading	**Not met**- the project has not increased wood storage in the areas that interact with the low flow channel, surveyors did not note sediment sorting, project formed one pool until structure was washed-out.

CONCLUSIONS

Habitat Restoration Impact on Status and Trends Indicators

North Fork Nooksack Indicators

There has been an uncertain channel response to the projects in the Status and Trends indicators evaluated for the North Fork (Table 2, Table 120). This is likely due to the lag between project implementation and the vegetation-based indicators for the North Fork and the broad trend toward an improvement in the indicators across all planning reaches between 2005-2017, likely driven by the channel response to regional climate patterns. The one indicator that was assessed across reaches that does not rely on vegetation growth, side channel connectivity, has shown a fairly strong response to the North Fork projects, with two project reaches accounting for ~14% of the side channel length in the lower North Fork in 2016. The length of connected side channel in project reaches has varied through time, and there have been years when there has been considerably less length. Pool formation and wood cover were only assessed at the project-scale.

Table 120: North Fork Status and Trends Indicators

NF Habitat Indicators	Current Status	Change Since Plan Adoption	Restoration Project Influence
Forest Island Area	Not Meeting Target	Increasing area	Increased island area in project and non-project reaches. Islands are associated with logjams in project reaches.
Forest Island Count	Not Meeting Target	Increasing count	Increased island count in project and non-project reaches. Islands are associated with logjams in project reaches.
Side Channel Length	Good	Increasing length	Mixed results with side channel length increasing and decreasing within project areas by survey year. ~14% of current length in projects.
Floodplain Forest Conditions	Very Good	N/A	Projects have not targeted floodplain forest stand age.
Active Channel Area	Not Meeting Target	Narrowing active channel	Channel narrowing in project reaches, some forest encroachment is related to logjam structures.
Pool Formation (Project Level)	N/A	N/A	Pool formation was noted for all of the projects. Logjams generally were forming secondary pools in braids and side channels, although where the main channel was interacting with stable structures, deep primary pools occurred.
Wood Function (Project Level)	N/A	N/A	Projects increased wood cover in the project reaches, and increased wood-formed pools from baseline mapping in 2005 in several reaches.

Forest Island Area and Count

Both forest island area and island count have a considerable amount of variation in them through time, but the expected response to restoration would be an increase to the target levels and then maintaining the island area- reflecting an increase in channel stability. Looking through the photo record, there appears to be a strong decrease in island area across all reaches in the late-1930s and again between 1994 and 2005 to the lowest historic value at the time of the plan adoption with a subsequent recovery of island area after 2005 to levels that have exceeded the historical average. This is still below target, but the recent trend has been toward increasing island area and count. All of the habitat restoration work focused on increasing island area and count that has been completed in the North Fork has occurred in this period of increasing forest island area throughout the lower North Fork, making it difficult to separate the response to the project from the broader recent trend of increased island area.

Comparing the changes in the forested island area to the targets for "Good" and "Very Good" conditions, one of the reaches (Lone Tree) has exceeded the historic (1933-1998) maximum island area and one (Mahaffey Canyon) has reached 75% of the historic maximum area. Across the North Fork the island area has increased since the time of the plan adoption from 28 hectares to 75.2 hectares, still well below the target of 135.2 hectares for "Good" conditions. Island count has similarly increased across the lower North Fork from 33 to 42 forested islands, but remains below the "Good" threshold of 96 islands. The Wildcat Reach exceeded the "Good" threshold of 75% of the historic maximum area and the Lone Tree Reach has equaled the historic maximum within the reach boundaries. In both of these reaches maturing islands are associated with logjam structures.

Restoration has occurred in four of the planning reaches (Lone Tree, Wildcat, Hatchery and Farmhouse) with the goal of increasing side channel length and channel stability. This should be reflected in an increase in the forest island area and count following project implementation. Two of the project reaches have seen an increase in forest island area following the projects- the Lone Tree reach and the Hatchery reach, although this is within the context of the entire river showing an increase in island area in that period. After an increase between 2005 and 2010, both the Wildcat and Farmhouse reaches have seen a slight decrease in island area, but in 2016 both remained near their historic mean value. All four reaches have also seen an increase in forested island count between 2005 and 2016. Monitoring of the Wildcat and Farmhouse projects show the response to restoration are still uncertain, due to the lag in vegetation response to the project. The exception is the Lone Tree project, which has likely met its objective of increasing forest island area. When viewed across the lower North Fork, the increase in island area and count likely has more to do with regional climate patterns than restoration projects.

Side Channel Length

Cumulative wetted side channel length through time in the North Fork rose from the historic minimum length (~2,900 m) in 1938 until it reached approximately 10,815 m in 1966, which was slightly more than the average side channel length of the North Fork through the historic photo record. By 1976, the length had dropped to approximately half this length before increasing to its historic maximum in 1986. Side channel length fell continuously until 2005, when the salmon recovery plan was adopted and the focus of restoration in the North Fork became increasing the length of perennial side channels. By 2016, the length had again increased to approximately the historic average, with 8 of the 12 unconfined reaches showing an increase in length. The 2016 conditions exceed the target for "Good" conditions (>30% of the mainstem length) and the trend has been an increase in side channel length since the adoption of the plan.

In the four planning reaches of the lower North Fork Geographic Area where restoration projects have occurred since the adoption of the salmon recovery plan in 2005, two of the four reaches have seen an increase in side channel length (Wildcat and Lone Tree), while two have seen a decrease in side channel length (Farmhouse and Hatchery). These changes are within the context of overall increases in side channel length throughout the North Fork between 2005 and 2016. The Upper North Fork project occurred in the Deadhorse planning reach, where side channel length through time has not been monitored.

At the project scale, all five projects had an objective of increasing side channel length and all saw uncertain or partial success. For both the Wildcat and Lone Tree projects, changes in side channel connectivity through time has meant that some years the projects meet their targets and other years they do not. The 2016 side channel length in both of these reaches is directly related to the projects and accounts for ~14% of the overall side channel length in the lower North Fork. The Farmhouse Project has formed some secondary channels, but the high flow channels that were targeted for low flow connectivity have yet to become perennial channels. The Upper North Fork Project focused on improving redd success in side channel areas and this was not directly measured, although side channel length has decreased in each of the four surveys between 2002 and 2018 in the project reach.

