INTRODUCTION

Background

The Snohomish River valley has undergone dramatic changes since non-native peoples began to arrive and establish settlements in the mid-1850s. Pioneers harvested timber, drained thousands of hectares of marsh, ditched floodplain tributaries and cleared land to establish farms. Dikes, levees, revetments and bulkheads were constructed along the banks. The Army Corps of Engineers dredged the river and removed snags to facilitate navigation and port development. Major transportation routes and industrial developments were established in the estuary and floodplain. The cumulative impact of these land-use activities has been substantial loss and widespread degradation of salmonid habitat. Habitat loss and degradation, in turn, has reduced salmonid production capacity.

Several stocks in the Snohomish River basin are at risk. National Marine Fisheries Service (NMFS) listed chinook salmon (*Oncorhynchus tshawytscha*) throughout the Puget Sound Ecologically Significant Unit (ESU) as a Threatened species under the Endangered Species Act in May 1999. In November 1999, the U.S. Fish & Wildlife Service (USFWS) listed bull trout char (*Salvelinus confluentus*) throughout the Coastal/Puget Sound Distinct Population Segment (DPS) as a Threatened species. Washington State identifies the status of one coho salmon (*Oncorhychus kisutch*) stock and one summer-run stealhead stock (*Oncorhynchus mykiss*) in the Snohomish River Basin as depressed (WDFW *et al*., 1994). Puget Sound coho salmon has also been identified as a candidate species for Federal listing under the Endangered Species Act. All stocks in jeopardy use habitat in the Snohomish River valley during multiple life-history stages (e.g., adult and juvenile migration, spawning and rearing).

While habitat loss is not the sole factor contributing to decline of these species, addressing habitat deficits is a critical component of recovering threatened stocks to viable and harvestable levels. Salmonid stocks evolved to the suite of habitat conditions available in the watershed, thus maximizing stock diversity and productivity. Conversely, habitat modifications associated with settlement and development have lowered production potential. The historical context of salmon habitat and production losses provides a restoration template. It clarifies the causes of decline, provides reference conditions for restoration and allows land managers to set clear and attainable restoration goals (Sedell and Luchessa, 1982).

Objectives

This report examines historical change in habitat quantity and production potential for chinook and coho salmon in the Snohomish River valley over the last 150 years. The objectives are as follows:

1. ***To describe and quantify salmonid habitat alterations in the Snohomish River valley over the last 150 years;***

2. ***to assess the impact of modified habitat conditions on the production potential of coho and chinook salmon; and***

3. ***to inform and guide the development of a restoration strategy through historical analysis.***

A complimentary document describes restoration opportunities identified through field investigation in the context of historical condition and productivity (Haas, 2001).

Watershed and Study Area Description

The Snohomish River basin, located northeast of Seattle, Washington, is the second largest Puget Sound drainage (Figure 1-1). Two major tributaries, the Skykomish and Snoqualmie rivers, originate in steep, narrow valleys in the Cascade Mountains, descend into broad alluvial floodplains, and merge near the city of Monroe. The main stem flows for 34.5 kilometers through a valley that was carved beneath continental glaciers, before emptying into Possession Sound between the city of Everett and the Tulalip Indian Reservation.

The Snohomish River at the confluence of the Snoqualmie and Skykomish rivers has an average annual runoff of 8.601 x 10^9 m^3 (6,973,000 ac-ft) and an average annual discharge of 273 cms (9,625 cfs) (USGS, 1997). The extremes during the period of record (water years 1964-1998) are a maximum of 4,248 cms (150,000 cfs) on November 25, 1990 and a low of 21.6 cms (763 cfs) on October 30, 1987 (USGS, 1997).

The study area encompasses the pre-development (mid-19th century), 100-year floodplain from the confluence of the Snoqualmie and Skykomish rivers to Port Gardner and Possession Sound (Figure 1-2). We selected this area because of its importance to depleted salmon stocks, high level of modification and potential for restoration. Large tributaries—Quilceda Creek, Allen Creek, the Pilchuck River, and French Creek—except for the lower reaches within the Snohomish River 100-year floodplain, are outside the scope of this project.

The river includes four main reaches (delineated based on valley confinement, slope, and relative degree of hydromodification)(Figure 1-2; Table 1-1). Reach 1, from Port Gardner to the head of Ebey Slough at RK 13.0, is the lower estuary component, which includes the main stem and three major distributary sloughs. Reach 2, from RK 13.0 to RK 24.5, is heavily diked and tidally influenced. The floodplain is between 2.5 and 5 kilometers wide. Reach 3, from RK 24.5 to RK 27.5, contains several forested islands and shallow riffles. The upstream limit of reach 3 at Thomas's Eddy is the upstream limit of tidal influence. The floodplain is approximately 1.5 kilometers wide, but much of the channel is diked or armored. Reach 4, from RK 27.5 to the confluence at RK 34.5, is a pool-riffle channel with several side-channels. It has greater habitat complexity in side-channels, less bank armoring, and more riparian forest than the other reaches. The floodplain is approximately 1 kilometer wide downstream of the State Route 522 bridge and 0.5 kilometers wide upstream to the confluence of the Snoqualmie and Skykomish rivers.

Fisheries Resources

The Snohomish River and its tributaries support a large commercial and recreational salmon fishery. Anadromous fishes include multiple stocks of four Pacific salmon [chinook (*Oncorhynchus tshawytscha*), coho (*Oncorhychus kisutch*), chum (*Oncorhynchus keta*), pink (*Oncorhynchus gorbuscha*)], trout [cutthroat (*Oncorhynchus clarki*), steelhead], and char [Dolly Varden (*Salvelinus malma*), and bull trout (*Salvelinus confluentus*)]. Resident freshwater fish include trout [cutthroat (*Oncorhynchus clarki*), rainbow (*Oncorhynchus mykiss*)], char [brook trout (*Salvelinus alpinus*), bull trout, Dolly Varden], mountain whitefish (*Prosopium williamsoni*) and many others.

Puget Sound chinook salmon was listed as a threatened species under the Endangered Species Act in May 1999, and bull trout char in December 1999. Coho has been proposed as a candidate species for federal listing. All stocks in jeopardy use the main-stem Snohomish downstream of the confluence during multiple life history stages (e.g., adult and juvenile migration, spawning, rearing).

Four naturally spawning chinook stocks exist within the Snohomish River basin: Snohomish River Summer, Snohomish River Fall, Bridal Veil Fall, and Wallace River Summer/Fall. These stocks exhibit two primary juvenile life history patterns known as "ocean-type" and "stream-type". Ocean-type chinook generally emerge from the gravel from mid-March to mid-April and migrate rapidly downstream to the estuary, where they rear for several days to several months. However, some ocean-type chinook rear in rivers prior to migration to the estuary for several weeks to several months, prior to migrating to the estuary (Hayman *et al.*, 1996). Stream-type chinook emerge from the gravel between the end of March and early May and migrate to main-stem rivers where they rear in channel margins and off-channel areas for up to 18 months prior to entering the estuary. Between 25 and 30 percent of Snohomish River fall chinook exhibit a stream-type life-history strategy (WDFW unpublished data).

The Snohomish River basin contains four coho stocks: Snohomish, Skykomish, South Fork Skykomish and Snoqualmie. The Snohomish coho stock status is listed as depressed (WDFW *et al*., 1993). Coho fry generally emerge from the gravel during March through mid-May and rear for one to two years in freshwater before heading out to sea. Juveniles traveled as far as 41 kilometers and an average distance of 19 kilometers to winter rearing habitat (Scarlett and Cederholm, 1984). The primarily freshwater component of the estuary provides summer and winter rearing habitat for coho fry. Coho are generally thought to migrate rapidly through the transition between fresh and salt water.

ASSESSMENT METHODOLOGY

Summary

We quantified habitat changes over time and reconstructed pre-settlement conditions using historic maps and text. We measured surface area of aquatic habitats on 1996 1:12000-scale aerial photos and compared it to habitat area on 1933 1:12000-scale aerial photos (oldest aerial survey), U.S. Coast & Geodetic Survey map (1884-5), Army Corps of Engineers (USACOE)(1874) map, and General Land Office (GLO) plat maps (Surveyor General, 1866-74). The GLO survey notes (1866-74), Nesbit (1885), Interstate Publishing Company (1906), Army Corps of Engineers Annual Reports to the federal government (1876-1979), and Northern Star Newspaper (1877-79) provide further description of pre-settlement conditions.

