Historic and Current Factors that Limit Coho Salmon *(Oncorhynchus kisutch)* Production in the Stillaguamish River Basin, Washington State: Implications for Salmonid Habitat Protection and Restoration

A report prepared for:
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EXECUTIVE SUMMARY

This report identifies current and historic factors that limit the production of coho salmon (*Oncorhynchus kisutch*) in the Stillaguamish River basin (1,942 km^2) of western Washington. The headwaters of the North and South forks of the basin are steep forest-lands in federal, state, and private ownership. The low-gradient forks flow through glacially-sculpted valleys and join at the town of Arlington. The mainstem flows east from the forks through a broad alluvial valley for 28 river kilometers through dominantly agricultural land. The river and its tidal marshes enter Port Susan and Puget Sound, 24 kilometers north of the city of Everett. The river splits into two channels from river kilometer 10 to 17, the main channel in this reach at present being Cook Slough.

The report's purpose is to quantify and describe the current and historic quantity and quality of coho salmon habitat, and the watershed processes that create and modify it, in order to help local managers develop a successful plan for protecting and restoring coho habitat. We describe the kinds of changes to habitat, how much change has occurred, and the causes of changes to coho habitat. Such information is critical to setting clear goals for the restoration of lost and degraded salmonid habitat (Beechie and others, 1994; Sedell and Luchessa, 1982).

Off-channel habitats have been critically diminished. Such slower-water habitats are important rearing areas for juvenile coho and other salmonids. Beaver ponds, sloughs, and tidelands account for the majority of habitat lost in the last century. Between 67% and 91% of these habitats have been eliminated. Over 90% of losses are due to channels being cut-off, filled, straightened, or diked. Channel narrowing and shortening has diminished habitat in the mainstem and forks in the historically anadromous zone to a lesser extent than off-channel habitats have been decreased. Moreover, a fish ladder at a falls on the South Fork has increased the length of habitat, resulting in a net overall gain.

A decrease in tributary and main stem pool area (18% less pool area) offsets the gain in habitat in the mainstem and forks, and reduces habitat in tributaries (21% less pool area), resulting in reduced juvenile coho rearing capacity in both habitat types. Pool spacing correlates with the number of wood pieces/meter in both rural and forest adjacent stream channels that have low (<0.01) and moderate (>0.01 and <0.04) slopes. Stream channels in agricultural lands have far less wood debris than in forested and rural residential areas; the average and maximum number of pieces per 100 meters in agricultural stream channels is 70% less than what is found in stream channels in forested and rural residential lands.

The basin has sustained substantial losses to both summer and winter juvenile coho rearing capacity, although there have been greater losses in winter rearing capacity. Summer juvenile coho rearing capacity in the 1990's is 65% of the 1933 estimate (~1.5 million smolts in 1933 compared to 0.97 million in the 1990's). Potential winter production has been reduced even more, to 31% in the 1990's of that in 1933 (~ 3.1 million in 1933 and 0.97 million in the 1990's). These figures mean that, historically, summer rearing capacity limited coho. Currently, either summer or winter rearing capacity can limit coho. Spawning habitat is currently not a limiting factor in 98% (71 out of 72 streams) of the streams evaluated in the field.

Historically, summer coho rearing was distributed, in decreasing amount, in tributaries, beaver ponds, and side-channel sloughs. Winter coho rearing, in descending quantity, was from beaver ponds, tributaries, side-channel sloughs, distributary sloughs, and tributaries. Over 95% of summer and winter rearing capacity loss (~250,000 and 700,000, respectively) is from loss of beaver ponds, side-channel sloughs, and tributary habitats. The loss in production from these habitats changed their relative importance. For example, beaver ponds and sloughs formerly produced over 75% of the juvenile winter coho. Currently, beaver ponds and tributaries produce over half of the winter production. Tributaries and main stem habitats now account for less than two-thirds of summer production. Correspondingly, tributaries and mainstems have gained in relative importance.

The estimated juvenile coho rearing capacity is 11% to 33% higher than previous estimates, although the lower range of our estimate overlaps with the upper or average of two of the three previous estimates. Our higher estimates are likely due to more accurate and extensive fish use data; we found that fish use in small tributaries has been previously underestimated by 30% to 70%, in different watersheds. In addition, we made more detailed estimates of the amount of coho production from beaver ponds.

The land uses responsible for most habitat loss—over 90% of summer and winter coho smolt loss—are diking and channel straightening, which cut off floodplain channels and narrowed or shortened mainstem channels, and the filling of floodplain channels. Other impacts are more important in small tributary habitat, primarily habitat degradation (including pool loss) due to forest practices, and culverts which block access to habitat. Blocking culverts is particularly important in the Stillaguamish because tributaries currently produce more than any other habitat type. Approximately 37% of summer and 21% of winter coho loss in tributaries is due to blocking culverts.

We recommend an overall goal for restoring coho in the Stillaguamish River be that of maintaining and restoring watershed processes that form and maintain habitat. Objectives include focusing protection efforts on habitat types and watersheds having a relatively high rearing value, and targeting restoration activities where the largest benefit can be made relative to cost. Planners must have knowledge of historic habitat condition, specific habitat requirements, and habitat-forming processes to successfully achieve restoration objectives.

Coho habitat *protection* efforts should focus on all habitat types, with priority given to those most critical to juvenile salmonids—beaver ponds, tributaries, sloughs, and main stem habitats. Research is needed on how juvenile salmonids use mainstem habitats, because of the growing relative importance of mainstem habitat as the amount of other habitats types has diminished. Protection efforts might include greater enforcement of existing regulations, purchase of properties that include critical habitats, and incentives for landowners to protect habitats from further degradation.

Coho habitat *restoration* efforts should focus on creating beaver pond habitat, reconnecting and restoring slough habitats, and reestablishing access to habitat blocked by culverts in small, low-gradient tributaries. Areas identified as having historically high densities of beaver ponds, such as low gradient tributaries on or along a floodplain, are critical areas for developing beaver ponds. Restoring isolated or degraded sloughs also can potentially recoup large amounts of habitat and production. For example, reconnecting two former lower-river mainstem meander bends, now large side-channel sloughs, can increase juvenile coho rearing capacity by more than opening all known culvert blockages. Reconnecting small, low gradient tributary habitat by removing or replacing blocking culverts is also important, even though benefits may not be as great as restoring sloughs and beaver ponds. Culvert blockages have been systematically identified and prioritized, and correcting culvert problems typically have low costs and large habitat gains.

Riparian restoration work should focus on reestablishing large conifers. Replanting is necessary because of the systematic decrease in conifers in the Stillaguamish riparian zone over the last century. The loss of conifers has resulted in a loss of small and large-scale channel structures (e.g., wood along banks, and forested islands, both of which create edge habitat), and subsequent habitat diversity. Landslides triggered by forest practices, in combination with riparian logging, have caused numerous large tributaries to widen and aggrade at some point in the last 50 years. Focusing conifer reestablishment efforts on streams that have widened and aggraded in past decades because of their trend toward stability.

Regional experience suggests that successful restoration planning can be undertaken in five steps. The first step is to identify an overall restoration goal, and the second is to assess habitat losses, steps undertaken in this study. A third step is to identify potential proj??ects and their potential strengths and weaknesses, or costs and benefits. A series of questions that can help with step three include asking - (a) What is the local management objective? (b) Assuming that the local objective is the maintenance and recovery of depressed stocks, what is the historic and current limiting factor for that stock? (c) What are the physical & biological processes that create and maintain critical habitat types for that stock? (d) Does the project focus on a location that can be utilized sooner rather than later? (e) Are there other issues (e.g., productivity due to lack of food) that need to be dealt with first or simultaneously? (f) Besides the benefits related to the objective, what other kinds of benefits can be gained from the project? Step four is to rank each project based on the existing information. The final step is to determine project feasibility.

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CHAPTER 1: INTRODUCTION

Purpose and Approach

The goal of this study is to develop information on the historic and current coho salmon habitats in the Stillaguamish River basin. This information is necessary for planning to protect and restore freshwater salmon habitat in the basin, with an emphasis on coho. A secondary goal is to identify priority actions to stabilize and recover the coho population. The study focuses on actions aimed at maintaining and restoring landscape processes that form and create salmon habitat. It also prioritizes general actions based on predicted benefits for the recovery of depressed Stillaguamish coho stocks.

An assessment of habitat losses is fundamental to setting protection and restoration goals. Our habitat loss methodology is similar to that used by Beechie and others (1994) in the Skagit River basin. We quantify historic freshwater coho rearing habitat and identify from this the physical factors that limited coho smolt production. We use information from the earliest aerial photographs (1933) to identify historic habitat types. This information also suggests desired future conditions and causes of prior habitat degradation. We also quantify current freshwater coho rearing habitat and identify physical factors limiting current coho smolt production. We then compare the historic and current estimates of coho smolt production and limiting factors. We relate potential coho smolt production for physical rearing habitat types (e.g., sloughs, beaver ponds) to land-uses (e.g., agriculture, urbanization, and forestry). We also qualitatively discuss changes to habitat quality, such as sediment supply, riparian alteration, and stream temperature.

The current and historic estimates of production within the context of habitat-forming processes help identify types of relevant restoration activity (Beechie and others, 1996). Specific projects can then be prioritized using an assessment of the amount of critical coho habitat gain relative to project cost. Habitat forming processes are also important in prioritizing projects because they create spatial and temporal constraints.

Study Area

The 1,770-km2 Stillaguamish River basin extends from sea level to 2,086 meters in the Squire Creek drainage (Figure 1-1). Average annual rainfall ranges from 76 cm/yr to 381 cm/yr (USGS, 1984). Lower elevation forests (less than 700m) are within the western hemlock zone (Franklin and Dyrness, 1973). Dominant conifer species in these forests are western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and Sitka spruce (*Picea sitchensis*). Deciduous trees include red alder (*Alnus rubra*), black cottonwood (*Populus trichocarpa*), and bigleaf maple (*Acer macrophyllum*). Middle elevation forests, higher than 700 m, are in the silver fir (*Abies amabilis*) zone, and higher elevation forests (greater than 1300m) are in the alpine fir (*Abies lasiocarpa*) zone.

According to data from Washington Department of Natural Resources, Snohomish County Surface Water Management, and the Tulalip Tribes Natural Resources Department, there are 1,432 kilometers (890 miles) of anadromous stream habitat in the basin, or about 31% of the network of third order or higher streams (Figure 1-1, Table 1-1 and Figure 1-2). Figure 1-2 indicates that the majority of "preferred" coho habitat (less than 0.04 channel slope) is associated with forest and agricultural lands. The majority of lowest gradient habitat (less than 0.01 channel slope) is in agricultural lands. According to 1991 land cover data, forestry accounts for over 60% of land use adjacent to all streams in the basin, including the streams above the anadromous zone (Figure 1-3). Rural residential accounts for an additional 22%, agriculture 15% and urban land use accounts for less than 2%.

Salmon streams are generally at elevations below 750 meters, as depicted by the white in Figure 1-4. Anadromous fish indigenous to the Stillaguamish include chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), steelhead trout (*O. mykiss*), cutthroat trout (*O. clarkii*), and dolly varden char (*Salvelinus malmo*). Stillaguamish adult coho enter the basin in the late summer and early fall, and spawn between the months of November and February. Eggs incubate for several months, and fry emerge from the gravel between March and April. Coho juveniles, in general, spend the summer in the areas of emergence (Beechie and others, 1994; Sandercock, 1991). Between September and October juvenile coho, in general, migrate with the first high flow events to winter rearing areas from 2 to 38 km downstream (Scarlett and Cederholm, 1984). Coho salmon normally rear in freshwater for one to two years, smolt, and migrate from their winter rearing area to salt water between March and April (Beechie and others, 1994).

Figure 1-1 - Location of the Stillaguamish River basin and major rivers.

Table 1-1 - Stillaguamish River basin – Streamside land use in the anadromous zone (Source: Snohomish County Surface Water Management, 1991)

Land use	**Streamside land use (kilometers)**	**Total stream kilometers**
Urban	32	**2%**
Rural	322	**22%**
Agriculture	209	**15%**
Forestry	869	**61%**
Total	**1432**	**100%**

Figure 1-2 - Stream kilometers by stream channel slope and streamside land use in the Stillaguamish River basin anadromous zone.

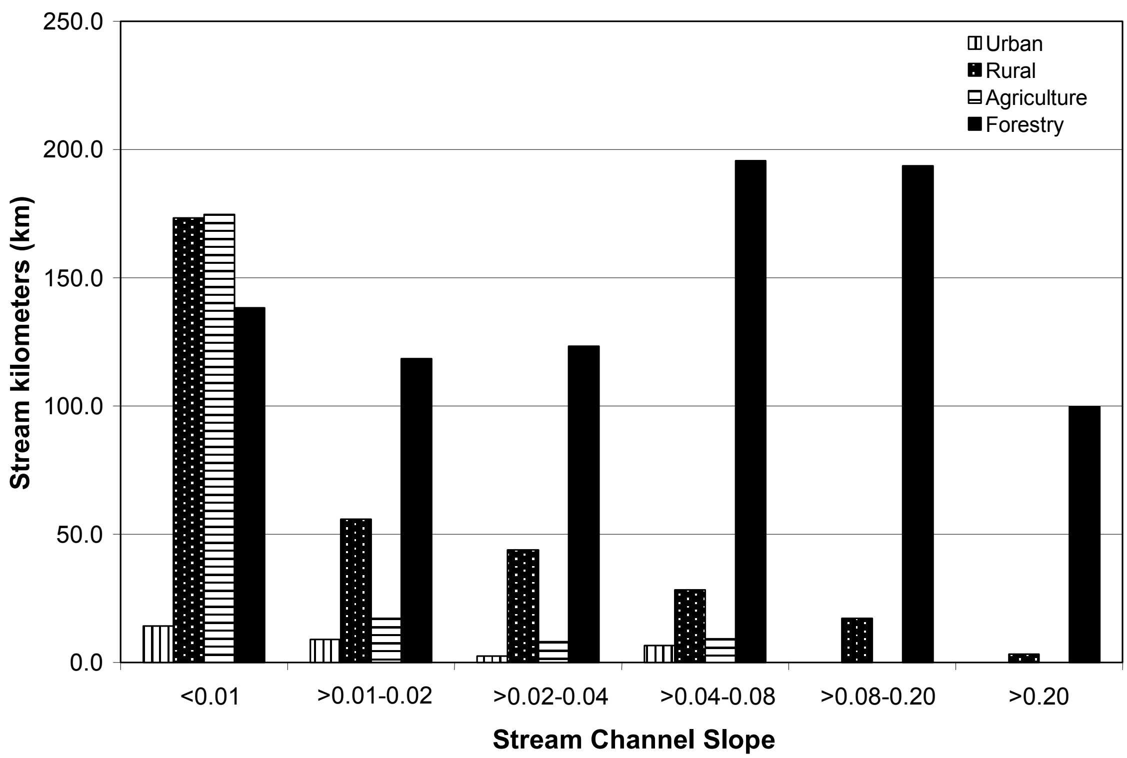


Figure 1-3 – Streamside land use in the Stillaguamish River basin
(Source: Snohomish County Surface Water Management, 1991)

Figure 1-4 - Extent of current coho salmon upstream migration
(Source: Williams and others, 1975; Pess and others, 1998)

CHAPTER 2: CHANGE IN HABITAT QUANTITY

Approach to Identifying Habitat Types and Impacts

We identified habitat types with a combination of field measurements; 1:24,000-scale U.S. Geological Survey (USGS) topographic maps (1978), 1:12,000 scale ortho-photos (1991), 1:24,000 scale aerial photos (1995), the National Wetlands Inventory maps (1989), and the Washington Department of Natural Resource hydrography layer (1992).