Floodplain Forest Conditions

Comparing the floodplain forest age and area to the targets for "Good" and "Very Good" conditions, nearly all of the reaches show that they are currently above the target values. When the whole lower North Fork Geographic area is summed, it exceeds the "Very Good" targets and the trend has been an improvement since the adoption of the salmon recovery plan. Only two reaches failed to reach the threshold for "Very Good" conditions (Kenny/Coal and Below Boulder), and both failed based on the area of forest older than 20 years, rather than the amount of forest older than 75 years. All of the project reaches currently meet the targets for floodplain forest encroachment.

The projects in the North Fork did not directly address forest stand age, but the long-term goal is to provide stable forest patches that can begin to meet the age criteria.

Active Channel Area

The active channel area is the largely unvegetated area of the channel that reflects frequent flow and recent migration. Changes in the active channel width reflect both watershed-scale changes in sediment and flow from weather and climate variation and site-specific conditions such as bank materials and floodplain vegetation characteristics. Increases in channel stability will likely be reflected in a narrowing of the active channel area through time as floodplain vegetation encroaches and increases the bank resistance to erosion. The goal is to reverse the trend in the North Fork of increasing active channel width through time, although short-term fluctuation in width in response to flood events is anticipated.

The target active channel area is based on the historic conditions high flow channel area of the river. The high flow and low flow channel areas were determined from aerial photo and map-based habitat mapping by Collins and Sheikh (2004). The target for a "Good" condition was based on the aerial photo record that was available at the time of their assessment (1933-1998). The "Very Good" target was based on the high flow channel area from the Government Land Office surveys in the 1890s, as interpreted by Collins and Sheikh. Eleven of the fourteen of the analysis areas reached their historical maximum active channel area in the 2005 or 2010 photo years; shortly after the adoption of the Salmon Recovery Plan. The trend of rapidly increasing channel area at the expense of floodplain forest through the 1990s and early 2000s drove the restoration strategy to focus on forest encroachment and island formation (Hyatt 2007).

Over the whole Lower North Fork, the active channel area was greater than the "Good" target in both 2005 and 2016. The trend was toward channel narrowing during that period, but it did not drop below the target of the mean value from 1933-1998. The North Fork Nooksack did meet the active channel area target for the "Good" condition in four of the reaches and met the target for the "Very Good" condition in the Maple Creek reach.

The four lower North Fork reaches with habitat restoration projects in them generally show a similar trend, with a peak in the 1990s and early 2000s and a more recent decline in active channel area. Of these reaches, only the Lone Tree project reach has narrowed to a degree that is less than the 1933-1998 mean. There is a several year lag between project implementation and when vegetation would be mature enough to be considered forested instead of high flow channel. In the Wildcat Reach, vegetation encroachment is occurring in the areas associated with the logjams. The Wildcat project was only recently completed and the Farmhouse project is still being implemented, so it is expected that these project reaches will continue to narrow in response to the project as the stable bars begin to revegetate.

Pool Formation and Wood Function

Pool formation and wood function was monitored at the project scale in the North Fork for all project reaches regardless of whether it was included as a project objective. Pool formation by logjam structures was documented in all five of the project reaches, although there were only secondary pools in the Upper North Fork and Island Stabilization project reaches. This is likely due to the lack of stability of the structures when interacting with the main channel of the river. In the Wildcat and Farmhouse reaches, engineered logjams formed primary pools. In the Wildcat Reach 7 of the 23 pools were formed by engineered logjams. In the Farmhouse Reach 15 of the 49 pools were formed by habitat structures, including three primary pools in the main channel (increasing from zero in 2005). These pools tended to be the deepest pools mapped. All 5 of the pools greater than 2 m deep and 10 of the 17 pools deeper than 1 m were formed by engineered logjams.

South Fork Nooksack Indicators

The projects have had a positive impact on all three of the South Fork status and trends indicators (Table 16, Table 121). Restoration projects have driven the increase the number of wood-formed pools and increased the habitat diversity the project reaches relative to the non-project reaches. Project reaches have also seen a slight decrease in artificial armored banks and an increase in logjam banks when compared to the pre-project conditions.

Table 121: South Fork Status and Trends Indicators

SF Habitat Indicators	Current Status	Change Since Plan Adoption	Restoration Project Influence
Habitat Diversity	Not Meeting Target	Increasing Diversity	Project reaches saw a substantial increase in habitat diversity, driven by increased pool formation.
Pool Quantity	Not Meeting Target	Decreased distance between pools	Projects has increased the number of pools within the project reaches and many project reaches exceed the target. Summed across the South Fork, the river is still below target due to the poor pool spacing in the untreated project reaches.
Pool Quality	Not Meeting Target	Increasing wood-formed pools	Projects has increased the percentage of wood-formed pools within the project reaches and nearly all project reaches exceed the 70% target. Summed across the South Fork, the river is still below target. In the upper South Fork pool-formation is dominated by bedrock and in the lower South Fork, bank armoring is common pool-forming feature.
Edge Habitat	Good	Slight increase in natural types	Natural low flow edge types (bars, natural banks and logjams) are the dominant type throughout the South Fork. Most of the upper South Fork has no bank armoring or other artificial edges. Restoration has had a modest impact on reducing bank armoring in the lower South Fork and increasing the length of complex wood edges.

Habitat Diversity

Habitat Diversity was summarized at both the project reach and planning reach scales. Since the project extents often cross planning reach boundaries, the project reach mapping was compared to non-project reaches for both the pre-project and post-project periods to assess effectiveness. For the planning reaches, the habitat diversity indicator at the time of the adoption of the recovery plan is compared to habitat targets for "Good" and "Very Good" habitat conditions. There was a slight increase in habitat diversity in the non-project reaches during the monitoring period, from 9.0 primary units per km to 10.4 units per km (a 15.6% increase). This change represents the background variation in habitat diversity in the absence of habitat restoration projects. Project reaches saw an even greater increase in habitat unit diversity from 10.8 units per km to 15.5 units per km (a 43.1% increase). Nearly all of the project reaches saw an increase in habitat diversity when compared to the baseline monitoring, with the exception of the Saxon Project Reach, which was the most diverse reach of the river when the baseline mapping was done.

When comparing the project extents to the “Good” target of 15 units per kilometer, several projects didn’t meet the habitat indicator target. These included the Acme, Kalsbeek, River Farm, Sygitowicz/Todd and Van Zandt projects. The reasons for this vary by project and include structures with limited interaction with the low flow channel, wide structure spacing, and structures that are designed to provide functions that are not related to habitat diversity. These functions can include increasing wood cover in existing pools, or providing bank protection.