Habitat types assessed in this analysis include marshes, blind tidal slough channels, distributary sloughs, side-channel sloughs, side-channels, small floodplain tributaries, beaver ponds and main stem. We classified marshes as tidal or non-tidal palustrine and further delineated tidal marsh into three habitat zones: estuarine emergent marsh (EEM), emergent/forested transition (EFT) and forested riverine/tidal (FRT) (Hayman *et al.*, 1996).

We applied regional rearing density, and when available, smolt production estimates for chinook and coho salmon over historic and current habitat areas in the Snohomish River valley (Reeves *et al.*, 1989; Beechie *et al.*, 1994, Hayman *et al.*, 1996; Pess *et al.*, 1999; Swales and Levings, 1989). Rearing capacity is defined as the expected number of parr that available habitat can support. Smolt production capacity is defined as the expected number of smolts that could be produced from available habitat (rearing capacity multiplied by the survival to smoltification factor) (Beechie *et al.*, 1994). We calculated the change in rearing capacity and smolt production capacity throughout the study area over time.

In the main stem, we estimated relative change in smolt production potential through field surveys of current edge cover (1998) and assignment of edge cover preference ratios for coho and chinook to each edge cover class (Beamer and Henderson, 1998). A minimum historic estimate was obtained by extrapolating edge characteristics observed along non-hydromodified banks over the entire bank edge. To quantify the impact of large woody debris (LWD) removal and restricted recruitment, we extrapolated LWD characteristics (e.g., % with rootwads) and abundance in a reach of the Nisqually River characterized by intact riparian forests and no diking to the Snohomish River.

Habitat Change in the Lower Estuary

The upstream boundary of the area referred to as the lower estuary in this analysis is delineated at the divergence of Ebey Slough from the main-stem Snohomish River.

Tidal Marsh

We delineated the lower estuary into three marsh habitat zones and compared pre-development and current (1996) habitat abundance. The estuarine emergent marsh zone is composed of low and high marsh vegetation such as grasses (*Deschampia* sp.), sedges (*Carex* sp.) and bullrush (*Scirpus* sp.). The emergent/forested transition zone encompasses the scrub-shrub wetland community between the EEM and the FRT zones. Cattails (*Typha latifolia*) predominate in the lower EFT, while willow (*Salex* sp.) and rose (*Rosa* sp.) predominate higher in the zone. The emergent/forested transition zone becomes increasingly tree covered at its upper extent as elevation increases and salinity decreases. Palustrine and riverine forest dominate the FRT zone.

The GLO survey (1866-74) provides useful data for delineating and characterizing marsh habitat zones. Surveyors identified species, diameter and distance from the survey marker of bearing trees at section corners, quarter section corners along section lines and river crossings. Survey notes identify trees using their common name (probable species names are identified in italics). In the study area, surveyors shot bearings to trees as small as 8 cm in diameter and as far away as 80 m. Otherwise, they noted that no tree is present in the quarter section adjacent to the marker.

The instructions given to surveyors in the mid-19th century regarding bearing trees were as follows: “A boundary corner, in a timbered country, is to be a tree, if one is found at the precise spot; and if not, a post is to be planted thereat; and the position of the corner post is to be indicated by trees adjacent, the angular bearing and distances of which from the corner are facts to be ascertained and registered in your field book" (Dodds, 1844). Dodds also indicated that bearing trees should be "in opposite directions, as nearly as may be [to the survey marker]", and in the absence of the requisite number of bearing trees within a "convenient and suitable distance", a mound should be established to mark the location. This protocol and the broad range of tree species and sizes suggests that surveyors shot bearings to the nearest trees if they existed within a reasonable shooting distance without regard to size or species.

Other references provided supporting evidence for delineation of the estuary into three vegetation zones based on bearing tree size and spacing (or absence of trees). The delineation between the estuarine emergent marsh and the emergent/forested transition zone is clearly visible on 1933 1:12,000-scale aerial photos and within remnant marsh areas currently. A description provided by a naturalist and early resident of the city of Snohomish supports delineation between the emergent/forested transition zone and the forested riverine/tidal zone. He describes Puget Sound estuaries: "The open tide marshes seldom extend over 3 miles in a straight line from salt water. Then come the spruce lands that require diking against tidal overflow, with open patches of ordinary tide marsh...."(p. 74 Morse in Nesbit, 1885). An ACOE map (1874), land-use map from the turn-of-the-century (Plummer *et al.*, 1902) and 19th century photos (Everett Public Library) provided further evidence of forest cover upriver of the emergent/forested transition zone.

Our assessment of vegetation cover based on these data should be viewed in light of the following caveats:

- It is possible that some GLO surveyors introduced bias by selecting trees that would be most readily identified in subsequent surveys;
- logging commenced several years prior to the survey (however, it does not appear to have been widespread; the surveyors identified only one bearing tree within the study area as a stump in the survey and made no reference to harvested timber); and
- the largest size-class may have been missed because of high-grade logging or small sample size. Four cedar stumps measured during field reconnaissance (1998) exceed the diameter of all trees identified in the GLO survey within the study area.

Blind Tidal Slough Channels

We estimated the pre-settlement abundance and area of blind tidal channels (> 6 m wide at the mouth) by identified blind tidal slough networks, remnant channels and channel scars on the 1:12,000-scale 1933 aerial photo series. Field reconnaissance indicated that channels smaller than 6 m wide at the mouth were not evident on aerial photos and often were dewatered at low tide. In the field we measured width at the mouth of intact and remnant channels networks using a tape measure, stadia rod and Laser Rangefinder®. We extrapolated measured widths to filled channels of comparable drainage areas. Using the regression between blind tidal channel width at the mouth and total channel area developed by Collins (1998) in the Skagit River estuary, we estimated blind tidal channel area.

Distributary Sloughs and Main stem

We estimated changes in distributary slough and main stem channel area on a 1:24,000-scale map of historic and current wetland area (Bortleson *et al.*,1980) using Arcview®. Bortelson *et al.*1980 is based on the USC&GS map (1884-5) and US Geological survey 1:24,000-scale topographic maps (1973). We believe the 1973-map is adequate for measuring current distributary and main-stem channel area because nearly continuous diking has prevented channel movement between 1976 and the present.

Habitat Change in the Floodplain

For this analysis, the “floodplain” refers to the 100-year floodplain between the divergence of Ebey Slough from the main stem and the confluence of the Snoqualmie and Skykomish rivers.

Riparian

The intent of this analysis is to compare the riparian forest with potential to contribute LWD to the Snohomish River in ~1870 (prior to significant human intervention) and 1998. We reconstructed pre-settlement floodplain and upland riparian forest composition from the GLO survey notes (see tidal marsh assessment methodology, p. 6). We analyzed GLO data from the floodplain riparian forest along the Snohomish River in the zone between the large palustrine marshes at Marshland and French Creek and from valley wall to valley wall upstream to the confluence. We selected this range because it contains evidence of recent channel migration prior to diking, and thus the trees with potential for recruitment to the Snohomish River. We also analyzed size and species composition of GLO bearing trees on and directly above valley side-slopes adjacent to the Snohomish floodplain to document size and species composition of trees recruited from valley walls. The Snohomish River between the confluence and the head of Ebey Slough currently abuts valley walls along approximately 8 percent of its length.

We documented riparian forest composition in 1998 through field surveys at 13 floodplain riparian and 5 non-floodplain riparian sites between RK 24 and RK 34.5 (Figure 2-3); Downstream, nearly continuous bank armoring has largely eliminated opportunities for local wood recruitment. Using a logger’s tape, we measured diameter at breast height (dbh) of 15 trees at each site roughly along a transect perpendicular to the channel. Sites are located approximately every one kilometer along each bank within the riparian zone, defined as the constrained channel migration zone plus one site potential tree height (56 m) for this analysis. We delineated the constrained channel migration zone (CMZ) on aerial photos as the meander amplitude including remnant channels and oxbows, excluding the components of the CMZ isolated by dikes and bank armoring.

Palustrine Wetlands

We delineated and measured the area of expansive wetland complexes at Marshland and French Creek on the GLO plat maps (1884) using a planimeter. The western boundary of the Marshland marsh also appears on the USC&GS map (1884-5). It shows the marsh extending further to the west toward the city of Lowell, suggesting that the GLO plat maps provide a conservative estimate of wetland area. We characterized vegetation and extent of standing water within marsh complexes using the GLO survey notes (1866-74).