Habitat types include: 1) side-channel sloughs, 2) distributary sloughs, 3) small tributaries, 4) large tributaries and main stems, 5) lakes (greater than 5 ha), and 6) ponds (less than 5 ha) (Beechie and others, 1994). *Side-channel sloughs*, sometimes called flood overflow channels, diverge and reconnect to a mainstem, usually occur on a floodplain, or on the lowest terrace near a main stem (Beechie and others, 1994). *Distributary sloughs* are similar to side-channel sloughs except they do not reconnect with a mainstem, instead flowing directly into an estuary. Small tributaries have a summer low-flow width of less than 6 meters; channels more than 6 meters wide are large tributaries or mainstems (Beechie and others, 1994). We compared habitat area estimates from 1991 and 1995 to estimates from the earliest aerial photographs (Pacific Aerial Surveys, 1933), orthophotos (1942), and maps (Army Corps of Engineers, 1930).

We inventoried beaver ponds throughout the anadromous zone. The open water area of every beaver pond was estimated from 1991 (1:12,000-scale) aerial photographs. Area estimates include only open water bodies. Narrow channels, canals, or open water partially filled with emergent vegetation were not estimated. Ponds that could be reasonably accessed were field visited to determine if aerial photographic measurements were comparable to field measurements. Aerial measurements were within 5% of field measurements.

We could not use the earliest photos to estimate historic beaver pond area, so we developed a model to estimate the historic distribution of beaver ponds. The model applies historic beaver density estimates from the literature and trapping records from the late 1800s to potential beaver habitat for the existing stream channel network. Potential beaver habitat is based on stream gradient, stream channel confinement, and discharge and incorporates portions of the basin that no longer has beaver populations (see Appendix C for details).

Types of land use impacts to habitat include 1) blocking culverts, 2) hydromodification, and 3) impacts in streams that have not been hydromodified, grouped together as "non-hydromodified" reaches (Beechie and others, 1994). Hydromodified reaches are areas that have been affected by diking, ditching and channelization, dredging, and bank protection, while non-hydromodified reaches include impacts such as the loss of wood debris and subsequent loss of pool area, and large scale changes in sediment loads (Beechie and others, 1994). The Tulalip Tribes and Stillaguamish Tribe recently completed a study that identifies blocking culverts (1996). There are no dams in the basin.

Overview of Habitat Gains and Losses

Beaver ponds and sloughs (e.g., distributary and side-channel) account for most of the habitat loss (Table 2-1, Figures 2-1 and 2-2). Beaver pond area in 1995 is 7 to 20% of the area estimated for 100 years prior. Slough habitat is 19 to 41% of the area measured for ~1930. Mainstem, lake and tributary habitat have increased 7% to 25%, due to installation of a fish ladder in 1956 at Granite Falls that allows anadromous salmonids access to the upper South Fork, which has a number of lakes that are now accessible to anadromous fish.

Table 2-1. Estimates of historical and present areas or lengths of summer coho salmon rearing habitats in the Stillaguamish basin.

Habitat type	Historic (ha)	Current (ha)	Change (ha)	**Percent Change**
Side channel Sloughs	52	21	-31	**-59%**
Distributary Sloughs	40	8	-32	**-81%**
Tributaries	208	222	+14	**+6%**
Mainstem	131km	168km	+37km	**+28%**
Lakes	195	237	+42	**+22%**
Ponds	474	44	-430	**-91%**

Figure 2-1. Estimates of historic habitat area (ha) of summer coho salmon rearing habitat in the Stillaguamish River Basin

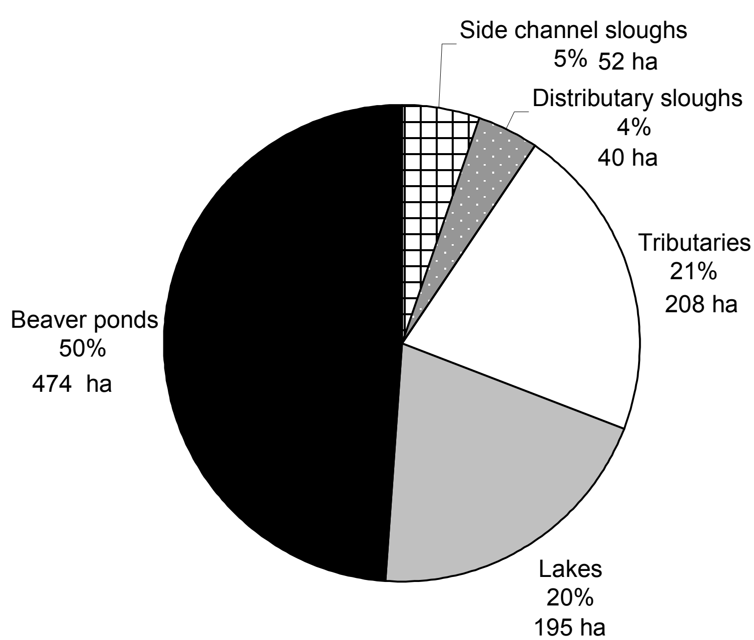
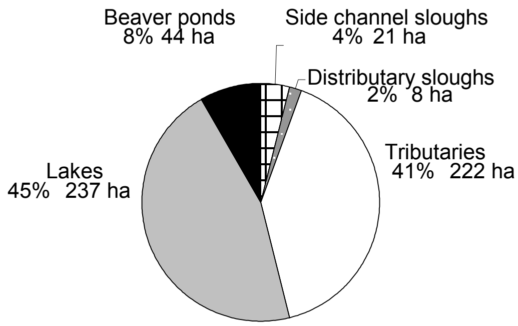


Figure 2-2. Estimates of current habitat area (ha) of summer coho salmon rearing habitat in the Stillaguamish River Basin



Between 100 and 600 ha of beaver pond area has been lost, depending on which beaver density estimate (2 to 16 dams/stream kilometer) from the literature is used to estimate 1800s conditions. We use the most conservative density estimate of 2 dams/stream kilometer (see Appendix C).

Measured ~1930 slough habitat was over 90 ha (Table 2-1). Since then, over 60 ha of side-channel and distributary slough habitat has been eliminated. Some of this habitat still exists but is disconnected from the mainstem. Our estimates of slough habitat loss are similar to those for the Skagit basin, where nearly 70 ha was eliminated in the past century (Beechie and others, 1994).

Tributary habitat increased 7% due to fish access to the upper South Fork Stillaguamish above Granite Falls. The increase in tributary habitat length, however, did not result in an overall increase in potential smolt production because of habitat degradation. There was an overall decrease in tributary juvenile coho rearing capacity due to the loss of pool area. Loss of pool area is due to the removal and reduction of wood, the loss of wood recruitment due to riparian timber harvest, and pool filling due to an increase in sediment supply. Similar to the Skagit study, losses were highest in areas dominanted by forestry activities because there is a much greater length of tributaries in forestlands than in agricultural, residential, or urban lands.

Changes to the Basin-Wide Distribution of Habitat

Habitat losses have occurred in all parts of the basin. Historically, habitat losses progressed up-river. In the estuary, or the lowermost part of the watershed, there has been a loss of over 30 ha of distributary slough habitat, or more than four-fifths of the amount present in 1886 (Table 2-2, Figures 2-3 and 2-4). The main reason for this loss is that the old mainstem was abandoned when the channel cut into Hat Slough (formerly "Hatt's Slough) in the early 1900s (see appendix B for detail). Hat Slough was formerly a secondary distributary channel. As a result, the Old Mainstem narrowed substantially and Hat Slough widened correspondingly. The area is significantly less because Hat Slough is much shorter than the old mainstem. Most of the change occurred between 1886 and 1930, but the Old Mainstem continued to narrow from 1930 to 1991.

Blind tidal channels in tidal marsh are also important habitat that has been lost. However, we did not include this loss in the present analysis, because the habitat is primarily important to other juvenile salmonids such as chinook, pink, and chum salmon (Levy and Northcote, 1982). Preliminary estimates are that about one-sixth to one-seventh of the original area of blind tidal channels remain (Appendix B).

Table 2-2. Historic and 1995 areas or lengths of summer coho salmon rearing habitats in three sub-areas of the basin.

Habitat type	Historic (ha)	Current (ha)	Change (ha)	Percent Change
Side-Channel Slough	52.0	21.3		
Estuary	4.5	0.7	-3.8	-84%
Lower Stillaguamish	32.1	9.7	-22.4	-69%
Forks	15.4	10.9	-4.5	-29%
Distributary Slough	39.7	7.7	-32.0	-81%
Estuary	39.7	7.7	-32.0	-81%
Tributary	207.6	211.7		
Estuary	2.2	2.0	-0.2	-9%
Mainstem	54.4	42.7	-11.7	-22%
Forks	151.0	177.0	+26	+17%
Mainstem	131.7km	170.4km		
Estuary	14.8 km	6.4 km	-8.4 km	-67%
Lower Stillaguamish	27.7 km	24.4 km	-3.3 km	-11%
Forks	89.2 km	139.6 km	+50.4 km	+56%
Lakes	195	237		
Estuary	1.2	1.2	0.0	0%
Lower Stillaguamish	96.8	91.8	-5.0	-5%
Forks	97	144	+47	+35%
Ponds	474	44.1		
Estuary	8.5	0.0	-8.5	-100%
Lower Stillaguamish	144.4	13.0	-131.4	-91%
Forks	321.1	31.1	-290	-90%

Figure 2-3. Estimates of historic habitat area (ha) of summer coho habitat in the Stillaguamish River estuary

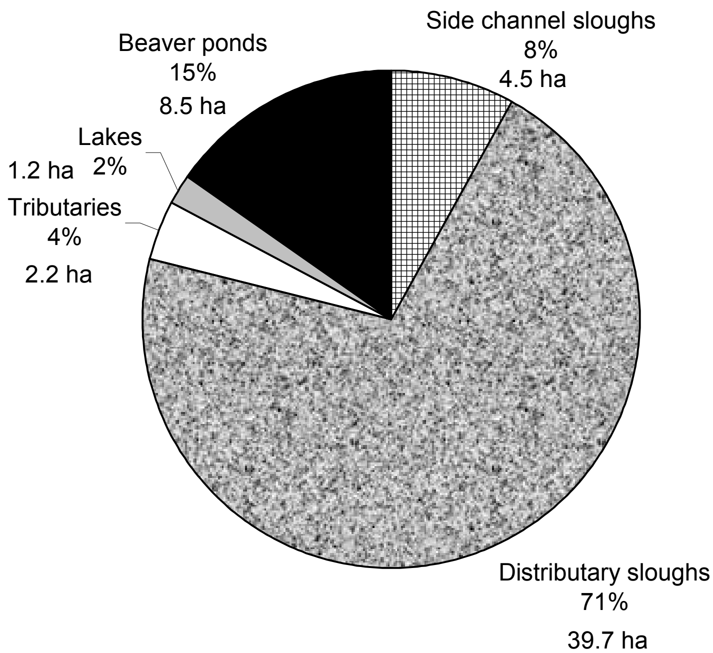
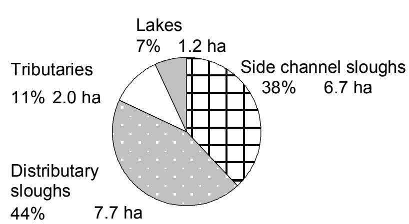


Figure 2-4. Estimates of current habitat area (ha) of summer coho habitat in the Stillaguamish River estuary



The largest loss in habitat in the lower Stillaguamish is of side-channel slough habitat and of beaver ponds. Downstream of the forks and upstream of the estuary, nearly twice as much side-channel slough area was lost compared to the amount lost in the forks (Table 2-2**,** Figures 2-5 and 2-6). Losses to side-channel slough habitat in the lower Stillaguamish account for 62% of the total loss of such habitat in the Stillaguamish basin. If side-channel slough lost in the estuary is included with the lower river, the total loss downstream of the forks is 70% of the amount of side-channel slough that was present in ~1930.

Cut off side-channels and the rerouting of a tributary (Portage Creek) into a former slough account for more than four-fifths of total channel area lost in the lower Stillaguamish (Figure 2-2). In the late 1800s, Portage Creek was rerouted into a side-channel, which connected to the Stillaguamish at river mile (R.M.) 13.5. The slough runs along the southeast portion of the valley floor, and reconnects to Cook Slough at Cook Slough RM 1.8. There was an 18% loss in tributary habitat in the lower Stillaguamish, with most being from the tributaries on the flood plain.