When looking at the salmon recovery plan reaches, none of the reaches met the target at the time of the plan adoption. While all of the reaches showed an improving trend in habitat diversity between 2005 and 2016, the target for “Good” was only met in two reaches in 2016- Hutchinson and Saxon. These two reaches have been the main focus of aggressive habitat restoration in the lower South Fork and includes the Saxon, Nesset’s, Nesset LWD Stabilization, Lower Hutchinson and Downstream of Hutchinson projects.

Pool Quality and Quantity

Pool quality and quantity is a measure of the distance between deep pools and the percentage of the pools formed by wood. The number of pools >1 meter residual depth in the Lower South Fork Geographic Area increased from 53 to 79 between 2000-2003 and 2016-18. While the 2016 conditions did not meet target spacing when summed across the South Fork, the trend since the adoption of the recovery plan has been toward more closely-spaced pools. Within non-project reaches the number of pools decreased in that period from 34 to 27 pools, while pool count increased in project reaches from 19 to 52 pools.

Comparing pre- and post- project pool spacing for project and non-project reaches showed that there was decrease in the distance between pools in all project reaches, with the exception of the Hardscrabble and Acme projects, which were projects that focused on improving quality of existing pools rather than creating new pools. Six of the ten project reaches reduced the pool spacing to meet the “Very Good” target of <1.0 channel widths between pools.

Nearly all of the planning reaches in the lower South Fork Geographic Area where data is available showed a decrease in pool spacing (improved conditions) since the adoption of the salmon recovery plan in 2005. This is due to a combination of restoration projects and natural process, such as channel migration and wood recruitment to the channel that forms scour pools. The one reach where pool spacing increased is the Todd Reach, where pool spacing increased by 0.6 channel widths (~40 m) between pools. This was one of two planning reaches in the lower South Fork where no restoration projects have been implemented. The other reach where no projects have been constructed is the BNSF reach, which saw an increase of two pools in the reach as the channel migrated along the railroad grade and eroded a forested patch of floodplain. In the upper South Fork, three reaches saw a slight increase in pool spacing: the Cavanaugh, Elk Flats and Howard reaches. Both the Howard and Cavanaugh areas had restoration projects in them, but the projects didn’t yield an overall decrease in pool spacing in the areas mapped in 2019.

The projects had a strong impact on the pool-forming feature with the majority of pools mapped in 2016-2019 formed by wood, commonly habitat enhancement structures. Prior to project implementation, 17 of the 53 pools (32%) in the lower South Fork geographic area were formed by wood, mostly natural logjams (Table 20). In an assessment of the current conditions, 56 of the 79 (71%) pools that were mapped were formed by wood- mostly engineered logjams. When the current conditions are summarized by project versus non-project reach, the positive impact of the engineered logjams on pool-forming feature is pronounced. Within project reaches, 85% of the pools were formed by wood, while outside of the project reaches less than half (44%) were formed by wood. Prior to project implementation in the upper South Fork project area, 5% of the 21 pools mapped in the project reaches were wood-formed. In 2019 surveys, 49% of the 33 pools were wood formed in upper South Fork project reaches.

Edge Habitat

Edge habitat represents the slow water area at the edge of the channel. Edge habitat type (gravel or sand bar, bank (generally steeper and vegetated), riprap, logjam) has a direct impact on the width of slow water at the channel margin, the habitat diversity, productivity and the rearing capacity of the river. Targets for edge type are 100% natural bank types (bars, banks and logjams) for “Very Good” and 90% natural edge types for “Good”.

For the lower South Fork in 2003, 62.8% of the wetted edge was classified as bar. Natural banks accounted for 22.7% of the edge habitat and armored bank was 14.6% of the wetted edge. Similar to mapping in 2003, bar edges are the dominant edge type in the lower South Fork in the 2016-18 surveys, representing 66% of the wetted channel edge. Natural banks account for 19.6% and armored banks have decreased in length to 12.3% of the wetted edge. Reflecting the habitat restoration that has occurred in the lower watershed between 2003 and 2018, the engineered logjam (ELJ) edge type makes up 2.1% of the total edge length mapped between 2016 and 2018. In the Upper South Fork, there was little change in the edge types through time. Riprap accounted for less than 0.1% of the edge habitat in both years, with bars (44%) and natural banks (56%) fairly evenly split in both years. While the South Fork as a whole met the “Good” target for natural edge types (>90% natural types) when it is summed across all of the reaches, the lower South Fork, where bank armoring is more prevalent did not meet the target.

The trend between 2003 and 2016 shows a slight improvement in edge types, with engineered logjams accounting for a small part of the increase. All of the project reaches that contained some length of riprap banks in 2003 showed an increase in natural edges in 2016-18 relative to the amount that would have been present without the project. For the planning reaches, all but two showed an increase in natural bank percentage between 2005 and 2016. The two reaches that were the exception, Van Zandt and Standard, saw decreases of 1.6% and 2.1% respectively. The total length of riprap edge in 2003-2005 mapping period was 6.7 kilometers in the lower South Fork and 0.9 kilometers in the upper South Fork. In spite of riprap removal and replacement with wood, the total length of riprap in 2016 increased slightly to 6.8 kilometers in the lower South Fork, largely due to channel migration encountering more existing riprap. The length in the upper South Fork decreased to 0.6 kilometers due to riprap removal as a part of the Skookum Reach projects.

Middle Fork Nooksack Indicators

The Middle Fork shares similar indicators with the North Fork- side channel connectivity, floodplain forest encroachment and active channel area (Table 122). There has been an uncertain channel response to the projects in the Status and Trends indicators evaluated for the North Fork. This is likely due to the lag between project implementation and the vegetation-based indicators. Unlike the North Fork there has not been a trend toward increasing vegetation encroachment on the floodplain. Side channel length, while increasing throughout the lower Middle Fork, has not responded strongly to the projects. There was ~260 m of side channel length in the Porter Project reach, accounting for ~5% of the side channel length in the lower Middle Fork.

Table 122: Middle Fork Status and Trends Indicators

MF Habitat Indicators	Current Status	Change Since Plan Adoption	Restoration Project Influence
Side Channel Length	Good	Increasing length	Porter Project slightly increased side channel length.
Floodplain Forest Conditions	Very Good	N/A	Projects have not targeted floodplain forest stand age.
Active Channel Area	Not Meeting Target	Widening Active Channel	Channel narrowing is expected in project reaches, but there is a lag in vegetation response to the projects.