Small Tributaries

We measured accessible and disconnected floodplain channel length on the Washington Department of Natural Resources (WDNR) hydrography layer (1998). Current tributary length encompasses all accessible streams and ditched channels. In this analysis, we use the sum total of all accessible and disconnected floodplain channels as shown on the 1996 1:12:000-scale aerial photos for the historic estimate. We were unable to obtain a actual length estimate from historic maps, because many small floodplain channels were not delineated on early maps, presumably because of the lack of a defined channel through extensive marshes.

Side-channels

In this analysis, we define side channels as secondary or overflow channels, which are connected to the main stem at both ends. Length was measured on 1933 and 1996 1:12,000-scale aerial photos. The extent of side-channels in 1996 was field checked. Because some features may not have been detectable on the 1933 aerial photos, the change in side-channel length between 1933 and 1996 may be underestimated. Earlier maps were not used in this analysis because they only show primary watercourses.

Side-channel Sloughs

Side-channel sloughs are perennially flooded former pathways of the main stem that are predominately pool habitat. Slough areas were measured on 1933 and 1996 1:12,000-scale aerial photos and the GLO plat maps (1884) using GIS.

Beaver Ponds

We estimated the area impounded by beaver ponds along small tributaries and side-channel within the floodplain. The existence of beaver ponds within French Creek marsh in the late 19th century and the FRT zone in 1998 has been documented, but the relative contribution of beaver to the formation or enhancement of these features is unknown, and thus they were catalogued as separate features, while recognizing that beaver play a substantial role in the enhancement of these habitats.

We estimated the area of beaver ponds along small tributaries and side-channels within the study area on 1996 1:12,000-scale aerial photos and verified the extent of many ponds through field reconnaissance. We estimated pre-trapping beaver pond density in the Snohomish floodplain over a range of 2 to 10 dams per kilometer of stream based on the historic density estimated by Pollock and Pess (1999) in the Stillaguamish River basin. It is thought that beavers saturate all available habitat in the absence of human interference (Naiman *et al*., 1988; Pollock and Pess, 1998). Beaver ponds were found to saturate available habitat in undisturbed, untrapped streams of the Stillaguamish River basin (Pollock and Pess, 1998).

Pollock and Pess calculated an average beaver pond size in the Stillaguamish River basin at 1,480 m^2 (1998). It is believed to be a conservative estimate of historic pond size because beaver could maintain more stable, and consequently larger dams prior to human interference (Pollock and Pess, 1998). We multiplied average pond size by the mean pond density estimate of 6 ponds/km and by total length of floodplain tributaries and side-channels adjacent to but not within Marshland marsh, French Creek marsh and tidal marshes in the FRT zone.

Habitat Change in the Main stem

Channel Position and Area

We measured the surface area of the low flow channel, unvegetated bars, vegetated bars, and forested islands on the1933 and 1998 1:12:000-scale aerial photos using ArcInfo®. We also used ArcInfo® to calculate main-stem channel and forested island area on the GLO plat maps (1884). We have assumed that the channel area represented on the GLO maps is the wetted channel at the time of the survey; bars are not shown.

Pools

We measured pool dimensions during the low flow period in September 1998 for all pools within the main stem from RK 24.5 to the confluence of the Snoqualmie and Skykomish rivers (RK 34.5). We measured pool lengths and widths with a Laser Rangefinder® (precision ± 1 m) and maximum and tailout depth with a handheld sonar (precision ± 1 ft). Measurements with the Rangefinder® are less accurate than the instrument's precision because we shot lengths and widths from a boat to the closest object (e.g., rock, tree, or snag) to the pool's edge. We identified primary pool forming features as freeform, wood, bedrock, or riprap-augmented freeform.

Large Woody Debris

We documented wood debris abundance, longitudinal distribution, cross-sectional location and physical characteristics through two inventories during the low flow period (August-October 1998) and during minus tides (Collins *et al.*, 2001, submitted). In the first inventory, we tallied wood debris (>0.1 m diameter) between RK 6 and 34, and in Steamboat Slough (RK 0-10). A 0.1-m minimum diameter was selected for consistency with the ACOE snagboat records. We classified pieces by location within the channel cross-section (thalweg, low flow channel margin, bar, bank) and by depth class (0-2 feet below the surface, 2-4 feet below the surface, and >4 feet below the surface) in RK12.5-21.5 and RK 32-34. For the remainder, we tallied only pieces within the thalweg. Generally, any pieces at depths greater than 5 feet were obscured, and thus not documented.

In the second inventory, we examined debris characteristics – age class, dimension, and location in the channel along an upstream (RK 31-33), middle (RK 27-29), and downstream (RK 17) segment. We identified three general decay classes: "young" (most bark and limbs attached), "old" (no bark or limbs attached), and "intermediate". We measured log length, diameter (dbh), and rootwad diameter with a tape measure and stadia rod when time and access permitted, and otherwise visually estimated the dimensions with periodic checks for quality control. We noted the location of pieces within the channel profile as on/in bank, on/in bar, snag (protruding water surface of the low flow channel), or submerged (beneath the water surface of the low flow channel).

Edge Habitat

Beamer and Henderson (1998) calculated relative fish abundance associated with various edge habitats along hydromodified and natural banks in the Skagit River through electrofishing and snorkel surveys. They gathered data on juvenile salmonid use associated with various cover types and normalized the data to fish abundance along riprap-armored banks. Habitat types included: no cover, boulder, cobble, plants, riprap, rubble, bankroots, debris piles, single logs and rootwads (Table 2-2).

We gathered bank edge habitat data in the Snohomish River to characterize current conditions and estimate fish production losses associated with bank armoring and wood removal. We sampled three of four reaches along the Snohomish River main stem. We did not collect edge habitat data in reach 1 because no data were available on relative fish usage of edge habitat types in a brackish environment.

We classified the channel edge as bar, backwater, natural bank, or hydromodified bank on 1996 1:12,000-scale aerial photos. We randomly selected half of all natural and hydromodified bank units in reach 4 and 3 using a random number table. In reach 4, we surveyed 48 and 51 percent of the total bank edge, respectively. In reach 3, we surveyed 65 and 31 percent of the total bank edge, respectively. We surveyed 40 percent of the total bank edge along reach 2, which is uniformly diked. Historic data to assess changes in bar edge and backwater habitat were not available, so we assumed that they remained constant.

During field surveys we delineated edge cover types in the randomly selected bank units on an enlarged tracing of the 1996 1:12,000-scale aerial photos. We based edge cover type delineation on cover along the bank in the slack water margin, but did not measure the width of edge cover. We extrapolated the total lengths of edge cover types measured in sampled units over the total length of channel edge in the segment.

Changes in Chinook and Coho Salmon Rearing Capacity and Production Potential

For chinook and coho salmon, we estimated the impact of habitat changes on rearing capacity, and when survival to smoltification estimates were available in the literature, smolt production capacity from habitat in the Snohomish estuary, floodplain and main stem. Rearing capacity is the usable area multiplied by the parr rearing density estimate for a given season. Smolt production capacity is defined as the expected number of smolts produced from available habitat during a given season (Beechie *et al.*, 1994). The potential smolt production for a specific habitat area is obtained by multiplying the rearing capacity by the survival factor from parr to smolt. Production estimates are based on an assumption that coho and chinook juveniles disperse evenly to use all available habitats. We estimate historic and current smolt production potential in the estuary for chinook and coho. In floodplain habitat units, we estimated chinook rearing capacity and coho smolt production capacity. Historic and current rearing capacity estimates in the main stem for chinook and coho are presented in relative terms. Historic estimates are based on extrapolations from cover along natural banks to armored banks and from LWD characteristics in a pristine reach of the Nisqually River to the Snohomish River. We obtained rearing density and smolt production potential estimates from regional data for various habitat types.

Lower Estuary

We calculated chinook and coho salmon smolt production capacity in the Snohomish estuary by delineating habitat zones, determining usable area within each habitat zone prior to development and currently, and multiplying the usable area within each zone by regional smolt production estimates for comparable habitats per unit habitat area. We delineated habitat zones, because data from the Skagit delta show variable usage of blind tidal channels by out-migrating juvenile chinook among the zones (Hayman *et al.*, 1996). Habitat zones correspond with fish use because vegetation reflects hydrology, salinity, elevation and food availability. Habitat types include blind tidal slough channels and distributary slough and the main-stem edge. Mudflats and Port Gardner are beyond the scope of this analysis.