The losses to beaver pond area in the lower Stillaguamish is even greater, with more than 90% of the conservative historic estimate lost by 1995 or 131 ha of the original estimated 144 ha (Table 2-2, Figures 2-5 and 2-6). Most loss to beaver ponds is from trapping, in combination with the conversion of forested streamside areas to agriculture. The number and extent of beaver pond habitat is, currently, kept low by the annual removal of 200 to 300 beavers per year in the Stillaguamish River basin (see appendix B for detail).

All of these habitat losses in the lower Stillaguamish—to sloughs, beaver ponds, and tributaries—are due to floodplain land uses. Prior to extensive forest removal we found that the flood plain consisted of alder, hemlock, spruce, cedar, bigleaf maple, Douglas fir, cottonwood, vine maple, and willow (see Appendix D). Approximately 38% of the trees surveyed by the General Land Office (~1870) were estimated to be less than 60 years of age, while 31% were between 61 and 199 years, and 31% were greater than 200 years old. Today, much of the floodplain downstream of the forks is either devoid of trees (approximately 75%), or is largely composed of small hardwood stands that are less than 60 years old trees (approximately 75%), or is largely composed of small hardwood stands that are less than 60 years old.

Figure 2-5. Estimates of historic habitat area (ha) of summer coho habitat in the lower Stillaguamish River

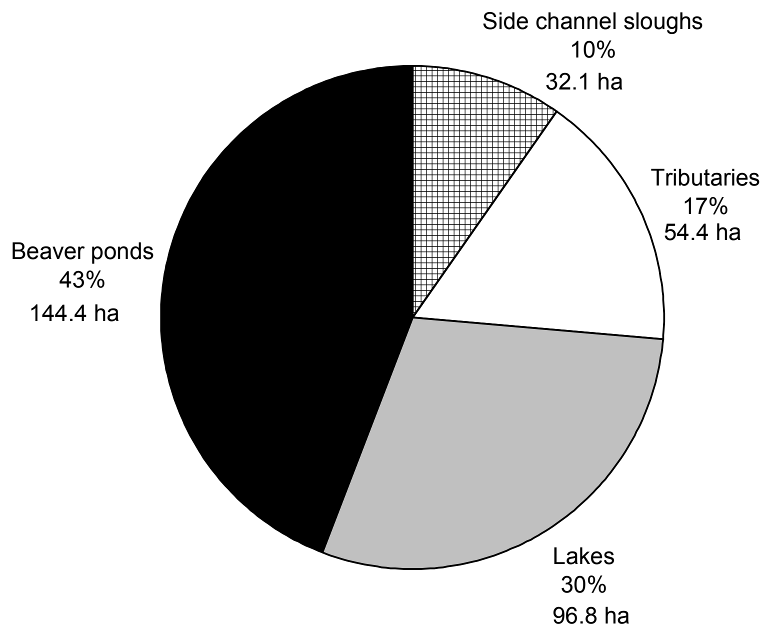
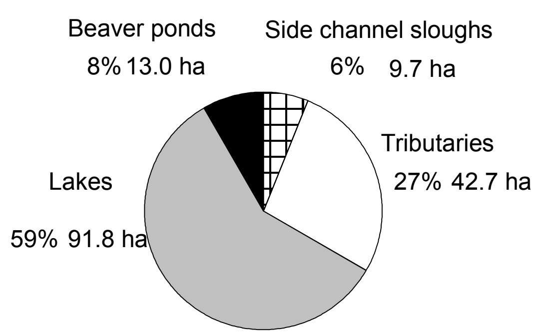


Figure 2-6. Estimates of current habitat area (ha) of summer coho habitat in the lower Stillaguamish River



There was also a modest loss in mainstem channel area from the lower Stillaguamish. The river shortened overall from 37.9 km in 1933 to 33.9 km in 1991. The active channel also narrowed in all reaches from 1933 (average width of 145 m) to 1991 (average width of 100 m). As a consequence of the shortening and narrowing, there is 37% less channel area, or 185 ha less channel area in 1991 compared to 1933 (see Appendix B for more discussion of this and other explanations). Most of the shortening is from the cutoff of two meanders between 1937 and 1941. The narrowing appears to relate to construction of levees. Approximately two-thirds of the main stem has bank protection (Appendix B).

Habitat losses in the forks are similar to the lower Stillaguamish, with large losses in beaver pond and side-channel slough area (Table 2-2, Figures 2-7 and 2-8). Most of the floodplain sloughs lost along the two forks are side-channel sloughs that were filled (Appendix B). Loss of side-channel slough habitat can be attributed to the combined effects of flood plain conversion to agricultural and bank protection. The Granite Falls fish ladder has increased available tributary, mainstem, and lake habitat in the South Fork. However, while the fish ladder has increased mainstem habitat overall, mainstem habitat in the historic North and South forks anadromous zone has decreased since 1933.

Figure 2-7. Estimates of historic habitat area (ha) of summer coho habitat in the North and South Fork Stillaguamish River

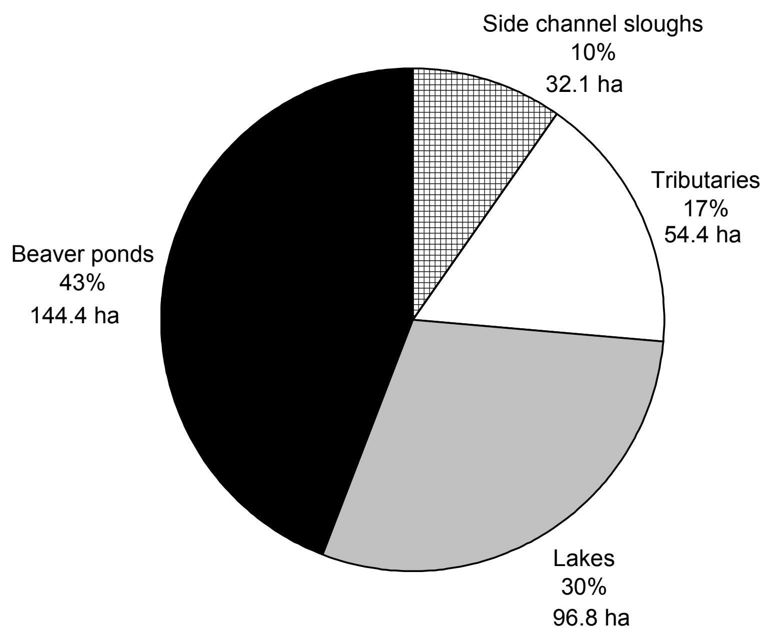
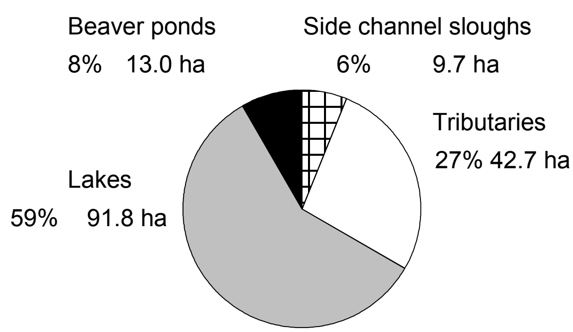


Figure 2-8. Estimates of current habitat area (ha) of summer coho habitat in the North and South Fork Stillaguamish River



Land Use Causes of Habitat Loss

The vast majority (~85%) of lost juvenile coho summer and winter rearing capacity is due to the draining and filling beaver ponds and other wetland areas. The main portion of this loss occurred in the lower Stillaguamish and North and South Forks. Channel straightening makes up over 5% of the remaining habitat loss. Most of the channelization occurred in the estuary for agricultural purposes. Channels that have been cut-off or filled in the lower Stillaguamish and forks account for approximately 5% of the habitat loss. Tributary habitat has been primarily altered by habitat degradation due to forest practices, culvert blockages, and channelization. We narrowly define habitat degradation due to forest practices as loss of pool habitat due to loss of wood because of timber harvest or land conversion in the riparian zone. Habitat degradation and culvert blockages are the primary cause of summer coho smolt loss in tributaries.

Table 2-3 – Land-use causes of habitat loss in the Stillaguamish River Basin.

	Habitat Lost (ha)				
Land Use Cause of Habitat Loss	**Estuary**	**Lower Stillaguamish**	**North and South Forks**	**Tributaries**	**TOTAL**
Culvert Blockages	0	0	0	4.4	4.4
Cut-off channels	2.4	13.9	0.3	0	16.6
Filled channels	1.4	7.6	3.2	0	12.2
Channelized/Straightened	32.0	0.9	0.8	1.1	34.8
Fill and drain ponds/lakes	8.5	136.4	290.0	0	434.9
Forest Practices	0	0	0	6.4	6.4
TOTAL	**44.3**	**158.8**	**294.3**	**11.9**	**509.3**

CHAPTER 3: CHANGE IN COHO SMOLT PRODUCTION

Approach

Coho smolt production capacity is the expected number of smolts produced from the available habitat area for summer and winter (Beechie and others, 1994). Each habitat type is assigned a potential smolt production estimate (smolts/m^2) from published values or local data (Table 3-1).

Estimates for the useable area factor, rearing density, and survival to smoltification come from Beechie and others (1994) and Reeves and others (1989) (Table 3-1). Estimates of potential winter smolt production will be less if the average winter stream temperature is less than 7°Celsius (Reeves and others, 1989). Several data sources in the Stillaguamish indicate that the average winter stream temperature is less than 7° Celsius. Average winter stream temperature collected from 1976 to the present at a local hatchery is less than 7° Celsius. Thermograph data collected throughout the entire basin by Snohomish County Surface Water Management, the Tulalip Tribes, and the Stillaguamish Tribe during the winter of 1996, and spot stream temperature measurements collected throughout two winters, also average less than 7° Celsius.

We completed quantitative physical fish habitat surveys for 9% (65.3 km out of 706 km) of the preferred coho habitat area (see Appendix A for details). We focused on these areas because juvenile and adult coho use was considerably higher in channels with slopes less than 0.04 than those greater than 0.04 (The Tulalip Tribes, unpublished data) (Table 3-1). We use channel unit data from the habitat surveys to estimate potential summer and winter coho smolt production. We then extrapolate the data to other stream segments that have a similar stream channel slope, confinement, and channel type. We did not extrapolate to channels with slopes greater than 0.04 (step-pool habitat) (channels with gradients greater than 0.04) because the majority of stream reaches surveyed were less than 0.04, and were either forced pool-riffle or plane-bed channel types. We field-verified an additional 15% (118km) of the preferred coho habitat zone. This survey consisted of basic field measurements such as stream gradient, bankfull width, and channel type. Altogether, approximately 25% (183 km out of 706 km) of the preferred coho habitat area was surveyed.

Table 3-1 - Habitat surveys in small & large tributaries. Mainstems are excluded.

Channel Slope	Surveyed with Quantitative Methods (km)	Surveyed with Qualitative Methods (km)	Extrapolated (km)	Total Length (km)
<0.01	19.2	24.3	284.8	328.3
>0.01-<0.02	8.2	28.2	164.1	200.5
>0.02-<0.04	25.7	49.6	102.3	177.6
Total Length	**53.1**	**102.1**	**551.2**	**706.4**

To estimate historic coho production from small and large tributaries we use a useable area factor, rearing density, and survival to smoltification from Reeves and others (1989) (Table 3-2). Estimates for present-day coho production are also from Reeves and others (1989), but include more detailed data on useable area and potential smolt production in different channel units such as different pool types (e.g., lateral-scour pool, dam pool, etc.), riffles, and glides.

To estimate small tributary habitat loss, we use a study that identified culverts blocking juvenile and adult coho passage conducted by the Tulalip Tribes and Stillaguamish Tribe (1996). Approximately 500 culverts were field surveyed in the anadromous zone for gradient, condition, and blockage potential. Over 60 were identified as a coho blockage. Quantitative fish habitat surveys were conducted as part of the culvert study, upstream of each culvert to determine the amount of habitat blocked and the potential coho production to be derived from fixing the blockage. Habitat and production estimates were then used to determine habitat and production lost due to improper culvert placement.

Table 3-2 - Habitat unit equivalents, parr densities, density-independent survival to smoltification, and smolt production estimates for six habitat types.

Habitat type	Useable area equivalent (units/m^2)	Parr density (parr/unit)	Survival to smolt stage	**Potential production (smolts/area or distance)**
Side Channel & Distributary Sloughs				
Summer	0.75	1.7	0.25	**0.319/m^2**
Winter	0.50	5.0	0.31	**0.775/m^2**
Small and Large Tributary				
Summer Pool	1.00	1.7	0.25	**0.425/m^2**
Summer Glide	0.70	1.7	0.25	**0.297/m^2**
Summer Riffle	0.50	1.7	0.25	**0.213/m^2**
Winter Pool	0.70	5.0	0.31	**1.085/m^2**
Winter Riffle	0.00			**0.000/m^2**
Mainstem				**600/km**
Pond				
Summer Pond (all sizes)	1.00	1.5	0.25	**0.375/m^2**
Winter Pond <500m2	1.00	5.0	0.31	**1.550/m^2**
Winter Pond >500m2	0.50	5.0	0.31	**0.775/m^2**
Lake				**25/ha**

It is difficult to estimate habitat and coho production losses in mainstems and large tributaries because their use by coho salmon is not well known (Beechie and others, 1994). There is no information on the seasonality of coho use in these habitats, so we use the same habitat value is used for each season. We use 600 smolts/km as an estimate for coho smolt production in main stems, as Beechie and others (1994) used in the Skagit. The estimate is from data collected on the Bogachiel River by the Washington Department of Fish and Wildlife (WDFW). The estimate is considered very conservative estimate, because the data ranges between 340 to 2,734 smolts/km (Beechie and others, 1994).

We calculate historic and current coho smolt production for individual beaver ponds using useable area equivalent, rearing density and surival to smoltification from Reeves and others (1989). We applied 25 smolts/ha to lake habitat, which is also based on Reeves and others (1989) (Beechie and others, 1994).