Side Channel Connectivity

In a pattern that mimics the unconfined reaches of the North Fork, the length of side channel increased to the mid-1960s, dropped and then steadily grew until a rapid drop at the time of the adoption of the Salmon Recovery Plan in 2005. Cumulative side channel length through time in the Middle Fork rose from the historic minimum length (~650 m) in 1943 until it reached approximately 4,450 m in 1966, which was slightly more than double the average side channel length of the Middle Fork through the historic photo record. By 1975, the length had dropped to approximately 30% this length before increasing to its historic maximum in 1994. Side channel length then fell precipitously to 770 m by 1998 and was near the historic low by 2005, when the salmon recovery plan was adopted and the focus of restoration became restoring the length of side channel areas. By 2016, the length had again increased to twice the historic average, with 2 of the 3 reaches showing an increase in length. This increase was driven by the Welcome Reach, which greatly exceeded its historic maximum in 2016. The Kulshan Reach has continued to see a decrease in side channel length since reaching its historic maximum in 1994. In the Porter Reach, where restoration projects have occurred since the adoption of the salmon recovery plan in 2005, there was an increase in side channel length in 2016 with 260 meters of the 660 meters associated with the instream project. The 2016 conditions for the lower Middle Fork exceed the target for "Good" conditions (>30% of the mainstem length) and the trend has been an increase in side channel length since the adoption of the plan.

At the project scale, both projects had an objective of increasing side channel length or creating mid-channel islands to split flow. Neither appears to have met their stated objective since they were constructed. There was an increase in side channel length of 260 m noted in 2016 associated with the Porter Creek Project, which accounted for approximately 5% of the overall Middle Fork side channel length.

Floodplain Forest Encroachment

Comparing the floodplain forest age and area to the targets for "Good" and "Very Good" conditions, all of the reaches show that they are currently above the "Very Good" target values. The percent of the forest that is older than 75 years shows that the Kulshan reach has the lowest percentage of older forest, while the other two reaches are nearly double that amount. The stands that are older than 20 years are fairly well distributed among the three reaches, with all three reaches exceeding 50% of the potential vegetated area. Comparing the floodplain forest age and area to the targets for "Good" and "Very Good" conditions, all of the reaches show that they are currently above the target values. When the whole lower Middle Fork Geographic area is summed, it exceeds the “Very Good” targets. The Porter project reach currently meets the targets for floodplain forest encroachment.

The projects in the Middle Fork did not directly address forest stand age, but the long-term goal is to provide stable forest patches that can begin to meet the age criteria.

Active Channel Area

The active channel area is the largely unvegetated area of the channel that reflects frequent flow and recent migration. Changes in the active channel width reflect both watershed-scale changes in sediment and flow from weather and climate variation and site-specific conditions such as bank materials and floodplain vegetation characteristics. Increases in channel stability will likely be reflected in a narrowing of the active channel area through time as floodplain vegetation encroaches and increases the bank resistance to erosion. The goal is to reverse the trend in the Middle Fork of increasing active channel width through time, although short-term fluctuation in width in response to flood events is anticipated. The targets, based on the GLO surveys and the aerial photo record, are similar to the North Fork.

Both the Kulshan and Welcome reaches have maximum active channel areas in the mid-1970s. The Porter reach was at its widest in 1998 following a major channel avulsion that left a large area of recently disturbed floodplain. A second avulsion in the reach back into the original channel occurred before the 2016 photos, yielding a similarly wide active channel area. All three reaches were at their minimum width in 2005 at the time of the Salmon Recovery Plan adoption.

The active channel area targets for “Good” conditions were met in all of the reaches of the Lower Middle Fork in 2005, when two of the reaches, Porter and Kulshan, were at their historic minimum area. In 2016, all of the reaches are wider than the 2005 conditions, leaving only the Kulshan reach meeting the target for “Good” conditions. As mentioned above, it is expected that the Porter reach will continue to narrow due to the natural recovery of the floodplain, as was seen between 2005 and the first avulsion in the mid-1980s. The restoration projects will likely encourage this process by providing stable patches of floodplain associate with the engineered logjams, similar to the channel response we have seen in the unconfined project reaches in the North Fork. Over the entire lower Middle Fork, the channel is currently not meeting target and the trend has been an increase in channel width since the adoption of the salmon recovery plan.

The channel avulsions in the Porter reach have masked the potential influence of the habitat restoration projects on the active channel width. The reach is currently near its historic maximum, but will likely narrow as vegetation encroaches on the recently abandoned channel area. There is a several year lag between project implementation and when vegetation would be mature enough to be considered forested instead of high flow channel. The Porter Reach projects were only recently completed, so it is expected that these projects will continue to narrow in response to the project as the stable floodplain areas begin to revegetate.

Habitat Restoration Project Effectiveness

The 23 habitat restoration projects in the forks of the Nooksack River identified 103 individual project objectives. The objectives span a variety of river management objectives from reducing sediment through access road abandonment to reducing bed scour by changing the frequency of inundation of the floodplain. Objectives were general (i.e. increase instream cover) and specific (increase the length of woody cover engaged at low flow by 760 meters, increase length at high flow by 1438 meters). In cases, how the objective was stated affected the determination of success. There were often a variety of strategies for addressing the objectives, some of which were more straightforward for monitoring than others. Because of this, there has been a recent effort in WRIA 1 to state SMART objectives in common ways to improve the ability to monitor projects (WRIA 1 SRB 2019). There were general themes to many of the objectives, which allowed them to be grouped into categories with common indicators and then evaluated for success. The three most common habitat objectives were pool formation (18 objectives), thermal refuge creation (17 objectives) and secondary channel length (15 objectives) (Table 123). These reflected the different hypotheses about limiting habitat in the South Fork (creating cool water holding habitat) and North Fork (improved incubation success).

A second group of objectives were fairly common: habitat unit diversity (10 objectives), riparian habitat (7 objectives), wood loading (7 objectives), floodplain reconnection (8 objectives) and instream cover (6 objectives). There were seven other project-specific objectives that were less common and dealt with habitat limitations to spawning habitat (fine sediment, spawning gravel quality and redd scour), flow impedance, bank protection, and edge habitat.

Table 123: Common project objectives for Nooksack watershed projects.