We estimated the usable area of blind tidal channels as the surface area of 3rd order and higher channels, because 1st and 2nd order channels were observed to dewater during low tide. Since juvenile salmonids are typically associated with the channel edge and rarely found in the swifter water in the channel center, only the channel margins were assumed to provide usable rearing habitat. Consistent with Rosenfeld *et al.* (2000) and field observations in the Snohomish estuary, we estimated the usable area along the channel margin at 5 to 10 meters. For the pre-development production estimate we assume a 10-meter width. Because wood removal, bank armoring and dredging have likely diminished the current usable area along the main stem and distributary sloughs from historic levels, we estimated current production capacity over a range of usable area based on a 5 and 10 meter edge habitat width.

For chinook salmon, we extrapolated production capacity estimates from blind tidal channels in the Skagit delta to the usable area within each habitat zone within the Snohomish estuary. Blind tidal channel habitat in the EEM zone and the EFT zone in the Skagit delta had an average production capacity of 21,916 chinook smolts/unit usable area (Beamer *et al.*, 1999). Habitat in the FRT zone had an average production capacity of 2,857 chinook smolts/unit usable area (Hayman *et al*., 1996).

For coho salmon, we assumed that main-stem edge, distributary slough edge and blind-tidal sloughs in forested riverine/tidal zone, the freshwater component of the estuary, provides the only usable habitat. We followed an assumption of Beechie *et al*. (1994) and Pess *et al*. (1999) that water temperatures in rearing areas remain below 7° C for substantial periods during the winter, a factor which effects rearing density in the coho smolt production model (Reeves *et al*, 1989). We also assumed coho smolt production capacity from main-stem edge, distributary slough edge and blind-tidal channel sloughs is equivalent to the smolt production capacity estimate for large beaver ponds (Reeves *et al*., 1989). This is the same assumption made by Beechie *et al.* (1994)

and Pess *et al.* (1999) for distributary sloughs. Based on these assumptions we use estimates of 3,190 smolts/hectare of usable area in summer and 7,750 smolts/hectare of usable area in winter.

Floodplain

We estimated the chinook rearing capacity from floodplain wetlands using a chinook rearing density estimate of 854 pre-smolts/hectare from floodplain ponds within wetlands along the Coldwater River, British Columbia (Swales and Levings, 1989). We assumed an equivalent rearing density (smolts/hectare) regardless of age (year 0+ vs. 1+) or time of year (summer vs. winter). We estimate coho smolt production from standing water within floodplain palustrine wetlands at 3,750 smolts/hectare in summer and 7,750 smolts/hectare in winter using a coho smolt production estimate for large beaver ponds (>500 m^2) in Oregon (Reeves *et al.*, 1989).

We believe these estimates for ponds to be appropriate in the Marshland marsh because the size, slope, and discharge of floodplain creeks draining the sub-basin fall within the range of beaver damming sites (Pollock, pers. comm.), and beaver are know to saturate available habitat in the absence of human interference (Naiman, 1988). Even if beaver were not a primary influence in shaping the habitat, evidence of ponded water is well-documented (Northern Star Newspaper, April 14, 1877; U.S. Surveyor General, 1866-74), and thus Marshland likely contained habitat conditions similar to a complex of beaver ponds. The GLO notes describe French Creek marsh as inundated during July and August at the time of the survey on account of beaver ponds (U.S. Surveyor General, 1866-74).

A range of potential rearing capacity and smolt production is provided for each marsh based on assumptions of usable area. The most conservative summer estimates of usable area for Marshland and French Creek are 20 and 31 percent, respectively, based on the percentage of the area underlain by Muckleteo Muck, a deep organic soil of material derived dominantly from sedges (Debose and Klungland, 1983). The number of survey points located in standing water during the February survey by the GLO (1871) provides an upper estimate of summer usable area in Marshland. Although, the exact extent of standing water in French Creek marsh is unknown, the description of French Creek marsh as "…swampy and generally overflowed to the depth of 12 inches in consequence of beaver dams…" during the GLO survey (July and August, 1866) suggests that at least one-half (50%) of the marsh contains standing water in summer.

The upper summer estimates of standing water are used as minimum estimates of standing water in winter. Maximum estimates of standing water in Marshland during winter are estimated based on the percentage of sites (91%) that were too wet to build a mound during the GLO survey in February 1866. Since French Creek was also described as inundated in winter, yet the survey notes lacked detailed survey marker descriptions, we assumed the same upper estimate (91%).

We also applied the chinook rearing density estimate (Swales and Levings, 1989) to side-channel sloughs and beaver ponds along floodplain tributaries (not in French Creek or Marshland marshes) and side channels. Beechie *et al.* (1994) and Reeves *et al.* (1989) provide coho smolt production estimates for side-channel sloughs and beaver ponds. Estimates are based on an average percent pool area of 64 percent, average width of 4 m, average beaver pond density of six ponds/kilometer, average pond size of 1480 m^2, historic channel length of 34 kilometers and contemporary channel length of 5 kilometers.

Main stem

To assess the relative impact of bank armoring and wood removal on rearing habitat, we apply edge cover type usage coefficients (Table 2-3) for juvenile coho and chinook from the Skagit River to the Snohomish (Beamer and Henderson, 1998). We estimated historic rearing capacity relative to current rearing capacity under various assumptions by calculating a weighted average of usage coefficients normalized to rip-rap for natural and hydromodified banks along sample units. The unit averages for natural and hydromodified banks were extrapolated over the entire length of channel edge to obtain a weighted average for the Snohomish River. This value is set equal to one and compared to weighted averages associated with predicted historic and future condition scenarios. Historic condition scenarios are based on equivalent large woody debris characteristics and loading in a reach of the Nisqually River, characterized by intact riparian forest and no diking. The future condition scenario is based on the hypothesis that decaying, remnant old-growth logs in the Snohomish River will not be replenished under current land management.

HABITAT ABUNDANCE AND CONDITION PAST AND PRESENT

Pre-Settlement Condition

Immigrants to the Snohomish valley in the mid-19th century encountered a mosaic of tidal marsh, palustrine marsh and mixed deciduous/conifer forest (Figure 3-4). A naturalist and early resident of the city of Snohomish describes pre-settlement conditions along Puget Sound rivers:

> *"The open tide marshes seldom extend over 3 miles in a straight line from salt water. Then come the spruce lands, that require diking against tidal overflow, with open patches of ordinary tide marsh. These seldom extend over 6 to 8 miles back from salt water, and above them are tracks of marsh interspersed with ordinary bottom land, not subject to tidal but liable to river overflow" (Morse in Nesbit, 1885 p.74).*

Other settler accounts, GLO survey notes (1866-74), and 19th century photos support the applicability to the Snohomish of this general description. Photo 3-1 (1892) shows heavy forest cover on Ebey Island in the area referred to in this report as the forested riverine/tidal zone.

Prior to extensive snagging, diking, and logging in the Snohomish River basin, the river transported abundant large woody debris. Morse reports an "astonishing" amount of drift for up to 24 hours straight during floods several times a year in Puget lowland rivers (Nesbit, 1885). He described main-stem channels as, "distinguishable from a tide-marsh slough chiefly by the snags and drift [LWD] accumulated on the flats on either side of its channel, and extending beyond the grass covered tide marshes from half a mile to a mile"(Nesbit, 1885 p.76). He noted a dominance of spruce logs up to 8 ft in diameter and 200 ft in length, and an occasional fir and cedar in the 10- to 12-ft diameter range and up to 300 ft in length (Nesbit, 1885). Photo 3-2 (~1890s) shows a large snag along the Snohomish River estuary.

Much large wood also accumulated within main-stem and distributary channels. The maximum diameter of snags removed annually from Puget Sound rivers ranged between 3.7 and 5.2 m from 1898-1909 (Collins *et al*., 2001, submitted). There is no evidence of major raft jams in the Snohomish River such as were encountered in the Stillaguamish and Skagit rivers. However, an Army Corps map (1874) identifies a jam at the head of Ebey Slough and an accumulation of snags one mile downstream of city of Snohomish at Clark's Bend. An 1884 report refers to a drift pile 1.5 miles upstream of Snohomish between Pilchuck and French creeks (USACOE, 1884). Major Nathaniel Micheler describes a reconnaissance mission up the Snohomish on October 22, 1874:

> *"...The [main river] is very shallow and filled with snags, and consequently is not used; the same...with...Union [Slough] as it contains two jams...Ebey's Slough is unfit for navigation, containing several jams, and being very narrow and crooked in places. Steamboat Slough is the only one navigable...The latter contains very deep water...to the head of navigation at Snohomish City, fourteen miles from its mouth. No jams or rafts exist, and but few snags are encountered until you reach Clark's Bend, a sharp turn in the river, which is filled with them; from there to Snohomish City, two miles above, the channel becomes again clear" (USACOE, 1875).*

History of Development and Resource Exploitation

The establishment of a community along the shores of Tulalip Bay in 1853 by John Gould marks the beginning of non-native settlement in the vicinity of the Snohomish River valley (Interstate Publishing Company (IPC), 1906). The first steamboat entered the estuary in 1855 (IPC, 1906). In 1859 the town of Lowell (RK 11.3) was established on the left bank of the Snohomish River followed by the towns of Snohomish (RK 20.6) and Everett in 1860 and 1891, respectively (IPC, 1906).