Overview of Historic Change to Smolt Production

We estimate total summer smolt production to have decreased by 42% (~1.49 million smolts compared to 0.97 million smolts), while total winter production has decreased by 71% (~3.10 million smolts compared to 0.97 million smolts) (Figure 3-1). Most loss in production reflects the loss of slower water, off-channel areas (beaver ponds, distributary sloughs, and side-channel sloughs) (Figures 3-2 and 3-3). Tributary and mainstem habitat has become relatively more important to potential smolt production. This increase is also because of the gain in habitat above the South Fork fish ladder.

Summer smolt production was greatest in tributaries and beaver ponds, followed by side-channel and distributary sloughs, and mainstems (Figure 3-2). Currently, mainstems produce more than sloughs, and tributaries contribute more than half of total number of summer smolts. Together, tributaries and mainstems account for 71% of the total summer amount. Historically, tributaries and mainstems produced less than one-third of the overall summer smolt potential. The greatest loss of summer smolt production is in beaver ponds, distributary slough, and side-channel slough habitat.

Winter productivity was greatest in beaver ponds and sloughs, which accounted for more than 75% of the winter coho smolt estimate (Figure 3-3). The greatest loss of winter condition smolt production is also in beaver ponds and sloughs however beaver ponds still remains the most important winter habitat. Tributaries now produce more than both slough types. Winter mainstem length and lake area production has increased.

Figure 3-1 - Historic v. current summer and winter coho smolt production from the Stillaguamish River basin

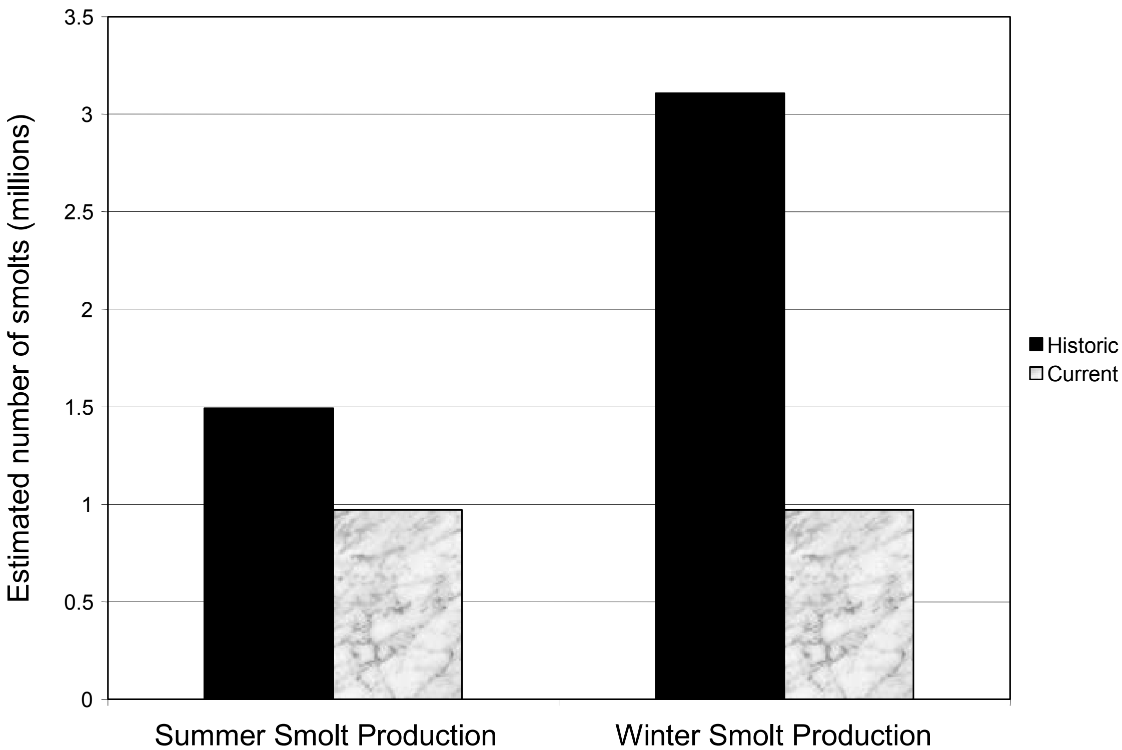


Figure 3-2 – Historic v. current Stillaguamish coho summer smolt production.

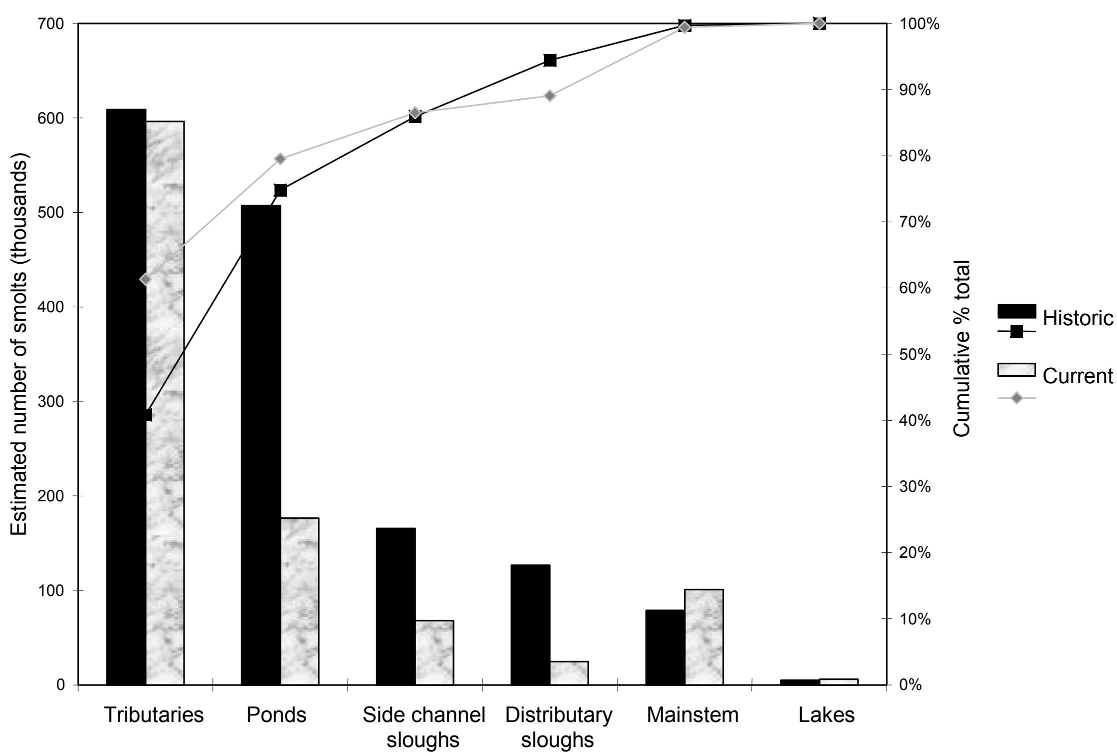
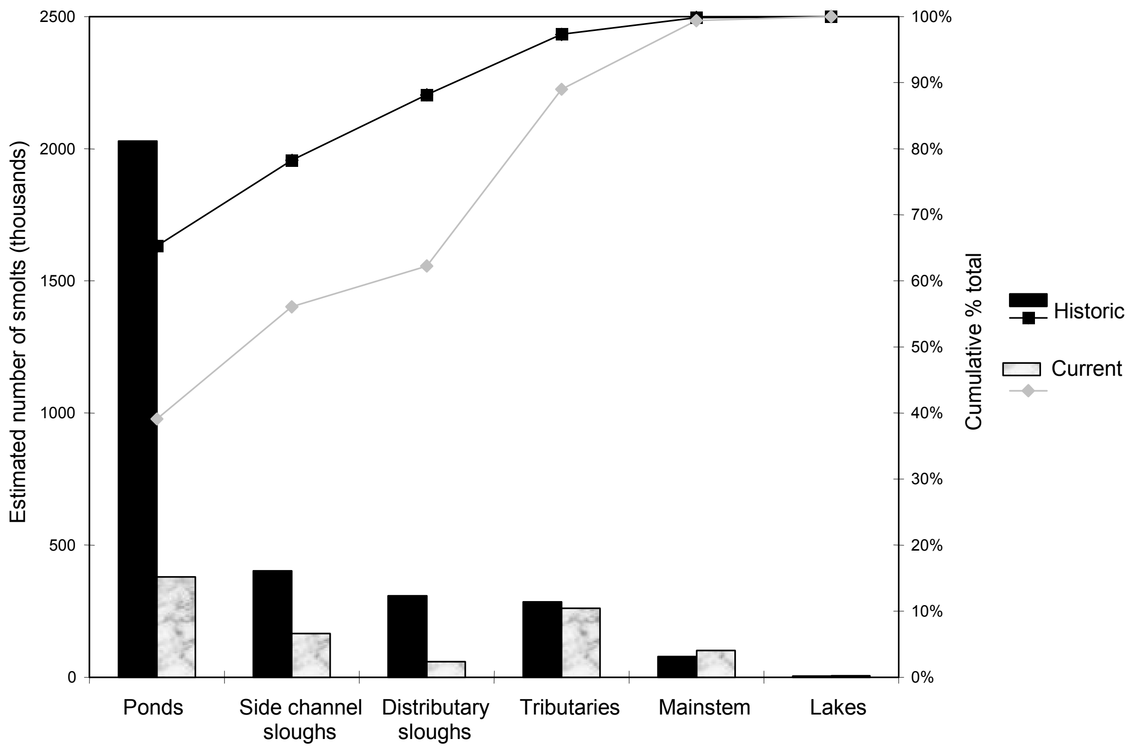


Figure 3-3 – Historic v. current Stillaguamish coho winter smolt production



Range of Production Estimates

Total seasonal coho production estimates vary between 5% and 37% based primarily on two values about which there is uncertainty—the amount of anadromous stream miles and the number of beaver ponds per channel length (Table 3-3).

Table 3-3 - Variation in total smolt production estimates.

	Summer Rearing		Winter Rearing	
	Historic	**Current**	**Historic**	**Current**
Tributaries	±46%	± 54%	± 38%	± 54%
Beaver Ponds	± 66%	± 0%	± 66%	± 0%
Total	± 22%	± 37%	± 5%	± 16%

Recent studies in western Washington show that stream type maps underestimate the length of fish-bearing channel network can be underestimated by as much as 70% (Bahls and Ereth, 1994; Loch and McHugh, 1998). This error stems from streams either not being on the map or misidentified as non-fish bearing. We estimate the amount of anadromous stream kilometers in the Stillaguamish River Basin using several different assumptions. Estimates can vary up to 54% depending on what assumptions are made. For our most conservative estimate we assume that all coho use habitat in stream reaches with a slope of less than 0.04. For our least conservative estimate we assume coho use up to a natural or known human-made fish barrier. The mean estimate assumes either no coho use for streams greater than 0.06 channel slope, or coho use up a natural or known human-made fish barrier. Extensive field work in the Stillaguamish suggests coho will go up to natural or human barriers, but juvenile and adult use will quickly drop off beyond a channel slope of 0.06. This suggests the mean to be the most accurate for when applied to the entire basin. Historic stream lengths and anadromous stream lengths were assumed equal to present stream lengths, except where there were known changes such as the construction of a fish ladder on the South Fork Stillaguamish, or known blocking culverts.

Historic smolt production estimates from beaver ponds vary by 66%, depending on assumed density of beaver ponds. We assume beavers used a currently unoccupied stream if it has the same characteristics of other streams presently occupied by beaver. This assumption is supported by field evidence; where beaver populations have been allowed to recover in the Stillaguamish, they saturate the landscape and utilize all available habitats. Field data collected in relatively undisturbed watersheds in the Stillaguamish suggests that beaver can build between 2 and 10 dams per kilometer of stream. This wide range of beaver pond densities is similar to historic beaver dam estimates in basins prior to European occupation (see Appendix C for details).

We assume that the average size of beaver ponds was similar to current pond sizes. This is a conservative assumption because historic populations were not subject to intense depredations from humans, thus were more stable and consequently able to maintain larger dams. Additionally, many prime beaver dam sites within the basin have been converted to agriculture and rural development, thus limiting beaver to more marginal sites (stream gradients greater than 4% and confined valleys).

Differences in Smolt Production within the Basin

Smolt production from the Stillaguamish estuary is less than at the turn of the century (Figures 3-4 & 3-5). The largest losses are from distributary sloughs. Summer smolt production potential decreased by over 100,000, and over 250,000 smolts for winter conditions. Beaver ponds and side-channel sloughs are the second largest loss, followed by mainstem and tributary habitats. Loss of each habitat type ranges between 62% to 100%, an amount that is comparable to loss in the Lower Stillaguamish, and greater than the forks.

The greatest losses in smolt production in the Lower Stillaguamish are from a decrease in beaver ponds, side-channel sloughs, and tributaries (Figures 3-4 & 3-5). This results in smolt production losses between 400,000 and almost 1 million, depending on whether it is summer or winter production. Between 68% and 94% of loss is due to loss of beaver ponds. Loss of side-channel sloughs has resulted in a decrease of 70,000 to over 200,000 smolts—a 70% decline. Tributary smolt production is 50% of estimated historic production for summer and winter conditions. This is a decrease of 40,000 to 80,000 potential smolts. Mainstem and lake production estimates for the lower Stillaguamish are 5 to 12% less than historic estimates.

In the North and South forks, there has been a decrease in beaver ponds, side-channel sloughs, and winter-rearing tributary habitat, but there has been an increase in main stem, lake, and summer-rearing tributary production (Figures 3-4 & 3-5). Decreases in beaver pond habitat production range between 64% and 94%, or a reduction of 0.2 million to over 3 million potential smolts, depending upon beaver pond density estimates. Side-channel slough habitat decreased by almost one-third (29%), while winter rearing production from tributaries is 9% less. Gains in mainstem and lake smolt production is more than 50% greater than historic estimates. Increased production from summer-rearing tributary habitat is 75,000 smolts, or 17% greater than historic levels. However, winter-rearing tributary production has decreased by 9% from historic levels despite gain in tributary area. This is due to the loss of key habitat types in the winter such as slower water pools and off-channel habitat (e.g., beaver ponds associated with tributaries and sloughs).