Objective Group	Number of Objectives	Objective Success			
		Met	Partially Met	Not Met	Uncertain
Pool formation	18	5	7	6	0
Secondary Channel Length	17	1	3	8	5
Thermal Refuge	15	1	4	4	6
Habitat Unit Diversity	10	3	3	3	1
Riparian Habitat	7	4	1	0	2
Instream Cover	6	4	1	1	0
LWD Loading	7	4	0	3	0
Floodplain Reconnection	8	2	1	1	4

Pool Formation

Forming pools was the most common objective of the instream projects evaluated in this report. The projects that focused on pool formation were nearly all in the South Fork, where pool habitat is considered to be limiting early chinook adult holding. There were 18 objectives in 18 projects that addressed pool formation. The pool objective was framed in different ways, such as decrease pool spacing, or improving "key habitat", or increase the number, depth and cover in pools. For monitoring, the general approach was to use local habitat mapping to identify pools before project construction and compare the results to post-project monitoring surveys. Project reaches were also compared to non-project reaches to evaluate the natural changes in pool counts and forming-feature in the river. Many projects had multiple post-construction surveys to evaluate change through time.

Of the 18 project objectives related to pools, 12 (67%) of them were met (5 times) or partially met (7 times). The seven pool objectives that were partially met either showed an increase in pools, but not to the target described in the objective (either depth or count), or an increase in the pool count, but not in the specific locations described in the objective. The six objectives (associated with five projects) that failed to meet the pool objective did not show any increase in pools relative to the baseline conditions. The projects likely failed to increase pools for several reasons- structures were not interacting with the low flow channel (Sygitowicz and Skookum projects), structures were built in existing pool areas (Hardscrabble and Acme projects), or structures were lost to high flow (Nesset's LWD Stabilization

Project). These are similar findings to those described for many of these same projects in 2011 (Maudlin and Coe 2012).

The effectiveness of projects, in terms of both pool count and depth, also changed through time as the river migrated through the project reaches. For example, the Lower Hutchinson Project, built in 2006, saw continued pool formation over the ten years of monitoring. One of the three logjams formed a pool immediately following construction, a second was identified in surveys 5 years later and a third pool was mapped 11 years after construction. In contrast, the 2008 Todd/ Sygitowicz projects saw an increase in pools shortly after construction, followed by a decrease to less than the baseline conditions in subsequent years. The one ELJ-formed pool that has persisted in the Todd reach has continued to increase in area and depth from a secondary pool in between 2009 and 2017, to a deep primary pool in 2018. Most of the project reaches saw an immediate increase in wood-formed pools following construction with minor changes through time. These changes may have been related to high flow events between to surveys, but more likely had to do with changes in how the low flow channel was interacting with the structures. While several projects did see an improvement in effectiveness with time, there is not an obvious increase in effectiveness through time in most of the reaches. This likely has to do with the ability of the channel to migrate within the project reach and change the degree that it interacts with structures built further from where the low flow channel was located at the time of construction.

Monitoring of the lower South Fork project reaches relative to the intervening reaches found that the count of deep pools increased in the project reaches from 19 to 52 pools, while it decreased in the intervening reaches from 34 to 27 pools. Prior to the restoration projects, 17 of the 53 pools were formed by wood- mostly natural logjams. Following restoration, 56 of the 79 pools were formed by wood- mostly engineered logjams. Within project reaches 85% of the deep pools were formed by wood, outside of the project reaches, it was 44% of pools. Similar results were seen in the upper South Fork, where wood-formed pools increased from 5% of 21 deep pools to 49% of 33 pools in project reaches.

Fish surveys found that the engineered logjams were also preferentially used by adult spring chinook. Only 15 of the 233 fish counted in surveys of an 8-mile reach of the lower South Fork occupied habitats that were not wood-formed pools. These habitats also contained a higher density of adult chinook in the pools, likely reflecting the greater depth and complex cover.

Secondary Channel Length

There were 17 projects objectives related to side channel length and flow conditions. The objectives addressed the dewatering of target side channel areas, metering high flow entering side channels and the length of side channel low flow habitat in the project reach. Projects also had objectives related to changing the planform of the channel to encourage an anabranching channel system and increase secondary channels. Since the habitat limitation was related to chinook incubation success, monitoring was focused on mapping during the low flow period to show the most limiting habitat for spawning chinook. The river discharge during the surveys still varied between years and likely explains some of the variation in side channel length. For many of the projects monitoring was done at the on-set of spawning and then during the winter low flow period to evaluate the persistence of the side channel through the incubation period. Since side channel connectivity is related to river stage and groundwater conditions, it can be difficult to compare results across sites and years.

Of the 17 objectives identified for the projects, the objectives were met once or partially met three times (23.5%). This is the lowest success rate of any of the common project objectives. Two of the three projects that partially met their objectives saw increases in side channel length that met the objective following construction, but more recent monitoring showed that the project reach had lost the side channel length and no longer met the objective. In one case, the project had the goal of converting the channel to an anastomosing system and there has not been enough time for the gravel bars to reforest into islands and meet the objective. Eight of the objectives were not met and five were considered uncertain, due to the lack of data specifically related to the objective. The eight objectives that were not met were generally related to a lack of increase in side channel length as a result of the project. In the case of the Kalsbeek project, there was a channel avulsion of the main channel into the target side channel area. The projects where there was uncertainty about whether the project objective was met had to do with the framing of the objective in terms of changes in flow side channel areas. Aside from hydraulic modeling that occurred during project design for some of these projects there is no baseline data for the flow and there has not been subsequent post project monitoring or modeling of the changes.

Based on the monitoring results, increasing stable side channel length is a difficult objective to achieve. Projects have been able to meet the objective for a few years and then changes in the channel (either migration or sediment and wood deposition) have disconnected the side channel. In these cases, further migration, erosion and deposition could lead to a reactivation of the side channel in the future. The one project (Larson's Phase 2) that met a secondary channel length objective framed it as high flow connectivity of a side channel and subsequent hydraulic modeling was used to demonstrate connectivity, which was different from the perennial connection most projects were focused on. Stating the project objective in terms of changes in flow makes it challenging to monitor without baseline data and frequent site monitoring.

Thermal Refuge Creation

Thermal refuge creation, defined as areas more than 2°C cooler than the surrounding water temperature, was the third most common project objective, with 15 objectives associated with 14 projects. Objectives associated with thermal refuge creation focused on two general strategies: improving the habitat quality in known areas of cool water and forming deep pools to intercept shallow groundwater and create thermally stratified habitat. Monitoring of water temperature was done with either an instantaneous probe to locate and map areas of colder water or with continuous temperature loggers placed at different locations in the project area to compare temperature changes through time. Monitoring was done at the project scale, so data collection methods and availability varied.

Of the 15 objectives that addressed thermal refuges, one was met and four were partially met (33%). The one project that met a thermal refuge objective was met was the Lower Hutchinson Project, which removed a levee to improve the main channel connection with a colder water tributary and improved habitat at the confluence. Four other projects partially met the objective. These projects created thermally stratified pools that were separated from the main flow of the river, so that mixing was limited. While all of these areas were generally connected at lower flow and accessible to juvenile salmon, this did not meet the goal of creating primary pool holding habitat.