Beginning in 1861 the first lumbermen in the region initiated timber operations on the town sites of Lowell, Everett and Marysville, and along Ebey Slough (IPC, 1906). Felling of the riparian forests along Union and Steamboat sloughs soon followed. Logging operations along the main stem commenced in 1864 (IPC, 1906), and by 1902 early settlers had harvested the entire forest within the Snohomish River floodplain (Plummer *et al.*, 1902). Photo 3-3 (~1900) shows an early logging camp and riparian forest along the Snohomish prior to clearing at an unidentified location along the Snohomish River. Logging companies used the river for timber transport and storage.

Log rafting in the estuary began in the early 1890s and continues to the present (Houghton *et al.*, 1995).

Logging crews cleared fallen trees from Steamboat Slough in the spring of 1864, thus opening it to steamboat navigation (IPC, 1906). Snag removal operations in the Snohomish River began in 1881 and commonly extended up to "Stretch's Riffle" about 5 miles upstream of the town of Snohomish (e.g., USACOE, 1892). Snagging records of the Army Corps of Engineers document removal of 8,576 snags from the Snohomish River, an average of 238 total pieces annually, between 1881 and 1909 (Collins *et al.*, 2001, submitted). We have not located snagging records specific to the Snohomish River for the period between 1910 and 1940. An additional 4,920 snags were pulled from the river and harbor (103 snags/year) between 1941 and 1968 (Collins *et al.*, 2001, submitted). Using these data to define the range, 17,000 (lower estimate) to 23,000 (upper estimate) logs were removed from the Snohomish River and estuary from 1881 through 1968 (Collins *et al.*, 2001, submitted). In addition to removing snags, the Army cut down 985 overhanging trees from riverbanks along the Snohomish between 1881 and 1906, an average of 58 trees/year (Collins *et al.*, 2001, submitted). Snagging operations have continued into the present in the estuary to remove boating hazards and accumulated wood on bridge supports.

Additional channel modifications include dredging, harbor construction, diking and bank armoring. The lower river up to RK 6.4 has been dredged annually since the construction of Port Gardner. Jetty Island and Port Gardner were constructed between 1895 and 1905, and the main stem was rerouted through the east waterway along the Everett waterfront. Recognizing the agricultural value of the Snohomish estuary and floodplain, early settlers reclaimed tidal marsh for cultivation through dike construction (Figure 3-5). In 1864 Dr. H.A. Smith enclosed a 26 hectare plot on Smith Island, but the dike failed 13 years later (Nesbit, 1885). By 1883 176 hectares had been "successfully" diked (Nesbit, 1885). By 1909 dikes had reclaimed Smith Island, North Spencer Island, North Ebey Island, north of Ebey Slough near Marysville, and most of the Everett shoreline (ACOE 1901; USGS, 1909). Dikes were constructed around the remaining tidal marsh by 1940, with the exception of marshes associated with Quilceda Creek, Otter Island, the western lobe of North Ebey Island, and scattered parcels along Ebey Slough.

Currently 71 kilometers of dikes in the lower estuary downstream of the divergence of Ebey slough from the main stem isolate the river from its former tidal marsh (Pentec, 1998).

Early settlers also recognized the agricultural value of vast marshes upstream of Ebey Slough. In reference to the bottomland marshes adjacent to the town of Snohomish, Morse wrote “No land anywhere can be found of superior fertility, or that will produce larger crops of grain or vegetables”(Northern Star Newspaper, April 14,1877). By 1882 settlers had staked claims to the entire Snohomish floodplain (Snohomish County Road Maps 1882). Ditching and draining of French Creek marsh began in 1875 followed by Marshland in 1883 (IPC, 1906). By 1940 most of the Snohomish River had been armored. The first pump-station was constructed on French Creek in 1956 (Ruskell, 1995), followed by the construction of a pump-station at Marshland in the early 1960s (SCSWM, 1995). Approximately 37 kilometers of dike or bank armor currently confine the Snohomish River upstream of RK 12.5 to the confluence of Snoqualmie and Skykomish River).

Habitat Change in the Lower Estuary

Tidal Marsh

Prior to settlement by non-natives in the mid-19th century, the Snohomish estuary contained 3,950 hectares of tidal marsh (mudflats excluded) between Priest Point and the divergence of Ebey Slough from the main stem (Figure 3-6). It included 5 percent within the estuarine emergent marsh, 29 percent within the emergent/forested transition, and 66 percent within the forested riverine/tidal zone. The current (1996) marsh patchwork encompasses approximately 600 hectares, or one-sixth of the historic extent (Figure 3-7). The FRT zone lost 95 percent of its historic area, the greatest habitat reduction among the three habitat zones. The EFT and EEM zones lost 68 and 38 percent of their historic habitat areas, respectively. Most of the marsh was diked and converted to agricultural uses. More permanent losses from industrial development, municipal sewage treatment, waste disposal, and infrastructure account for approximately 10 percent of the total reduction in tidal marsh area. These losses have impacted the EFT zone most heavily, while agricultural development accounts for the majority of the habitat loss within the FRT zone. In addition to these losses, estuarine emergent marsh eroded along the bayside of Smith Island. Reduced sediment delivery due to rerouting of the main stem through the east waterway and dredging is a possible cause.

The EEM zone was devoid of trees with the exception of an occasional spruce on natural levees along distributary sloughs. The EFT zone contained sparse and sporadic tree cover (Figure 3-8). The survey identified trees only 38 percent of the time, presumably because the zone was largely treeless, and at an average distance of 12 m. Trees were larger and more closely spaced along distributary sloughs and large blind tidal channels. The largest tree measured within the EFT zone during the GLO survey was a 1.2-meter diameter maple, and the average tree diameter within the sample population was 0.32 m. The EFT zone contained eight tree species, four deciduous (31%) and four coniferous (69%). Spruce (*Picea sitchensis*), the dominant bearing tree, comprised 41 percent of all trees surveyed by stem number and 62 percent of the total by cumulative cross-sectional basal area. Crabapple (*Malus fusca*) was the most abundant deciduous species, but maple (*Acer marcrophyllum*) had a much larger cross-sectional basal area.

Bearing trees in the FRT zone (downstream of the head of Ebey Slough) were identified 93 percent of the time at an average distance from the survey marker of 4 m (Figure 3-8). As in the EFT zone, larger trees and higher densities occurred along distributary sloughs and large blind tidal channels. The FRT zone contained ten tree species, four deciduous (56%) and six coniferous (44%). Alder (*Alnus rubra*) was most abundant, followed in descending order by spruce, pine (*Pinus* sp.), crabapple, and fir (*Pseudotsuga menziesii*). Spruce comprised approximately half the cumulative cross-sectional basal area. The largest tree identified during the GLO survey within the FRT zone was a 1.2-meter diameter spruce.

In addition to eliminating tidal marsh area, land-use practices likely have altered LWD characteristics, abundance and recruitment within marshes. We measured 9.5 pieces/hectare of LWD within 4 hectares of estuarine emergent marsh between the mouth of Quilceda Creek and Ebey Slough (we did not measure wood deposited in the EFT or the FRT zones). The average dbh was 1.1 m (STDEV= 0.46 m), and the average length, 9.6 m (STDEV=10.8 m). Sixty-eight percent of pieces in the sample population had rootwads, and the average rootwad diameter was 3.5 m. All pieces over 1 m appeared to be in an advanced stage of decay (no bark, no branches, irregular shape). LWD was observed to form scour pools within the marsh and provide topographic high points for colonization by high marsh species and woody species.

The absence of recently recruited LWD probably reflects the reduced supply of very large wood debris (large enough to lodge in the emergent marsh) in the estuary and upstream. Because levees and the absence of large riparian trees continue to restrict the recruitment of large wood debris, the amount of estuarine wood debris will probably continue to diminish as old growth remnant decay.