Figure 3-4 - Change in Stillaguamish coho summer smolt production by habitat type

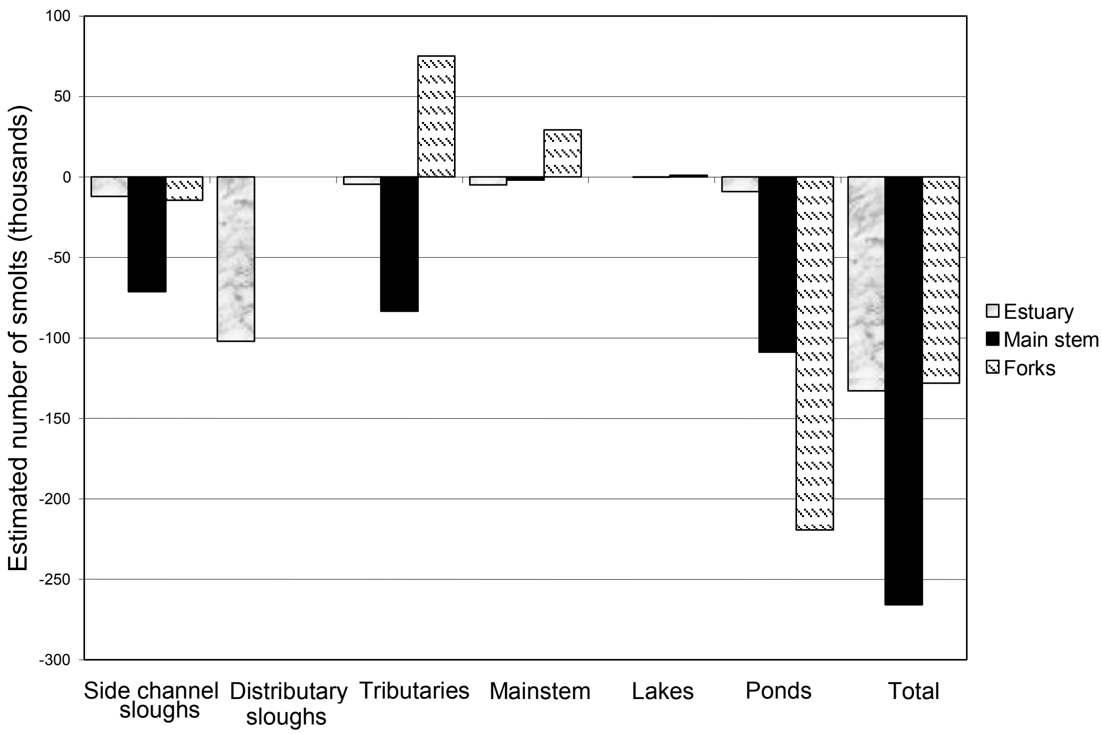
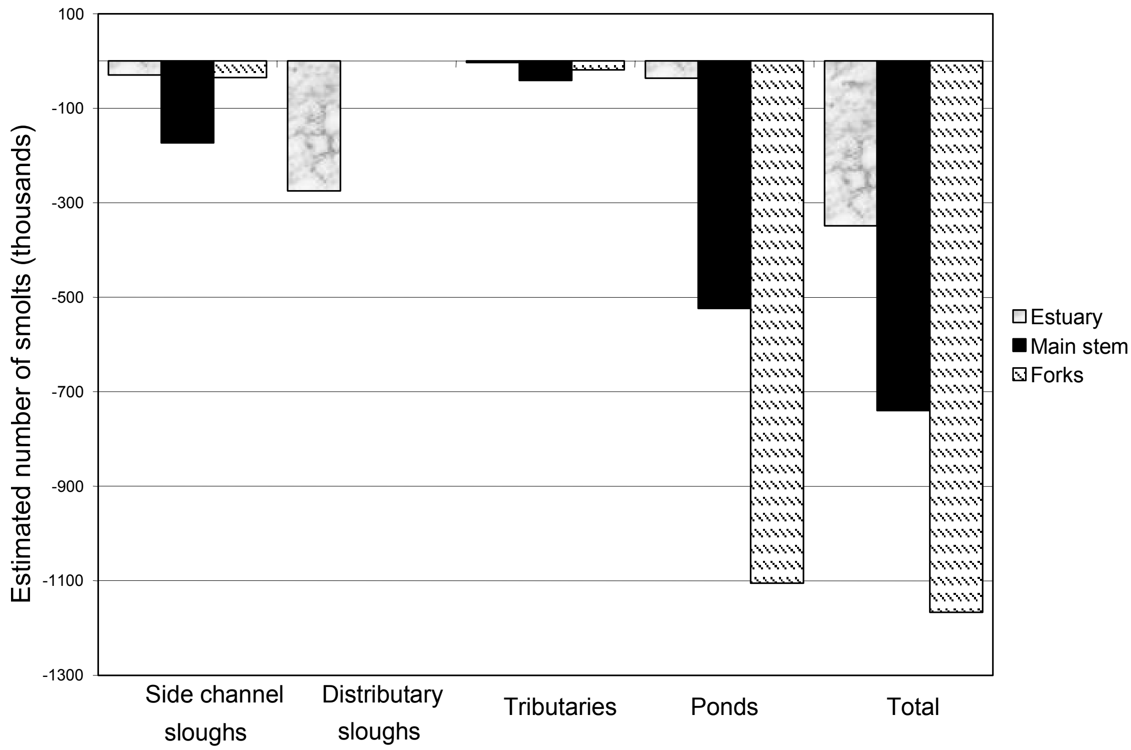


Figure 3-5 - Change in Stillaguamish coho winter smolt production by habitat type



Comparison of Smolt Production Estimates to Previous Estimates

Nelson and others (1997) estimated coho salmon smolt production in the Stillaguamish from coded-wire tag recoveries between 1986 to 1989 (Table 3-4). These estimates range from 514,680 to 826,297 smolts and average 649,081 smolts. Zillges (1977) estimated potential smolt production for the Stillaguamish at 864,094 using total accessible stream length for the entire basin. Seiler's (1984) two-year average estimate from scoop trap data was 388,253 (276,050 to 500,456 smolts).

Table 3-4 - Coho smolt production estimates for Stillaguamish River basin

Author	Mean	Minimum	Maximum	% Different Than This Study	Method
Pess and others	971,308	750,256 (summer)	1,193,899 (summer)	---	Limiting Factors Analysis
Nelson and others (1997)	649,081	514,680	826,297	-33% (±1%)	Coded Wire Tag Study
Seiler and others (1984)	388,253	276,050	500,456	-60% (±2%)	Scoop Trap
Zillges(1977)	864,094			-11%	Stream Length

Estimates from this paper compare favorably with the Nelson (1997) and Zillges (1977) estimates, but not to Seiler's (1984). Current smolt production estimates average 972,073 smolts (750,256 to 1,193,889) in summer habitats and 971,308 smolts (882,181 to 1,060,308) in winter habitats. The average for both summer and winter conditions is between 11% and 33% greater than Nelson and Zillges. There is an overlap between the distribution of each estimate. Our estimates are greater than the other estimates because we estimated a larger amount of available habitat area, and had more accurate data on beaver pond area. Habitat length and area estimates for Zillges were substantially less, while Nelson's habitat length and area estimates were more similar to what we used.

Land-use Effects

Hydromodification is the cause of more than 90% of lost summer and winter coho smolt production (Figure 3-6 and 3-7). Hydromodification includes channel filling, cut-off channels, diking, channelization, and the draining or filling of ponds. Beaver ponds are lost by a combination of trapping and subsequent pond draining and filling. Similar to the Skagit River, habitat loss from hydromodification is primarily related to protection of reclaimed areas for agricultural and residential uses (Beechie and others, 1994).

Small tributary habitat has also been altered by hydromodification, but other factors, such as habitat degradation due to forest practices and culvert blockages, also account for a large impact (Figure 3-8 and 3-9). We narrowly define habitat degradation due to forest practices as loss of pool habitat due to loss of wood because of timber harvest or land conversion in the riparian zone. Habitat degradation and culvert blockages are the primary cause of summer coho smolt loss in small tributaries. Winter coho smolt loss, however, is essentially due to hydromodification. Blocking culverts in small tributary habitat is an importrant because tributaries currently produce more than any other habitat type. Approximately 37% of summer and 21% of winter coho smolt production loss in tributaries is due to blocking culverts. There has been more loss of slow-water habitats, such as beaver ponds and sloughs, than mainstem and tributary habitats. As a result, there is a greater current dependence on coho production in mainstem and tributary habitats.

Assumptions and Limitations

Several important assumptions affect production estimates. Winter temperature and historic summer pool area estimates are two important factors (Beechie and others, 1994). The coho smolt production model estimates type of habitat used in winter according to average winter stream temperature (Reeves and others, 1989). Beaver ponds and backwater pools are the only habitat types that count towards winter smolt estimates when average winter water temperature is less than 7^{o} C. In warmer systems (those with an average winter water temperature greater than 7^{o} C), lateral scour pools and dam pools are also included as useable rearing area. Summer and winter survival rates are also greater for areas where average winter water temperature is greater than 7^{o} C. These assumptions result in higher estimated winter rearing densities for coho in areas where average winter stream temperature is less than 7^{o} C.

Several data sources in the Stillaguamish indicate that average winter stream temperature is less than 7^{o} C. Long-term average winter stream temperature data (1976 to present) collected at a local hatchery is less than 7^{o} C. In addition, thermograph data collected throughout the entire basin by Snohomish County Surface Water Management, the

Tulalip Tribes, and the Stillaguamish Tribe during the winter of 1996, and spot stream temperature measurements collected throughout two winters, also average less than 7^{o} C.

Estimated coho summer rearing densities in pools substantially decrease as pool area decreases (Reeves and others, 1989). Beechie and others (1994) point out that streams greater than 50% summer pool area have rearing densities that are two to three times as high as those with less than 50% summer pool area. We did not assume the entire basin to have greater than 50% summer pool area; instead we broke the basin down by watershed and channel type. As a result, we either measured summer pool area or predicted summer pool area based upon stream gradient, valley confinement, and channel entrenchment.

The model also assumes that spawning area is not a limiting factor, which we found to be the case in 71 of the 72 streams evaluated in the field. Percent spawnable area for Stillaguamish stream channels that have a stream gradient of less than 4% ranges between 0.1% and 20.0% and average 4.0%. The majority of spawnable gravels are in channels with a gradient less than 2%. It appears that summer rearing habitat can be fully seeded with the current amount of available spawning habitat, and that this would be the case even if there was an increase in early rearing survival rates (Beechie and others, 1994).

One assumption that can affect the conclusion that the watershed is not spawning limited is whether or not coho can redistribute themselves to use available summer and winter rearing area. We assume that all habitats can be seeded, regardless of location in the watershed. This means that fish spawning in one portion of the basin can redistribute themselves in other areas, so long as the habitat is available. Based on local (Nelson, 1997), and regional data (Peterson, 1982; Scarlett and Cederholm, 1984) this seems to be the case. For example, Nelson (1997) found that between 1986 and 1989, only half the coho smolt trapped and tagged in a particular stream in the Stillaguamish returned to spawn there. In addition, he found that approximately 4% of recovered tags where found in another sub-basin, in one case 70 km downstream of where the fish was tagged.

Scarlett and Cederholm (1984) found that 70% to 80% of juvenile coho in two tributaries of the Clearwater River basin in the Olympic Peninsula migrate from upstream to downstream areas during winter months. Juvenile coho would abandon mainstem and large tributaries during the winter months, and move into off-channel areas such as small tributaries and riverine ponds. Average travel distance downstream was 19 km, with a range between 5 and 41 km. It is hypothesized in the scientific literature that coho populations will redistribute themselves into such habitats during the fall and winter in response to conditions associated with higher flows such as an increase in velocities, turbidity, and bedload movement (Nelson, 1997; Scarlett and Cedeholm, 1984; Peterson, 1982).

Figure 3-6 – Proportion of summer coho smolt production losses due to three types of impacts on all habitat types in the Stillaguamish River basin.