The four objectives that were not met were either monitored and showed no thermal refuge in the areas targeted by the project, or the project did not create the desired habitat in a known cooler water area. The thermal refuge objectives had a high level of uncertainty associated with the monitoring. Two of the projects had no monitoring data available, although the Nesset's Project is the focus of on-going research on logjams and groundwater interaction. Four other projects presented continuous monitoring data that did not show pool stratification in the target areas, but lacked instantaneous data to define refuge areas and ensure that the continuous monitors were placed in a potential refuge location.

Monitoring of several of the sites over multiple years showed that thermal refuges can change through time. The area of the Lower Hutchinson Project refuge changed depending on how Hutchinson Creek entered the channel. In years where it entered into an eddy pool in the engineered logjam, the refuge area was larger than years when the creek entered into the riffle at the head of the pool. Isolated pools and backwater areas also changed depending on the location of the channel relative to the scour pool. For example, the large backwater thermal refuge at the Todd Project became isolated from the main channel as the river continued to migrate away from the structure.

Based on the monitoring results, thermally stratified pools in well-mixed areas of the main channel are unlikely to occur from restoration. In the Lower Hutchinson and Skookum projects a refuge was present in the main flow of the river, but this was a result of the cooler water plume of a tributary. These areas are important for adult spring chinook that enter the river in the spring and hold through the summer before spawning in the late summer and fall. The monitoring work also identified small, localized groundwater seeps that occur in pools that do not yield refuge areas, but may still be important for adult salmon holding for long periods in the warm water of the South Fork. Many of the pools that are isolated from the main channel have shown a strong thermal gradient as groundwater seeps interact with the limited surface water flow. These areas can remain connected to the main channel through sloughs and backwaters and likely provide thermal refuge areas for over-summering juvenile salmonids, but not for holding adult chinook.

Habitat Unit Diversity

Habitat unit diversity covers increases in habitat units in a variety of channel types. Some projects focused specifically on creating diversity in side channel areas, while others looked at the spacing of different habitat units, such as pools and riffles. Project objectives generally included pool spacing in the habitat diversity objective, making it similar to the pool formation objective. Project monitoring relied on field mapping of instream habitat before and after the project. In some cases, projects had multiple years of post-project data to assess how diversity changes through time.

Ten projects identified habitat diversity as an objective. The project objective was met (3 objectives) or partially met (3 objectives) 60% of the time. Projects that partially met the objective showed increases in aspects of habitat diversity, but did not meet the stated objective. For example, the Van Zandt Project saw an increase in secondary habitat units, but not primary (spanning the majority of the main channel) habitat units. The Wildcat Project saw a temporary increase, but failed to meet the target in the objective and the Saxon Project, which framed habitat diversity in relation to pools and pool depth, saw an increase in deep-pools, but not an overall increase in pools. Three projects did not meet the objective: Nesset’s LWD Stabilization due to structure failure; Skookum Edfro had not formed pools; and Larson’s Phase 1 because the side channel that was the focus of diversity did not persist. The Acme Project was uncertain, due to a lack of habitat monitoring data in the target side channel area.

As mentioned previously, when main channel habitat diversity is summed across the project reaches in the South Fork and compared to the non-project reaches, there has been a strong increase in the number of primary units per kilometer in project reaches. Non-project reaches showed a slight increase between 2003 and 2016 from 9.0 to 10.4 units per kilometer, while project reaches saw an increase from 10.8 to 15.5 units per kilometer (a 43.1% increase). Nearly all project reaches saw an increase in diversity, when it is defined as the number of units per kilometer. This doesn't capture projects that had the goal of increasing secondary unit diversity, such as side channel unit diversity.

Riparian Habitat

Riparian habitat in the project objectives often has to do with protecting floodplain forest and encouraging forest island formation. The objectives are focused on island area, active channel area and the condition of the riparian zone. In one case, the project relocated infrastructure from the riparian zone. Monitoring of riparian habitat was based on aerial photo and surface model interpretation of forest areas. There is a lag in response to a project while the vegetation in the targeted areas matures. Depending on how the objective was stated, this led to some uncertainty over whether the objective had been met. For example, the Cavanaugh Island Project had the objective of installing logjams around a targeted forest patch, while the Farmhouse had an objective based on forested and active channel area, which has a time lag as pioneering vegetation becomes forest.

There were seven project objectives related to riparian habitat. The objectives were met four times and partially met once (71% of objectives). The Skookum project had the objective of removing a county road from the riparian zone and the Cavanaugh project related to constructing logjams to protect an island. The NF Channel Island Project and Lone Tree both had a goal of increasing island area, which they met. The Wildcat Project reach has seen an increase in island area, but has not reached the target area yet. This area may continue to increase through time. Two objectives, both included in the Farmhouse project, were uncertain due to the lag in response of the vegetation. This is a recent and ongoing project, so there may be uncertainty related to this objective for several years while the vegetation continues to mature. Riparian habitat is the only objective group where no project objectives were considered "unmet".

Instream Cover

Instream cover as a project objective is related to the area of wood in the channel that provides hiding cover salmon. Wood cover area is measured in the field as a part of the habitat surveys. The objective has been fairly consistently stated as the wood area, but sometimes includes the number of wood-formed pools or wood cover in specific habitats. There were 6 instream cover objectives and four of these were met by the projects. One project partially met the objective and one project (Nesset's LWD Stabilization) did not meet the objective due to the failure of structures in the low flow channel. The later Nesset's project saw an increase in wood cover in the low flow and high flow channels, but did not meet the target established for the project for low flow cover.

The four objectives that were met all saw increases in wood cover area. The Downstream of Hutchinson Project objective was focused on the number of pools that had wood cover, while the Hardscrabble/ River Farm project saw an increase in the number of wood formed pools as well as an increase in wood cover. Instream cover project objectives were clearly stated and easily monitored, with no objectives considered "uncertain".

LWD Loading

The wood loading project objective was related to increasing the volume and residence time of wood in the project reach. Four of the seven project objectives were met. All of these objectives had to do with increasing the number of logjams or large pieces of wood in the reach following the construction. The Nesset's LWD Stabilization Project included two objectives related to wood loading and neither were achieved due to the lack of stability of the structures in the low flow channel. The Middle Fork LWD

Placement Project objective included loading and the expected habitat response to the increased wood. The project did not meet its objectives due to a combination of structure failure and a lack of interaction with the low flow channel. The overall success was low for this objective group (43% of projects did not meet the objective), but it is likely that the majority of projects would meet this objective, if it had been included as a project objective. Instead, most projects focused on the habitat functions of adding wood rather than the volume and residence time.