Blind Tidal Slough Channels

The abundance and area of blind tidal slough channels is substantially diminished (Table 3-4). Prior to development, the Snohomish estuary encompassed at least 94 blind tidal slough greater than 6 meters wide at the network mouth: 10 in the EEM zone, 33 in the EFT zone, and 51 in the FRT zone. Only 20 blind tidal slough networks have never been diked, filled, or tide-gated. Dike failures and intentional breaching reopened 6 networks and created 5 additional networks along agricultural ditches. Including new and restored channels, there were one-third as many networks in 1996 as historically.

Historic blind tidal channel area at high tide is estimated at 163 hectares: 20 hectares in the EEM zone, 64 hectares in the EFT zone, and 79 hectares in the FRT zone. In 1996, blind tidal slough area was approximately one quarter of the total pre-settlement area (including new and restored channels).

Distributary Sloughs and Main stem

The position of distributary sloughs and the main stem within the Snohomish estuary is very similar to channel location on the USC&GS (1884). Likewise, surface area of these features has changed little relative to blind tidal channel area (Table 3-5). The most substantial changes were the construction of Jetty Island from dredge spoils and the rerouting of the main stem through the East Waterway along the Everett waterfront (completed in 1905). Other significant modifications include the isolation and partial filling of a distributary slough channel between the main stem and Steamboat Slough, a loss of 5.9 hectares, and the excavation of a channel across Spencer Island between Union and Steamboat sloughs, a gain of 0.5 hectares. The net loss of distributary channel area in the Snohomish estuary is approximately 5 hectares.

Habitat Change in the Floodplain

The floodplain (upstream of Ebey Slough) has also experienced dramatic losses of juvenile coho and chinook rearing habitat as a result of forest clearing, marsh draining, beaver trapping, and isolation of the Snohomish River from its floodplain through diking and bank armoring (Table 3-6). The analysis encompasses riparian conditions, palustrine wetlands, small tributaries, side-channels, side-channel sloughs, and beaver ponds.

Riparian

The current (1998) floodplain and non-floodplain riparian forest differs substantially from conditions in the mid-19th century (Figures 3-9, 3-10). Approximately 32 kilometers of dikes and revetments confine the Snohomish River between RK 12.5 and the confluence (not all are directly along the bank edge). Only 30 percent of Snohomish River main stem between the confluence of the Snoqualmie and Skykomish rivers and the head of Ebey Slough has riparian forest greater than or equal to the height of a site potential tree (185 ft) and not isolated from the channel by dikes or revetments. Forested islands and bedrock outcrops along Lord’s Hill between RK 23.5 and RK 33 accounts for most of this length. Only 7 percent of the riparian zone is forested and not isolated by dikes or revetments between RK 12.5 and RK 23.5. Along this reach, riparian cover is generally limited to a single, sporadic band of young trees. Downstream of RK 12.5 at the head of Ebey Slough, riparian forest is sparse and primarily behind dikes. The entire main-stem channel edge along reach 1 is armored with the exception of the right bank between the Hewitt Avenue Trestle and the head of Steamboat Slough.

At the time of the first GLO survey (~1870), alder, maple, and vine maple (*Acer circinatum*) dominated by stem number within the diverse, deciduous-dominated floodplain component of the riparian zone (Figure 3-9). The average distance to bearing trees was 8.4 m. Four coniferous species –spruce, hemlock (*Tsuga heterophylla*), cedar (*Thuja plicata*), and yew (*Taxus brevifolia*) – comprise only 18 percent of bearing trees. As a proportion of cumulative cross-sectional basal area, however, conifer basal area exceeds deciduous basal area, 60 to 40 percent. Cedar, the largest tree species in the floodplain, averaged 1.2 m in diameter. While the largest tree surveyed had a diameter of 1.8 m, stump measurements at several locations in 1998 provide evidence of a larger tree class within the riparian zone than was documented in the GLO survey. We measured four cedar stumps having diameters of 4.2, 3.0, 2.7, and 2.0 m. Other species in the GLO survey with maximum diameters exceeding 1 m were cottonwood (*Populus trichocarpa*), maple, spruce and hemlock.

In 1998, cottonwood and alder dominated the floodplain component of the riparian forest, which is restricted to isolated stands and forested islands upstream of RK 24 (Figure 3-9). Sixty-seven percent of surveyed trees (N = 207) are cottonwood. The average tree diameter at floodplain riparian sites is 0.3 m, and the maximum is 1.5 m.

The non-floodplain component of the riparian forest at the time of the GLO survey was predominantly conifer by stem number, as well as cumulative cross-sectional basal area (Figure 3-10). Hemlock was most abundant, but fir predominated as a percentage of the cumulative cross-sectional basal area. A substantial component also consisted of cedar and spruce. The two deciduous species, maple and alder, comprised 17 percent of the forest by stem number and 6 percent of cumulative cross-sectional basal area. Bearing tree spacing in the non-floodplain component of the riparian zone averaged 7 m from survey markers.

The non-floodplain component of the riparian forest in 1998 had a larger deciduous element than was identified during the first GLO survey, but the species composition and tree size were similar (Figure 3-10). Hemlock appears less frequently in the 1998 sample population than in the GLO data, but alder and maple comprise a larger component of the contemporary sample population. The average tree diameter in 1998 was 0.46 m, and the maximum was 1.5 m. Old-growth forest abuts the left bank between RK 32 and 33.

In summary, the riparian forest along the Snohomish River has undergone major alterations, which have reduced riparian function. Bank armoring and clearing have eliminated much of the riparian forest and its interaction with the river. Where forests have re-established, most stands lack trees of functioning size as LWD. In the floodplain, the riparian zone has shifted from a diverse deciduous forest interspersed with large conifer to a riparian forest almost entirely dominated by cottonwood and nearly absent of conifer species. This may result in a shorter residence time of LWD and jams because cottonwood decays much more quickly than conifer species. However, cottonwood's quick growth rate relative to conifer species may also promote recruitment LWD of functioning size over a shorter timeframe.

Palustrine Wetlands

The Snohomish floodplain contained two huge palustrine marshes historically (Figure 3-4). The extent of Marshland and French Creek marsh as shown on GLO plat maps was approximately 1,950 hectares and 1,420 hectares, respectively. Marshland marsh, located south of the Snohomish River, extended for 13.5 kilometers between the towns of Lowell and Snohomish (Nesbit, 1885; U.S. Survey General, 1866-74). French Creek marsh occupied the valley southeast of the town of Snohomish and north of Lord's Hill, extending in a southeasterly direction from the Pilchuck River to Monroe.

These marshes are fairly similar in tree size and species composition to the forested riverine/tidal zone, but they appear to have had larger areas of open water and an absence of blind tidal channels. Although tidal backwater likely influenced these marsh (tidal influence extend up to Thomas's Eddy at RK 27), the primary influence on hydrology appears to have been tributary stream and river overflow. The GLO survey notes indicate that river overflow at Marshland and extensive beaver dams in French Creek contributed to ponded water on an annual basis (U.S. Surveyor General, 1866-74). Other notable differences among Marshland, French Creek and the FRT zone include dominant tree species and spacing.

Marshland was the least forested of the palustrine marshes. An article in the Snohomish Northern Star (April 14, 1877) identifies the predominant vegetation in Marshland as hardhack. In the GLO survey, no trees were identified at 21 out of 48 bearings, or 44 percent of the time, and the average distance of surveyed trees from a survey marker was 16 m (Figure 3-11). Most trees were small, averaging 0.08 m in diameter. In decreasing order of frequency, bearing trees were identified as pine, spruce, alder, maple and crabapple. Spruce dominated as a percentage of cumulative cross-sectional basal area.

Several sources refer to water level in Marshland. GLO survey field notes provide the best evidence, indicating that 13 of 23 survey locations at the time of the survey in March 1871 were submerged to a depth up to 1 m, and 5 were described as too wet to build a mound (U.S. Survey General, 1866-74). The GLO plat maps (U.S. Surveyor General, 1869-1874) describe the marsh as receiving 2 to 6 feet of overflow. The Snohomish Northern Star (April 14, 1877) reports the depth without reference to season as 1 to 2 feet.

French Creek marsh was covered in small trees and rich with beaver activity. The GLO survey notes indicate that beaver ponds and shallow standing water was prevalent throughout the marsh on an annual basis (U.S. Survey General, 1866-74). Two-thirds of the trees, primarily willow and crabapple, were deciduous, but conifer were on average over twice as large. The average distance to a tree from a survey marker was 5.5 m, and the average tree diameter was 0.13 m. Spruce was the dominant tree as a percentage of the cumulative cross-sectional basal area. French Creek marsh differed from Marshland in that it was more densely covered in small trees, but the habitat implications are unknown.