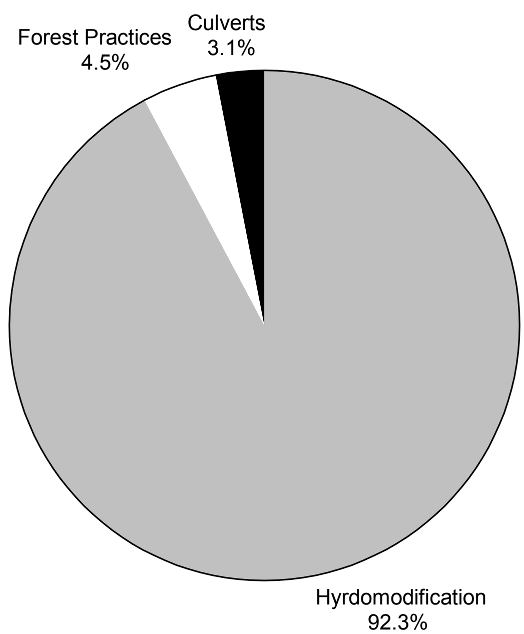


Figure 3-7 – Proportion of winter coho smolt production losses due to three types of impacts on all habitat types in the Stillaguamish River basin

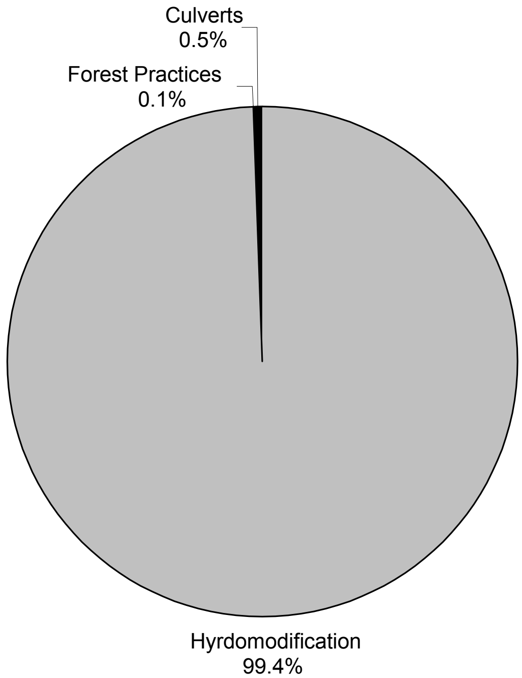


Figure 3-8 – Proportion of summer coho smolt production losses due to three types of impacts on small tributaries in the Stillaguamish River basin

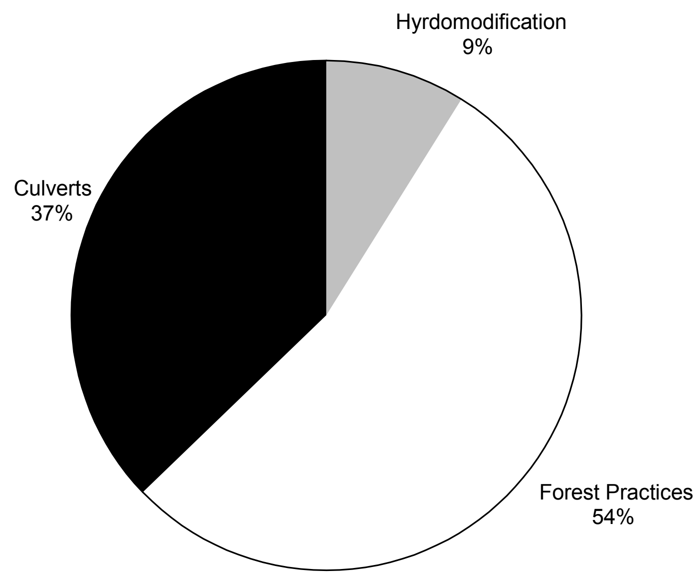
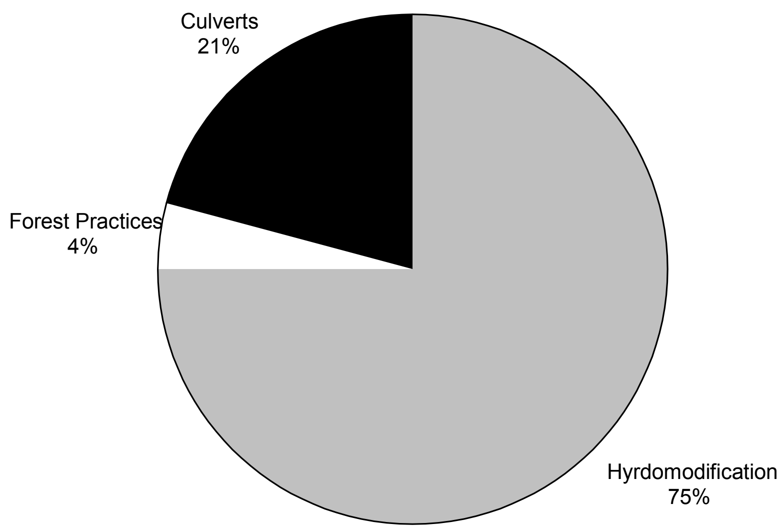


Figure 3-9 – Proportion of winter coho smolt production losses due to three types of impacts on small tributaries in the Stillaguamish River basin



CHAPTER 4: RESTORATION PLANNING

Restoration Strategy

We recommend the goal of Stillaguamish River basin restoration efforts be *to maintain and restore landscape processes that form and maintain salmonid habitat.* Further, restoration priorities should be *based on local management objectives, such as recovery of a depressed salmonid stock, in order to help focus the restoration goal* (Collins and others, 1994; Beechie and others, 1996).

Establishing the historic habitat condition, knowing specific habitat requirements, and understanding habitat-forming processes provides guidance in identifying specific habitat goals. Current habitat conditions provide a diagnostic to determine what specific habitat requirements are currently not being met. The synthesis of habitat-forming processes, historical condition, and current condition planning to:

1) Focus protection efforts on habitat types and watersheds that may have a relatively high production value, and
2) Prioritize and target restoration activity by largest benefit relative to cost (Beechie and others, 1994; Beechie and others, 1996).

There are various land use constraints on restoration (Beechie and others, 1996), such as landowners who do not want to participate, and areas where prime habitat occurs but which would be too costly to restore. Nonetheless, it is important not to compromise the scientific basis of recommendations, and to separate these constraints from the scientific basis of proposed actions. Explicitly identifying the reasons why one site is ranked over another is critical to prioritizing and monitoring the success of any action.

Restoring and Protecting Lost Habitats

Protection efforts in the Stillaguamish should focus on all habitat types, but most critical are those which are most important to existing coho smolt production. Restoration efforts should focus on protecting and creating beaver pond habitat, reconnecting and restoring slough habitat, and reconnecting small, low gradient tributary habitat (Table 4-1).

Loss of beaver ponds and sloughs accounts for 85% to 95% of overall lost winter and summer coho production. Beavers and beaver ponds are critical to recovery of the Stillaguamish coho. Beaver ponds can increase potential coho smolt production in a given area by 3 to 10 times. Areas identified as having historically high densities of beaver ponds, such as low gradient tributaries on or along a floodplain, are key areas for reintroducing beavers to allow for the creation of pond habitat. Land-use impacts on these habitat types have been the greatest because many of the activities that affect them are smaller-scale and unrelated, and subsequently more cumulative and difficult to regulate (Beechie and others, 1994). Types of efforts relevant to protecting beaver ponds, sloughs, and tributaries include, but is not limited to: greater enforcement of existing regulations such no net loss of wetlands, purchasing of properties that include such habitat types, and tax incentives for landowners to protect these areas from further degradation.

Restoring isolated or degraded sloughs will also result in some of the largest habitat and production gains for coho. For example, reconnecting two meander bends that were cut off in the 1930s and are now side-channel sloughs along Cook Slough could increase summer smolt coho production potential by approximately 22,000 and winter production potential by over 50,000. Reconnecting this side channel habitat could result in an increase in potential coho production that is the same or greater than opening all known culvert blockages. Restoring beaver pond and slough habitat will result in the largest benefits, relative to the other habitat types.

Even though benefits may not be as great, reconnecting small, low gradient tributary habitat by removing or replacing blocking culverts should be a significant component of any restoration strategy. This is because culvert blockages have already been systematically identified and prioritized, and because culvert blockages normally have low costs with large gains (Beechie and others, 1996). Beechie and others (1994) estimate that opening up 35 km of tributary habitat in the Skagit basin would increase coho smolt potential by the same amount as restoring 160 km of degraded tributary habitat.

Larger habitat types, such as mainstem habitat, are affected by large-scale activities, and are thus traditionally easier to regulate because of being more unified and direct.

Research is needed into coho use of mainstem habitats because there is a lack of such knowledge, and these habitats are growing in importance due to the decrease in other habitat types. On-going studies that examine the seasonal use of mainstem habitat by coho and chinook in the Skagit River basin will help answer some of these questions about the Stillaguamish (personal communication with Eric Beamer, Skagit System Co-operative, 1997).

Table 4-1. Summary of major land use changes to the Stillaguamish River basin, by habitat type, and possible activities and considerations.

Habitat Type	Major Effects of Land Use	Activities and Considerations
Off-Channel Areas	• Loss of beaver ponds due to beaver eradication, or filling and conversion of beaver pond area. • Disconnection of side-channel and distributary sloughs due to dikes, levees, and filling.	• Beaver protection and re-introduction • Reconnect isolated or de-graded sloughs.
Tributaries	• Disconnection of small tributary habitat due to blocking culverts.	• Reconnect isolated habitat by replacing culverts to increase fish passage.

Restoring and Protecting Degraded Habitats

Our analysis of changes in habitat quality to the Stillaguamish also has implications to fish habitat protection and restoration (Table 4-2). Forestry activities in steep headwaters throughout the Stillaguamish have caused significant increase in sediment supply. A significant amount of this erosion is localized at large deep-seated landslides in glacial sediments, which are a chronic source of turbidity all year long. Recommendations to help minimize landslides and reduce suspended sediment and turbidity include developing a landslide hazard zonation map using Washington State's Watershed Analysis mass wasting methodology to help identify the relative hazard of all hillslopes, and paying special attention to erosion from existing and potential large deep-seated landslides.

We also found that landslides and riparian logging have affected tributaries. Landslides triggered by forest practices, in combination with riparian logging, have caused numerous large tributaries to widen and aggrade at some point in the last 50 years. Restoring large conifers might most effectively be undertaken first in channels where widening and aggradation occurred in past decades, rather than the recent decade, because of their trend toward stability.

There has been significant decrease in woody debris in mainstem and large tributary habitats. Consequences of this loss include loss of forested islands and accompanying habitat diversity, loss of edge habitat, and loss of pools. Restoration work in the riparian zone should focus on reestablishing large conifers in main stem channels. There has been local downcutting, especially in Cook Slough, which will need to be taken into account if sloughs are to be reconnected.

Table 4-2 - Summary of major land use changes to the Stillaguamish River basin, by network position or watershed process, and possible restoration activities.

Watershed Area or Process	Major Effects of Land Use	Restoration Activities and Considerations
Suspended Sediment	• Forestry. • Large deep seated landslides in glacial sediments dominant (e.g. Hazel, DeForest, Gold Basin, Canyon Creek slides).. • Large persistent deep-seated landslides are chronic source of low-flow turbidity.	• Landslide hazard zoning to reduce triggering landslides from forest practices. • Priority on preventing large, deep-seated landslides in glacial sediments. • Evaluate use of log jam hard points to reduce erosion of toes of existing large deep-seated landslides.
Mainstem and Lower Forks	• Removing jams and snags may have destabilized sloughs, reduced channel complexity, edge habitat, and pools. • Meander bend cutoffs in Cook Slough appears to have caused downcutting. • Gravel mining since mid 1960s also likely to have caused local downcutting; also reduces vegetation on bars, and has undocumented effects on pool and riffle structure and stability.	• Reestablish source of LWD. Re-establish mature conifers; use information on time since last channel response, and type of response, to assign priorities to different channels. • May need to take into account effects of local downcutting in reconnecting some sloughs. • Evaluate amount and locations of gravel mining.
Tributaries	• Widening and aggradation from landslides triggered by forest practices. • Riparian logging has reduced LWD loads, which reduces pool number and channel stability.	• Use landslide hazard zoning to reduce triggering landslides from forest practices. • Reestablish mature conifers; use information on time since last channel response, and type of response, to assign priorities to different channels.

An Approach to Prioritizing Individual Restoration Actions

There are several steps to ranking individual restoration projects, two of which we have completed (Table 4-3). The first step is to identify an overall restoration goal. A logical second step is a watershed assessment that describes historic and current habitat conditions, an understanding of the watershed processes that influence that habitat, and general types of relevant projects. Step three is to identify projects and determine their strengths and weaknesses. Each project is evaluated using a set of questions or criteria, which identifies potential benefits and costs. Projects then can be ranked. Project feasibility (e.g., implementation potential) is the final step to consider.

Table 4-3. Steps in prioritizing potential restoration projects.

Steps	**Objective of Step**
(1) *Define restoration goal*	(a) Develop restoration strategy (b) Define overall restoration goal (c) Identify specific local management objectives.
(2) *Complete watershed assessment*	(a) Habitat loss and limiting factors assessments (b) Understanding of processes that affect habitat (c) Relate findings to overall restoration goal.
(3) *Identify and compare potential restoration proj??ects*	Compare projects using these criteria: (1) What is the local management objective? (2) If objective is recovery of depressed stock(s), what is historic and current limiting factor for a species or set of species? (3) What physical and biological processes create and maintain critical habitat types? (4) Does the project focus on a location that can be utilized sooner rather than later? (5) Do other issues (e.g., productivity due to lack of food) need to be dealt with first or simultaneously? (6) Besides the benefits related to the objective, what other kinds of benefits does the project have?
(4) *Rank projects*	Identify the relative strengths and weaknesses of each project.

The six questions in step (3) in Table 4-3 are the basis for assigning priorities to projects. The first and most important question to consider is whether or not the project relates to the local management objective. If not, the project should be dropped. The objective in the present discussion is to recover the Stillaguamish salmonid populations, and so the second next logical question is to ask what habitat limited smolt production historically and what limits it now? The analysis in this report indicates that either summer or winter rearing habitat can at present limit potential coho smolt production. Projects related to habitats that create, enhance, or maintain either habitat should be given a priority.

The third question is whether the project being considered works with or against the way in which a watershed naturally maintains such habitat. For example, let us consider two disconnected side-channels as potential restoration project because of the existing potential habitat. One side-channel, A, is in a location where downcutting along the main stem continues to occur. Another side-channel, B, is in an area where downcutting has already occurred, and the main stem channel is relatively stable. Which side-channel would we focus on and why? Side-channel B may have a greater likelihood of success because downcutting has already occurred, and we do not need to consider if the channel will become disconnected in the near term (e.g., 10 to 20 years). Focusing efforts on side-channel A could result in the slough becoming disconnected with the main stem channel in the near future and juvenile coho may not be able to utilize it. Additional costs will be incurred in order to help maintain the slough at a similar elevation to the main stem channel.

Areas of primary fish use, at all scales, should be considered first when prioritizing projects. Protecting and restoring habitat nearer areas where there is relatively high coho use, theoretically, has a greater probability of being used in the near term, because it can be more readily "seeded" by coho. Concentrating multiple project efforts in and around such areas may also increase coho smolt production benefits for similar reasons.

Another question that helps to focus and prioritize restoration projects is whether or not the project addresses the most important factors first. For example, should we expect an extension of summer coho use if removing a culvert opens up habitat where low flow and stream temperature problems occur during the summer? In this example, the stream temperature issue should be dealt with through riparian planting, in conjunction or prior to, removing the fish blockage. Issues that effect fish productivity such as food supply, and survival rates, should be identified and weighed in any restoration effort that reconnects stream habitat.

The final question is obvious but also important: what other types of benefits come from a fish habitat restoration project? Identifying all the potential benefits will help planners or managers who have possibly different management objectives, support or contribute to existing projects. For example, if beaver pond enhancement also increases habitat for a specific kind of native wild plant, and helps to reduce flooding for a local landowner, then other individuals can also help build support for the project. Different agencies can then identify what types of projects to work on together in specific areas, and local landowners can gain a better understanding of what benefits they may see come from a project.