Floodplain Reconnection

Floodplain reconnection objectives covered many different aspects of channel-floodplain interactions. Bedform roughness, flow impedance, and floodplain sediment storage were all objectives related to floodplain reconnection. Monitoring focused on the different aspects of the objectives, but in many cases, there was insufficient information to address the objective as it was stated. Because floodplain reconnection covered a variety of project objectives, there was a lot of uncertainty in whether the projects met their objectives. There is likely some overlap in these objectives related to side channel development and instream wood loading.

Eight projects identified objectives related to floodplain reconnection. Two of the eight objectives were met and one was partially met. The Larson's Phase 1 project framed floodplain connectivity in terms of flow impedance and bedform roughness, which both increased following the project. The Lower Hutchinson Project identified an increase in active channel width as an objective related to levee removal. The RM 30 Project had the objective of creating new floodplain surfaces in the active channel through the reach and a small area of floodplain was identified during the monitoring of that project, which was an increase, but did not meet the target. One project included post-project hydraulic modeling that showed the project had not yet met the objective of increased floodplain connectivity. It was thought that increased bed aggradation could lead to increased connectivity in the reach.

The most common outcome was an uncertain response to the project (4 project objectives). The Skookum-Edfro Project had no monitoring data or field observations associated with floodplain connectivity. Two of the projects did not monitor the objective- Kalsbeek and Lower Hutchinson, but described field evidence that suggested that their objectives (sediment deposition on the floodplain and lower flood velocity) may have been met. The Fobes Project was re-modeled and the results showed that there was potentially an increase in floodplain connectivity. Field evidence noted continued floodplain incision, though.

Other Project Objectives

Projects included a variety of other less common objectives that were assessed for success (Table 124). Sediment sources had to do with protecting unstable slopes from river erosion, abandoning access roads and decreasing the amount of sediment moving through the reach. Projects were successful at increasing the stability of unstable slopes and abandoning roads (reflected in the revegetation of bare soils), but monitoring sediment passing through the reach was not conclusive.

Table 124: Other project objectives included in project descriptions.

Objective Group	Number of Objectives	Objective Success			
		Met	Partially Met	Not Met	Uncertain
Sediment Sources	4	3	0	0	1
Redd Scour	4	0	2	0	2
Gravel Retention	3	1	0	2	0
Edge Habitat	2	2	0	0	0

Bank Protection	2	1	0	0	1
Salmon Abundance	1	0	0	0	1

Spawning and incubation success was the focus of two objective groups. Decreasing redd scour was generally focused on channel stability in the North and Middle forks. None of the projects met their objectives related to redd scour, although two partially addressed their objective. The Wildcat Project had the objective of narrowing the active channel to reflect a more stable channel, and the NF Island Augmentation Project was focused on preventing the main channel from occupying a productive side channel area. Two of the projects included no monitoring of redd scour in side channels. Spawning gravel retention was also an objective related to improving spawning success of chinook. The RM 30 project had two objectives related to spawning gravel- it sought to store gravel in the lee of the structures for spawning habitat and chinook use of the spawning gravel areas. Gravel was deposited in association with the structures, but spawning use of the areas did not occur. The Nesset's LWD Stabilization Project also had the objective of increasing sediment sorting around the structures, but the failure of the structures in the low flow channel meant that the objective was not met.

Restoration projects also had objectives related to channel edge habitat. The objective relates to improving channel edge habitat by removing rock bank armoring and/ or replacing it with complex wood structures. Both the Skookum Reach and Acme projects removed riprap bank armoring and installed logjams along the bank to meet this objective. Several other projects took a similar approach, but did not have improvements in edge habitat as an objective.

Using habitat structures to halt channel migration was a goal of two projects that were integrated approaches to habitat and flood management. The Saxon Project installed a long woody revetment along the bank to protect several houses from erosion and expand the opportunities for instream restoration without putting the properties at risk. The project has met the goal of halting erosion along the bank. The Acme Project had the goal of protecting some naturally higher ground along the edge of the channel to reduce the potential for adverse flooding of the town of Acme. The objective was stated in terms of reducing flood effects. The results of this were uncertain, since subsequent hydraulic modeling to evaluate the response to the project has not been done.

While increasing the chinook population is likely a goal of all of the projects, only one project had a stated biological objective. Phase one of the Larson's Bridge Project had the objective of increasing the abundance of adult salmon in the project reach. To evaluate this, the spawning records were evaluated within the reach and compared to spawning throughout the basin. The results could not separate an increase in fish from a redistribution into the newly created habitat. Subsequent changes in the understanding of the spring chinook population and a hatchery rebuilding program for the South Fork stock complicated the analysis. Evaluating changes in the abundance of the population relative to habitat restoration is an on-going challenge. Recent efforts to develop a chinook life-cycle model will help our understanding of how restoration changes the productivity and capacity of habitat and how that impacts our chinook population. Once completed, we should have better tools for answering this question.

RECOMMENDATIONS

Recommendations focus on four general areas of project development and monitoring: framing objectives, design elements, biological monitoring/ modeling, and cost effectiveness. The cost effectiveness includes the magnitude, immediacy and lifespan of the benefits.

Framing Objectives

The WRIA 1 Salmon Recovery Staff Team (SRST) has begun requiring local applicants to state their project objectives and benefits using common, measureable habitat indicators. These indicators are assessed by the project proponent based on the project design and their experience from past projects. The indicators are then review by local Technical and Combined Review teams and used to determine the likely magnitude of benefit of the project. The indicators are reviewed and revised annually by the SRST to ensure that they are meaningful for project review. Only a few of the projects included in this report included the assessment of the common habitat indicators during the grant application phase and it made it much easier to determine the project objectives and expected benefits. It is likely that determining project success will be much easier going forward and the number of projects with uncertain benefits should be reduced.

The project indicators will need to be tied to the habitat viability indicators for adaptive management of the salmon recovery plan. This will allow managers to determine how habitat restoration projects are affecting the overall habitat recovery goals. The habitat viability indicators in this report are draft recommendations and will need to be evaluated and possibly revised for the on-going update to the WRIA 1 Salmon Recovery Plan.