An article in the Snohomish Northern Star (April 14,1877) describes the French Creek marsh:

> *"It is nearly cut in half by a swath of spruce and cedar timber...The part below this belt, called the lower marsh, ...is splendid pasture land in the summer and fall. [It] is overflowed by freshets in winter and spring...The upper marsh is beaver meadow, covered with grass, hardhack and tea brush [(Ledum groenlandicum) with] no timber of any size."*

The contradiction in this account may indicate that beaver and their dams were removed from the lower marsh between the time of the survey 1866 and 1877.

Small Tributaries

Pump-stations, tide-gates, and floodgates have isolated tens of kilometers of habitat in tributaries in the Snohomish floodplain. The Marshland pump-station (RK 11.3) blocks access to a 76-kilometer network of channeled streams and ditches within the floodplain and 22 small hillside creeks. The French Creek pump-station (RK 22.9) impedes juvenile migration and access to adult chinook, and severely restricts adult migration for other species into 27 kilometers of creeks and ditches within the floodplain and 18 kilometers of anadromous fish habitat upstream of the floodplain. Eighty-nine percent of the floodplain component of the French Creek subbasin flows through ditches. Flood control structures also restrict access into seven small creeks along Ebey Slough including Allen Creek, but the extent to which these structure impede migration is unknown.

Side-Channels

Aerial photos from 1933 provide the earliest detailed record of side-channel habitat along the Snohomish main stem. The total length of side-channels decreased by 37 percent between 1933 and 1996. Most of the side-channels lost occurred along reach 4. Data from 1933 probably underestimates the overall loss since non-native settlements were established in the mid-19th century because significant bank armoring and the removal of thousands of snags occurred prior to 1933; Debris jams contribute to the formation of side-channels (Keller and Swanson, 1979).

Side-Channel Sloughs

Dikes, flow control devices, and agricultural development have degraded and eliminated off-channel rearing habitat in side-channel sloughs along the Snohomish

River. The area of side-channel sloughs accessible to juvenile salmonids has decreased by 55% between 1884 and 1996. At approximately RK 21.5 the Army Corps of Engineers installed floodgates on Hanson and Batt's sloughs (between 1940 and 1958). Farmers later drained and cultivated Hanson Slough. A pump-station on French Creek (RK 22.9) blocked anadromous salmonid migration between 1956 and 1991. A new pump-station and fish ladder constructed in 1991 still impedes adult salmonid migration (SCSWM, 1997) and blocks juvenile access into off-channel rearing areas. The pump-station continues to exacerbate poor water quality conditions in lower French Creek by restricting flow, thus contributing to French Creek's placement on the 303(d) list; temperatures and nutrient levels are high, and dissolved oxygen levels are low (SCSWM, 1997). Dikes restrict flow and access into Shadow Lake and associated wetlands (RK 25.8). No salmonids were captured in Shadow Lake during a summer electrofishing survey on August 16, 1998. Lake Beecher and associated wetlands are accessible(RK 27.4), but a sparsely forested riparian buffer and the introduction of predatory fishes such as bass (*Micropterus* sp.) have degraded its rearing value. Smallmouth bass feed voraciously on juvenile salmonids (Rieman *et al*., 1991; Tabor *et al*., 1993).

Beaver Ponds

We estimated historic beaver pond area along 32 kilometers of small, floodplain tributaries and side-channels (area within floodplain and estuarine marshes was analyzed separately) at 23 hectares. In 1998 beaver pond habitat within the Snohomish floodplain exists at the mouth of Cemetery Creek and in side-channels between RK 27.4 and RK 33. We measured the current (1998) habitat area in beaver ponds at 14 hectares, or 61 percent of the historic estimate.

Habitat Change in the Main stem

Channel Position and Area

Channel position and length has changed little over the period of record (beginning in1884) (Figure 3-12; Figure 3-13). Changes include the straightening of the Snohomish River one mile downstream of the city of Snohomish at “Clarks Bend”, which resulted in the formation of an off-channel feature known as “Mud Bay”, and a slight decrease in sinuosity upstream of “Thomas’s Eddy” along reach 4. The former occurred prior to 1933, and may have resulted from the removal of wood. The US Survey General identified “Clark’s Bend” as the most significant accumulation of snags between the city of Snohomish and the head of Ebey Slough (1875). The latter change in channel position occurred after 1933. The relatively stable condition of the Snohomish River probably reflects extensive diking and bank armoring, which commenced soon after the creation of the first maps. Oxbows, side-channel sloughs and floodplain topography provide evidence of more significant channel migration prior to 1884.

Changes in channel area are modest (Table 3-7), and probably to some extent, reflect natural fluctuations. Wetted area increased slightly between 1884 and 1933, but decreased by approximately one-fifth between 1884 and 1998. Likewise, bankfull channel area decreased by approximately one-fifth between 1933 and 1998 (bankfull channel area was not discernible from the 1884 GLO plat maps). Much of the loss in bankfull channel area occurred at the inside of the bend just upstream of the break between reach 3 and 4 at “Thomas’s Eddy” following the construction or reinforcement of a dike. Forested island area increased by approximately 4.5 times between 1884 and 1998. Most of the increase occurred subsequent to 1933, and is primarily a result of a recent channel bifurcation at the confluence of the Snoqualmie and Skykomish rivers. Forested island area also increased along reach 3 and 4 through the colonization of non-vegetated bars by cottonwood. Island expansion may reflect channel recovery following a flood event, riparian removal or other disturbance.

Pools

On October 1, 1998 during seasonal low flow, we measured the dimensions and distribution of 18 pools between the confluence of the Snoqualmie and Skykomish rivers (RK 33) and RK 24.5. Pools were large, deep, and lacking wood debris. They were spaced on average every 3 channel widths. Wood is the primary forming feature of only one shallow pool (Figure 3-14). Natural free-formed pools and bedrock-formed pools are of intermediate frequency and depth. Riprap-augmented freeform pools, the most common type, are the deepest. A riprap-augmented freeform pool at “Thomas’s Eddy” (RK 28) was over 8 m deep.

Deep pools increase holding area and cool water refuge for returning adults. Nielsen *et al.* (1994) found low temperatures (3-9^{o} C less) at the bottom of large deep pools with high volume to discharge ratios relative to smaller pools in three northern California rivers. Berman and Quinn (1991) hypothesize that the availability of suitable thermal refuge and holding areas within main-stem rivers may affect long-term population survival of spring chinook in the Yakima River, Washington.

Factors associated with riprap-augmented, freeform pools, however, may lesson their habitat value. Bank revetments reduce large woody debris recruitment by isolating the channel from the floodplain forest. Increased channel depth and “smooth” edges associated with armored banks may also decrease the potential for wood becoming incorporated into or racking up on channel banks. Beamer and Henderson (1998) found that juvenile coho and chinook exhibited a strong preference for natural banks and wood cover over armored banks along the Skagit River. Sub-yearling chinook, for example, were 5.4 times as abundant along wood cover banks than along riprap. Furthermore, Pess *et al. (1998)* found twice as many chinook redds adjacent to pools with high wood loading (3 times as much) over pools with less wood in the North Fork Stillaguamish.

Large Woody Debris

Overall, wood debris in the Snohomish consists of individual pieces of old, relict cedar on the bed of the river, and secondarily smaller-diameter young pieces on the banks; there are no major jams. In three sample areas, the majority of wood was “old”, (59%, 41%, and 96%, respectively upstream to downstream)(Figure 3-15). A large component of pieces which could not be classified accounted for 28%, 27%, and 0%, respectively, and most of these are also presumably “old” because the majority of submerged pieces are “old”. Most debris was in the low-flow channel (the wetted area during the summer and early fall). “Young” debris comprised the smallest component of the total sample (11%, 13%, and 2%, respectively). “Young” debris was found most frequently on banks and secondarily in the thalweg as snags in the upper two sample reaches.

Debris in the low-flow channel was greater in diameter than debris on banks and bars. Older pieces had a greater average diameter (0.47 m) but shorter length (7.2 m) than intermediate age (diameter = 0.32 m, length = 10.3 m) or younger pieces (diameter = 0.34 m, length = 11.5 m). Overall, wood debris averaged 0.42 m in diameter and 8.4 m in length.