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APPENDIX A: CHANGE IN PHYSICAL HABITAT CHARACTERISTICS

Field Methods

We consider several aspects of physical habitat characteristics – the number of pools, the amount of wood, the amount of available spawning habitat, and changes to the amount of pool area in stream channels. A decrease in pool spacing (increase in percent pool area) will increase potential coho production estimates because juvenile coho prefer pool habitat such as backwater areas, sloughs, and beaver ponds. Reduced numbers of pools (decrease in percent pool area) will reduce winter and summer coho production**.** Less wood can result in fewer pools, which can also lead to a reduction in juvenile coho rearing capacity. A lack of available spawning habitat can limit potential coho production because not enough fry are produced to seed all available rearing habitat.

We addressed these issues by collecting habitat data throughout the Stillaguamish River basin between the summer and winter of 1995 and 1997. We also used habitat data from the South Fork Stillaguamish collected by Beechie and Sibley (1997), who used the same methodology, and surveyed during similar time periods (e.g., June through September, and October through May). Data collected in habitat surveys includes bankfull width, stream channel gradient, wood loading (e.g., number and volume), percent spawnable area, channel units (e.g., pools, riffle, glide, and rapid), and pool-forming factors (e.g., woody debris, streambank, boulders) (see Appendix A-1). Channel units are as defined by Bisson and others (1982) and Reeves and others (1989). We measured bankfull width with a tape measure to the nearest 0.1m and surveyed gradients with a hand-level and stadia rod over a representative reach of each segment. We measured and counted wood pieces if more than 10 cm in width and 1 m long, and were at least partially within the bankfull width. Surface patches of gravel, potentially spawnable by coho, with a minimum 1m^2 size, were visually identified and measured. Patches were only included if in areas of potential coho spawning such as the tail-out of pools, riffles, and glides.

Gravel area is expressed as percentage of the total wetted channel area. The length and width of each habitat unit was measured using a stadia rod or tape measure.

We do not address changes to flow levels. It is known that flow levels (e.g., total annual, summer low, etc) in the Stillaguamish can affect annual coho smolt production (Nelson and others, 1997) either by changing the area (amount) of habitat, or affect habitat condition, as by increasing stream temperatures, or lowering dissolved oxygen levels. Nelson and others (1997) found a positive correlation between total annual flow, increased flow during spawning and winter rearing, and smolt yield for several streams throughout the Stillaguamish. Such relationships can effect annual smolt estimates, and result in large variations in observed smolt use and production.

Changes to Pool Area

Recent studies (Beechie and Sibley, 1997; Montgomery and others, 1995) show the importance of wood in forming pools in specific stream gradient classes (e.g., greater than 0.01 to less than 0.04) and corresponding channel types (e.g., plane-bed and forced pool-riffle). Approximately 25% of the total Stillaguamish anadromous zone has a channel slope greater than 0.01 and less than 0.04. We quantified the loss of potential coho smolt production from the loss of wood and pools in small and large tributaries, and the main stem habitat of the forks. Loss of pool area is from removal of wood and the loss of wood recruitment due to riparian timber harvest. Pool loss is also due to filling resulting from an increase in sediment supply.

We measured an average percent pool area in small tributaries of 36% (ranging between 31% to 40%), which is 18% less than historic estimates (Table 3-1). Loss of pool area in small tributaries of the Stillaguamish reduces the average overall smolt production potential for small tributary habitat in the historic anadromous zone by 33%. This varies between 5% to 50%, depending upon current channel condition. We estimated the "his-toric" amount of pool area in small tributaries with gradients between 1% and 4%, and large tributaries with gradients less than 2%. We take conditions in unmanaged, old growth forests of the North Cascades (e.g., North Fork Sauk) and Olympic Peninsula (e.g., South Fork Hoh) as a surrogate for historic conditions.

Table 3-1. Historic and current average pool area in small and large tributaries and mainstems.

Habitat Type	**Number of Segments**		**Average Percent Pool Area**	
	Old-growth	**Current**	**Historic**	**Current**
Small Tributary (>0.01 & <0.04)	6	134	54%	36%
Large Tributary and Mainstem (<0.02)	6	11	56%	35%

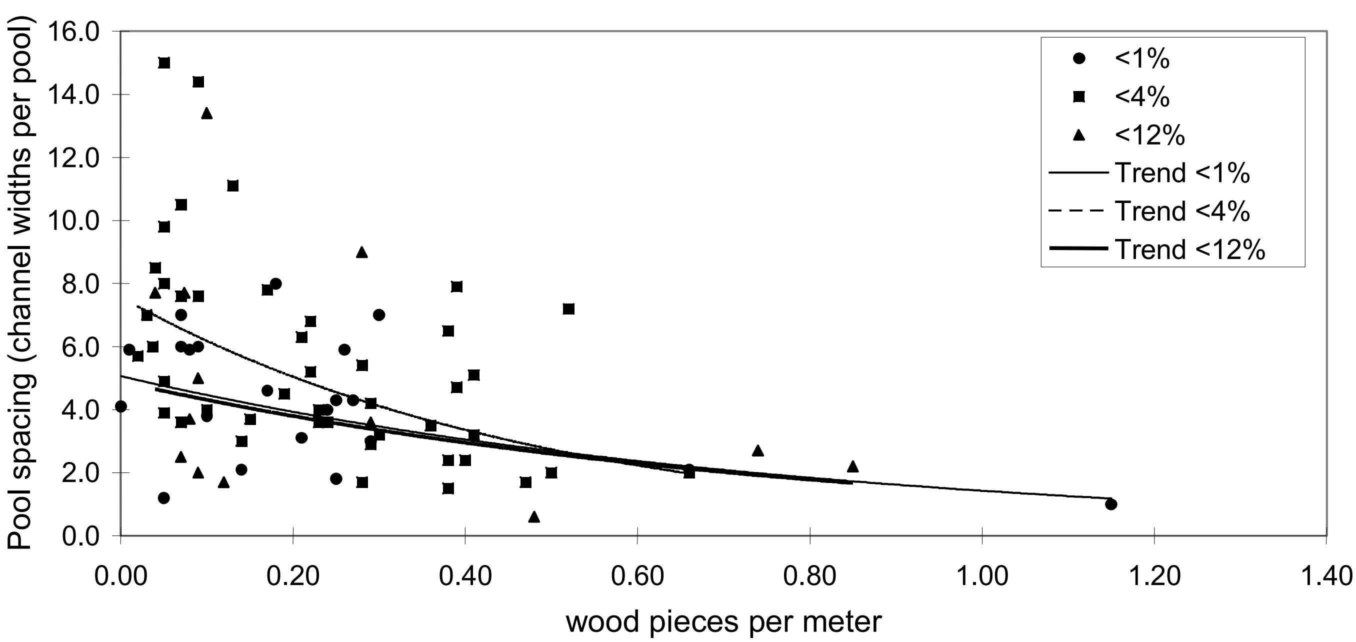
Current pool area in large tributaries is 22% less than historically (Table 3-1). A consequence of this loss in pool area is that the overall increase in tributary habitat length did not result in an overall increase in potential smolt production. Overall loss of smolt production in tributaries averages 2% for summer rearing conditions and 9% for winter rearing conditions. These changes have significant effects on smolt production; loss of pool area in mainstem and large tributaries reduced smolt production potential by 5% (see Chapter 4).

Variation in Wood and Pools by Stream Gradient

Pool spacing correlated to wood amounts in both low (<1%) and moderate (>1% and <4%) slope channels (Figure 3-1). Pools are more frequent in low-slope than moderate slope channels at a similar wood loading. However, pool spacing has greater correlation, and is more sensitive, to wood pieces in moderate-slope (r^2=0.34, p<0.001) than low-slope (r^2=0.30, p=0.03) channels. The relationship becomes weaker for steeper-slope channels (>4%) (r^2=0.17, p=0.21). These results are consistent with other studies, suggesting that woody debris is an important pool-forming mechanism because other obstructions cannot compensate for the loss of wood in specific channel types (Montgomery

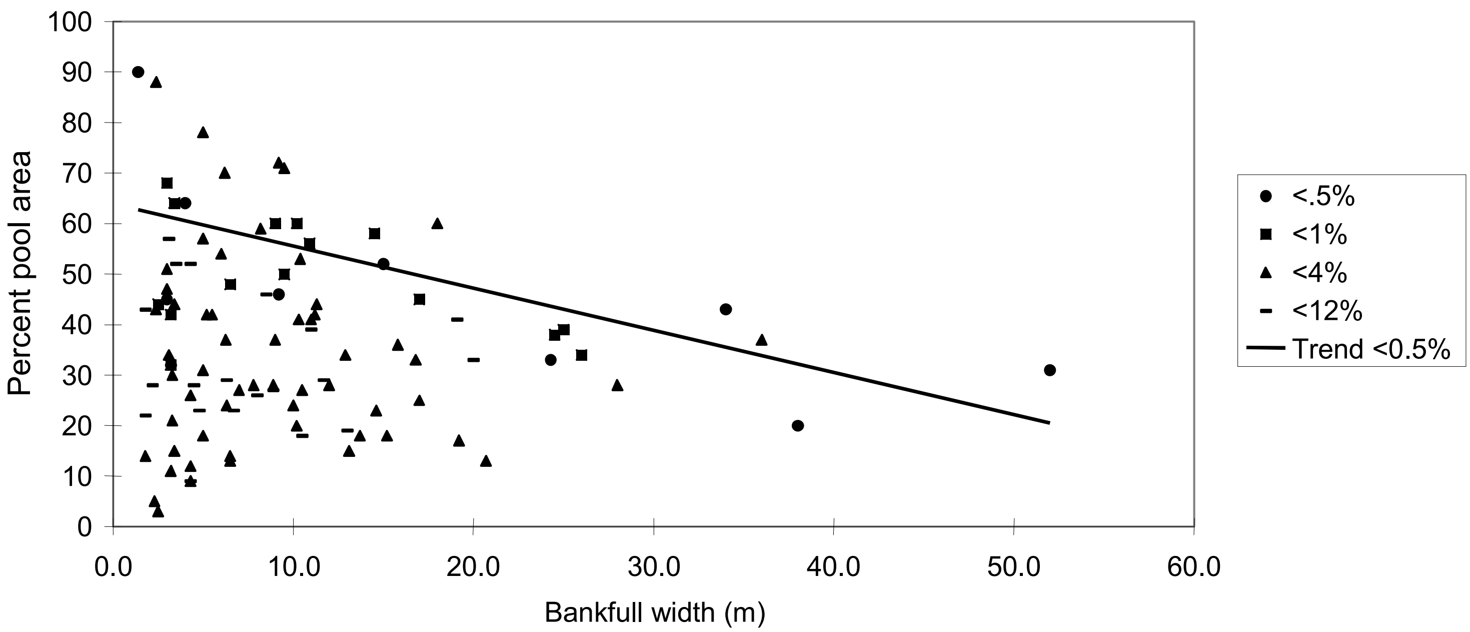
and others, 1995; Beechie and Sibley, 1997). Percent pool area decreases with an increase in bankfull width, regardless of channel slope (Figure 3-2).

Figure 3-1 - Relationship between wood pieces per meter and pool spacing by gradient class in the Stillaguamish River basin



a) Pool spacing for channels less than 0.01 = $5.0639e^{-1.2655x}$ (r^2 = 0.30, P=0.04)
b) Pool spacing for channels greater than 0.01 and less than 0.04 = $7.5752e^{-2.0352x}$ (r^2 = 0.34, P=0.0003)
c) Pool spacing for channel greater than 0.04 and less than 0.12 = 4.8944e-1.2593x (r^2 = 0.17, P=0.21)

Figure 3-2 - Relationship between bankfull width and percent pool area by gradient class in the Stillaguamish River basin



a) Percent pool area for channels less than 0.005 = -0.8348x + 63.891 (r^2 = 0.54)

Variation in Wood and Pools in Sub-Basins

The amount of wood in channels is similar for each sub-basin, with an average 15 pieces/100m in the lower basin, 20 pieces/100m in the South Fork, and 24 pieces/100 m in the North Fork (Figure 3-3). The differences are not significant. However, their may be less wood in the lower Stillaguamish, because riparian zones are typically dominated by small sparse stands of hardwoods and shrubs, while the South Fork has a large percentage of medium to large-sized conifer stands on Federal lands in the upper portion of the basin. A relatively large portion of the North Fork riparian zone is medium-sized conifer or mixed forest stands (Appendix D).

Average percent pool area in the lower Stillaguamish is greater (45%) than both the North Fork (28%) and the South Fork (35%) even though there is less wood (Figure 3-4). This is possibly because channel gradients are lower in the lower basin. Average channel slope in the lower Stillaguamish, 1.4%, is less than in the North Fork (2.6%) and the South Fork (2.8%). Wood abundance has a more important effect on percent pool area in stream channels steeper than 2% and less than 5% (Montgomery and others, 1995; Beechie and Sibley, 1997).

Figure 3-3 - Range of wood pieces per 100 meters by sub-basin.