Assessment of several of the project objectives included a lot of uncertainty. As the habitat indicators are revised annually, the results of this report can be used to help frame the project objectives in ways that make monitoring easier. Developing new indictors to better evaluate these objectives will be important going forward. This report can also be helpful in setting reasonable project expectations. Understanding how similar projects have functioned can help project proponents work with their designers to develop more effective projects. It can also help to identify where there is uncertainty in the benefits and where increased design effort may be required.

Design Elements

Based on the monitoring results, several of the project objectives have high likelihood of success. Instream structures were generally successful at scour pools and providing instream cover, increasing the habitat unit diversity (generally as a result of increase pools) and protecting vegetated patches of floodplain. These are key objectives to addressing the lack of key habitat and habitat diversity in the South Fork Nooksack and poor channel stability in the North and Middle forks. Projects were less successful at connecting low flow side channels (important spawning habitat in the braided reaches of the North Fork) and creating cool water refuge areas (important for addressing water quality limitations in the South Fork). Other project objectives, such as increased floodplain connectivity were difficult to assess, and will require a monitoring or modeling approach that can better answer questions about project effectiveness. Projects that focused on immediate benefits, such as aggressively locating structures in the low flow channel, generally saw a greater habitat response than structures placed in locations that required channel migration to interact with the structure. In several cases, the anticipated channel movement did not occur and the project did not meet its stated objectives.

From the monitoring it is also clear that engineering design has improved the stability of structures in the watershed. In the cases where existing wood material was stabilized without engineering design, the structures have generally been ineffective at providing a long-term habitat benefit. In many cases, the structures were washed-out by the river. There is evidence that several of the engineered structures have been damaged during floods, so continuing to evaluate the stability and function of structures as they age will be critical to refining designs and understanding the long-term benefit of the projects.

Changes to the conceptual design during the finalization of the design and construction phase to meet permit requirements or reduce environmental impacts can also change the effectiveness of the project. These changes are generally presented in the final design documents and as-built monitoring and would help inform effectiveness monitoring by adjusting the project objectives and the project-specific target for the habitat indicators.

Biological Monitoring/ Modeling

Linking freshwater habitat changes due to restoration to a response in the salmon population has been a challenge because habitat restoration focuses on a partial life-history of salmon and a limited number of environmental elements. One approach is to develop a Chinook life cycle model where changes in the capacity and productivity of habitat from restoration actions can be modeled across the whole life cycle of the two Chinook populations. The model resolution could either incorporate individual project reaches, or summed into the treated and non-treated sections of the river. The benefits of the projects could then be estimated in terms of the population abundance, diversity and productivity.

Monitoring of the population has also been done through spawner surveys and live counts of juvenile and adult salmon. These surveys are useful for estimating abundance and distribution of the population and indentifying associations between fish and habitat elements, such as habitat type, cover or water quality. Integrating these surveys into the monitoring of projects can help develop hypotheses about fish response to habitat restoration and help inform design objectives relative to the observed associations. Successive surveys targeted at specific life stages would likely be necessary to show changes in use through the year. This approach will not allow us to answer questions about the impact of restoration on the population parameters, but will demonstrate fish use at the project reach-scale.

Cost Effectiveness

Cost effectiveness of projects is considered as a part of the local SRFB grant review process. The technical and combined review teams assess the magnitude of the benefit, the longevity of the project approach, the immediacy of the benefit. The magnitude of benefit is assessed using the habitat indicators that are provided to the grant applicants. The longevity of the approach and immediacy of the benefit are generally based on the generic design elements (such as removing a passage barrier or installing large wood), rather than an assessment of the past performance of projects.

Monitoring of the projects showed that stable logjam structures constructed in or immediately adjacent to the low flow channel formed pools and provided cover within the first year of construction, regardless of the number of high flow events during the winter. Pool type (primary pool or secondary) was related to the main channel location during the low flow period. Secondary pools were commonly found side channels and braids of the river and where the thalweg of the channel was not strongly interacting with the structure, such as on lateral bars, or the inside of a mender bend. Structures that required channel movement or floodplain inundation to achieve their habitat objectives were more dependent on winter flow conditions.

Other objectives, such as thermal refuges or side channels, can be rapidly achieved, but appear to be harder to maintain through time. Thermal refuges were dependent on isolating the groundwater seep from the main flow of the river to reduce mixing or on the discharge and local hydraulics at a cool water tributary confluence. These benefits can be quickly achieved, but can change through time as channel migration changes the connectivity of groundwater sloughs and seeps and low flow conditions change between years. Side channel connectivity appears strongly related to the main channel location and is affected by local changes in bed elevation and debris deposition. Design approaches commonly assess side channel connectivity by assessing changes in flow depth and velocity in target side channel areas, but this doesn't capture the dynamic nature of the channel in the unconfined reaches of the river where side channels dominate. Monitoring has shown immediate side channel formation in response to projects in some cases, but in all cases the result has been intermittent connectivity through time. More recently, the designs have focused on providing opportunities for side channel creation by focusing the objective on stabilizing forest patches and planning for side channel connection at a variety of areas through time, rather than identifying one target area and designing the project around increasing flow in one area.

Lastly, other objectives may take decades to achieve. Slowing channel incision and reconnecting floodplains through increasing flow impedance will likely take many years to demonstrate changes in the relative elevation of different alluvial surfaces. Modeling can show changes in floodplain flow as a response to the project, but monitoring changes in connectivity of surfaces at different discharge levels through time will take time to establish the current conditions and determine change. There is an opportunity for repeated modeling of project reaches through time to gain a better understanding of how rapidly floodplain interaction is influenced by the project, but this requires detailed topography and hydraulic model development. A sample of representative project reaches could be modeled using this approach.

The lifespan of engineered logjam projects has not been determined. Projects have been constructed in the Nooksack watershed since 2001, but widespread instream restoration has only been implemented for the last 10-15 years. It has been assumed that structures will function for approximately 50 years with little maintenance, but monitoring has found that several of the structures have been damaged or lost during high flow events. Project design has evolved through time to try and balance cost and stability and evaluating how effective these changes have been will be important for informing future design. Periodically assessing the integrity of the structures will be important to determining the life span of the project, long-term maintenance requirements and ultimately the cost-benefit of the project. Projects located in heavily used recreational reaches or associated critical infrastructure will likely need frequent monitoring to maintain safety and ensure that there is no negative channel response to the project. Some projects may not require maintenance to meet many of their objectives, while some functions, such as bank protection, may require a long-term financial commitment to the project. Projects should be assessed both at the structure-scale to determine how any changes in stability are effecting the function and safety of the structure and at the reach scale to determine if the project is achieving its objectives and meeting the habitat viability indicator targets for the watershed.

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