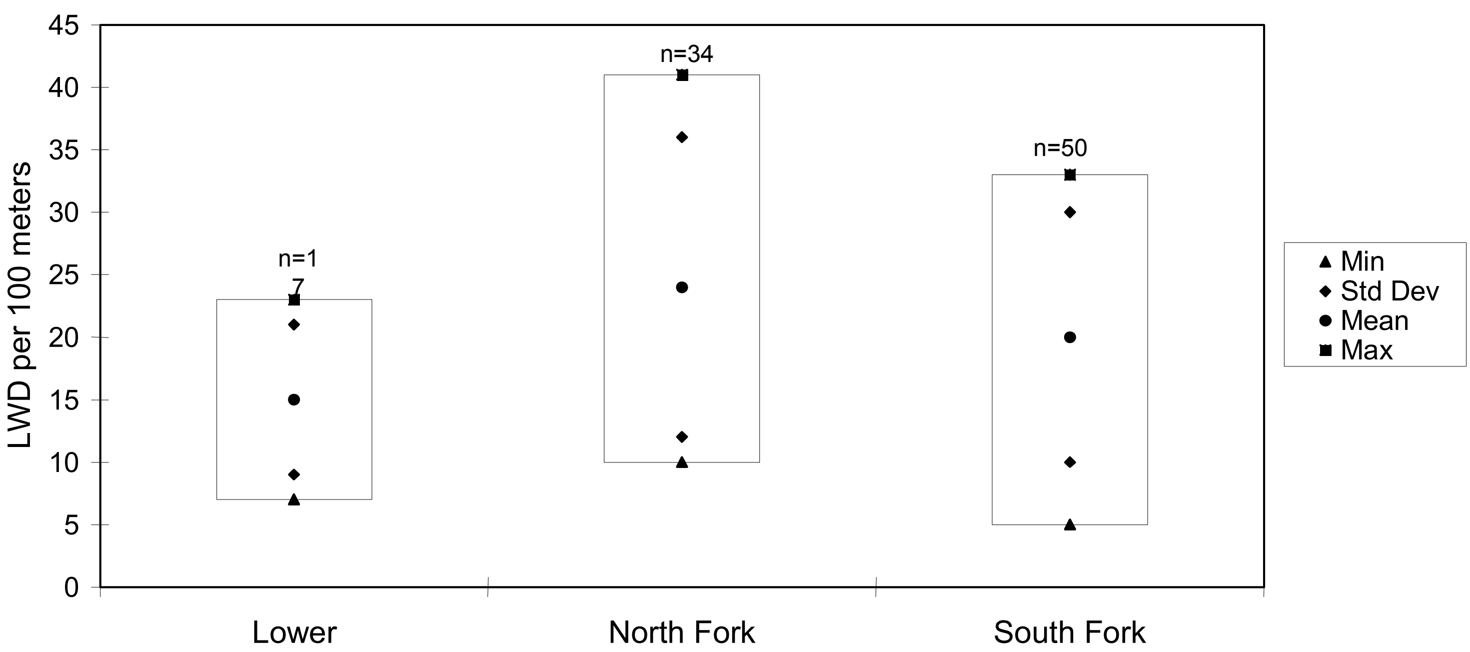
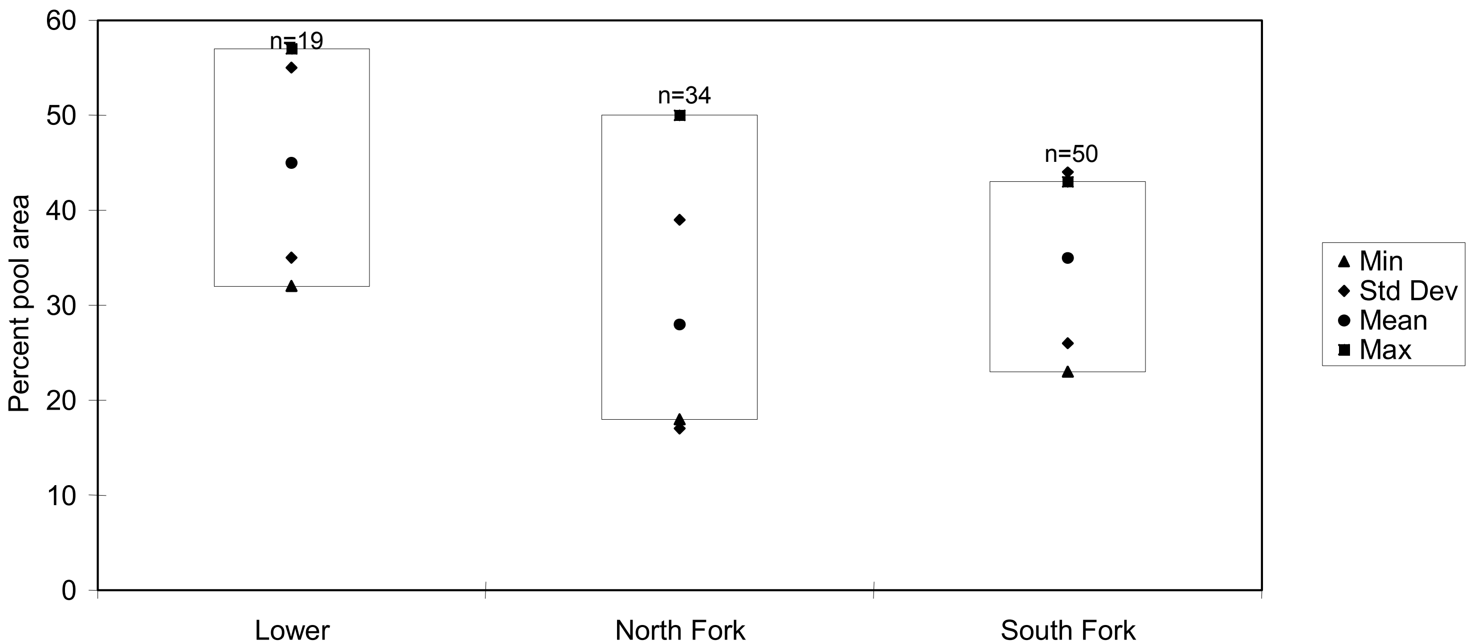


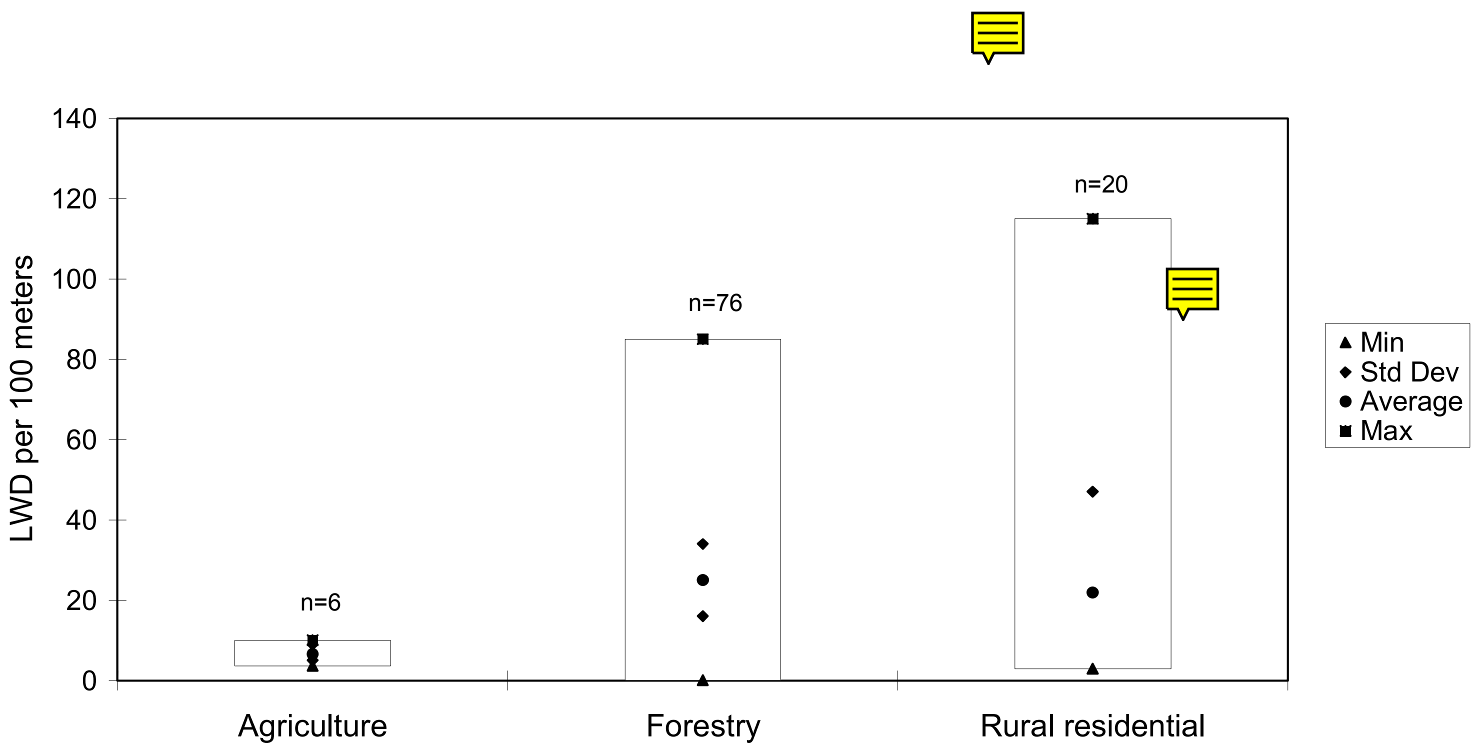
Figure 3-4 - Range of percent pool area by sub-basin.



Pool Impacts in Different Land Uses

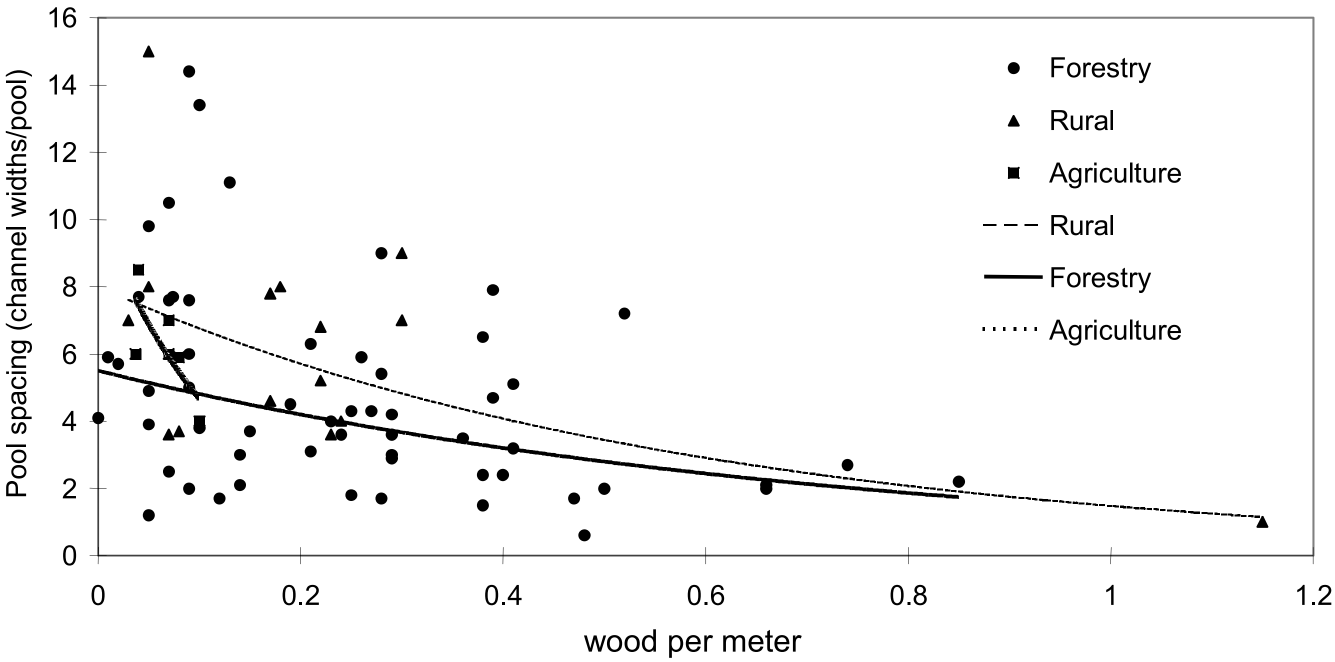
Similar to in the Skagit River basin (Beechie and others, 1994), most pool losses were in areas dominated by forestry activities because there is a much greater length of tributaries in forest lands than in agricultural, residential, or urban lands. However, stream channels in agricultural lands have less wood debris than in forested and rural residential areas (Figure 3-5). The average and maximum number of pieces in stream channels in agricultural lands is 70% less than in stream channels in forested and rural residential lands. This is not surprising since agricultural riparian areas are dominated by shrub and small-sparse or dense-deciduous trees, which do not function as stable wood in stream channels (see Appendix D). Forested and rural residential streams have a similar mean and range of wood loadings. Some stream channels in both land-use types with greater than 50 pieces per 100 meters include large old-growth pieces of wood.

Figure 3-5 - Wood pieces per 100 m of channel, in three land uses .



Less wood results in fewer pools and pool area in channels greater than 0.01 and less than 0.04 (Montgomery and others, 1995). Pool spacing decreases with an increase in wood pieces per meter (Figure 3-6) (Montgomery and others, 1995; Beechie and Sibley, 1997). The exponential curve suggests that wood is an important pool-forming mechanism because other obstructions such as boulders cannot compensate for the loss of wood.

Figure 3-6 – Wood pieces and pool spacing per meter of channel, by three land uses



a) pool spacing in rural residential lands = $8.0026e^{-1.6874x}$ ($r^2 = 0.54$, P=0.07)
b) pool spacing in forest lands = $5.508e^{-1.351x}$ ($r^2 = 0.17$, P=0.002)
c) pool spacing in agricultural lands = $10.153e^{-7.7474x}$ ($r^2 = 0.56$, P=0.09)

Available Spawning Habitat

We quantified available spawning habitat to determine if spawning habitat can limit potential coho production. Spawning habitat is defined as gravels 16mm and 64mm in size, which occur in riffles and the tail-out of pools. We found that spawning habitat does not limit potential coho production. Currently, only one of 72 streams evaluated in the field was spawning habitat limited. Summer rearing habitat can be fully seeded with the current amount of available spawning habitat.

Percent spawnable area for Stillaguamish stream channels that have channel slope of less than 0.04 ranges between 0.1% and 20.0% and average 4.0%. The majority of

spawnable gravels are in channels with a channel slope of less than 0.02. The lower Stillaguamish has a greater average percent spawnable gravel area for coho (9.7%) than both the South Fork (6.5%) and the North Fork (4.7%) (Figure 3-8).

Figure 3- 8 - Range of percent spawnable area for coho by sub-basin in the Stillaguamish River basin