Older debris was also less likely to have a rootwad attached. Thirty-six and 34 percent of “young” and “intermediate” wood had rootwads, respectively, while only 15 percent of “old” wood had rootwads. Rootwads of younger pieces were larger, and average rootwad cross-sectional area decreased in a downstream direction (3.5 m, 2.5 m, and 1.1 m). Overall, only 22 percent of debris pieces had rootwads and the average diameter was 2.4 m^2.

Cedar was the most common species, and was almost entirely “old.” For example, in the upstream-most sample, cedar accounted for 24% of debris that could be identified, and 100% of those pieces were “old.” Conifers unidentified to species accounted for most of the remaining “old” pieces in the same sample. Deciduous species were mostly “young” and “intermediate.” Alder, the most commonly identified deciduous species, was 35% “young,” 61% “intermediate” and only 3% “old.” Cedar pieces were more than twice as large in diameter than alder or unidentified pieces and nearly half as long. Cottonwood pieces were the largest overall, with the greatest length and the second greatest diameter.

The larger relative diameter of older logs than younger logs probably reflects old growth cedar remnants and the slower transport rate of larger wood through the system. The shorter length of old logs and smaller size of rootwads is probably due to attrition. The smaller diameter of logs on banks and bars is attributable to recent, localized recruitment from second- and third-growth stands. Decreasing relative abundance of younger LWD in a downstream direction reflects the lack of resistance to transport of small wood and decreasing recruitment due to higher levels of bank armoring and less mature forest along the channel edge

In the longitudinal survey, wood abundance averaged 112 pieces/river kilometer (18 pieces/channel width), although variation between reaches is high (Figure 3-16). The largest amount was in the low-flow margin (44%), and the second largest portion on the banks (34%). Banks and low-flow margin together accounted for 84% of debris. “Snags” accounted for 44% of the low-flow channel total. Pieces just beneath the surface (0-2 ft) below the surface) accounted for an additional 25%.

The largest concentration of wood in the thalweg is at a riffle known as “Thomas’s Eddy” (RK 28), which corresponds with and is likely related to the upper limit of tidal influence. A relatively high wood abundance in the upper few kilometers of the Snohomish may be due to a decrease in gradient as the steeper Skykomish enters the Snohomish River and the availability of local wood recruited from undiked, forested banks.

Wood debris characteristics in the Snohomish River are significantly different from those in undeveloped and unmanaged reaches of rivers in western Washington (Figure 3-17, Figure 3-18). For example, a reach of the Nisqually River (which has a smaller basin area and steeper channel slope than the Snohomish) that has a mature riparian forest and natural banks, has about eight times more pieces/channel width (a minimum of 140 pieces/channel width) than in the Snohomish River (Collins *et al*., 2001, submitted). In the Nisqually, most (89%) wood was in debris jams, which contrasts to the Snohomish where no jams were noted. The presence of jams in the Nisqually is in part because of the presence of abundant large (>1 m diameter) in-channel wood debris pieces which can function as key pieces in jams. In addition, most debris pieces in jams are long and have rootwads; in the Nisqually, 97% of jam-initiating logs and 54% of racked pieces had rootwads, while in the Snohomish River, only 22 percent of wood debris had rootwads (Collins *et al*., 2001, submitted).

The contrast between the two rivers is likely related to past land use. Directly and indirectly, forest conversion and harvest and river containment have reduced the size and quantity of recruited wood debris. The Snohomish has little opportunity to recruit wood debris of the size necessary to create key pieces or to recruit the quantity of stable pieces necessary to create large jams. Over 60 percent of the Snohomish River has little or no riparian forest along its banks (left, right, and forest island edge). Additionally, approximately 32 kilometers of dikes and revetments along the main stem between RK 12.5 and RK 33 and 44 kilometers of levees along the main stem and sloughs downstream of Ebey Slough isolate the Snohomish River from local sources of wood recruitment. The Snoqualmie and Skykomish rivers have also been heavily diked, thus reducing wood debris recruitment rates from upstream. As previously described, the Army Corps of Engineers removed thousands of snags from the Snohomish River and estuary.

Negative feedback mechanisms initiated by channel modifications may exacerbate the loss of wood from the Snohomish River. Without jam-initiating, key piece logs, rivers transport smaller logs, which would otherwise rack up on key pieces, more rapidly through the system. Additionally, the impact of diking on the channel cross-section may contribute to wood loss. In a diked channel, peak flow events exert greater forces on instream structures because the containment of flow between levees prevents the dissipation of energy over the floodplain.

Edge Habitat

Reduced wood debris loading and the addition of bank armoring have degraded juvenile salmonid rearing capacity within the main stem Snohomish River. Eighty-four percent (84%) of the total bank edge (not including bar and backwater edge) along the Snohomish upstream RK 12.5 has been diked and/or armored. Wood debris as a percentage of channel edge habitat along hydromodified banks is less than 50 percent of wood abundance along natural banks (Figure 3-19). Bankroot, rootwad, and debris pile cover types in particular are significantly less abundant along hydromodified banks.

In addition to the direct losses resulting from bank armoring, the indirect losses resulting from reduced wood debris loading and recruitment are evident along both hydromodified and natural banks. Relative to pristine reaches of Puget lowland rivers, wood in the Snohomish is infrequent, lacking rootwads and rarely accumulated in debris piles (discussed in previous section). Only two significant debris accumulations currently exist along the entire length of the Snohomish (RK 26.1 and RK 30.6). The implications of edge habitat changes on chinook and coho production potential are discussed in the following section.

CHINOOK AND COHO SALMON PRODUCTION POTENTIAL PAST AND PRESENT

Production in the Lower Estuary

Table 4-8 and Table 4-9 summarize the change in smolt production capacity within the estuary (downstream of RK 12.4) for chinook and coho due to the reduction in habitat quantity. Prior to development, the estuary could support approximately 2.6 million chinook smolts. Current chinook smolt production capacity is estimated at 1.0 to1.6 million smolts, a decrease of 40 to 61 percent. The 40 percent production loss estimate is based on the change in area of accessible habitat and an assumption that habitat available to juvenile salmonids in distributary sloughs and the main stem currently is comparable to pre-development conditions. The 61 percent estimate is based on an assumption that near continuous hydromodification and extensive wood removal have reduced available habitat in channel margins by 50 percent. Since these estimates reflect only production loss due to habitat quantity not quality (e.g., temperature, dissolved oxygen), they likely provide a conservative estimate of the overall production loss.

Chinook smolt production capacity varies by habitat type and zone (Figure 4-20; Figure 4-21) [The following breakdown of production loss is based on the mean of the high and low estimate]. In the mid-19th century prior to diking and development in the estuary, two-thirds of chinook production occurred within the emergent/forested transition (EFT) zone, with 18 and 13 percent occurring within the estuarine emergent marsh (EEM) zone and forested riverine/tidal zone (FRT), respectively. The greatest loss in production capacity (56%) occurred within the FRT zone. Prior to diking and development, blind tidal channels provided over one-half of chinook production in the estuary. Production potential in blind tidal channels has decreased by over two-thirds, and as a result, the majority of chinook production capacity now occurs within distributary sloughs rather than blind tidal channels.

Coho smolt production in the Snohomish estuary coincides with the FRT zone, the freshwater component of the estuary. Prior to development and diking, the estuary could produce approximately 97,000 and 292,000 smolts in summer and winter, respectively (Figure 4-22). Habitat loss has resulted in a loss of over one-half of the pre-development summer and winter smolt production capacity (Figure 4-22). As with chinook, coho production, which once occurred predominantly in blind tidal channels, now occurs primarily within distributary sloughs, due to the more extensive loss of blind tidal channel habitat (Figure 4-23).

Production in the Floodplain

The isolation, filling and draining of habitat in the floodplain (between the confluence of the Snoqualmie and Skykomish rivers and the head of Ebey Slough) has also had a substantial impact on chinook and coho rearing (Figure 4-24; Figure 4-25). Pre-smolt chinook rearing capacity in the floodplain decreased from a mean estimate of approximately 1.2 million in the mid-19th century to 36,000 in 1998. Summer coho smolt production potential decreased from a mean estimate of 3.4 million smolts in the mid-19th century to 155,000 smolts currently. Winter coho smolt production potential dropped from approximately 7.4 million to 376,000. Significant losses occurred due to the disconnection of side-channel sloughs between RK 22 and 24, but the vast majority of lost production for both species occurred in the Marshland and French Creek marshes (Table 4-10).

Since the extent of standing water in each marsh within a given season is not known precisely, historic production estimates were generated over a range of usable rearing area estimates. Historic estimates of chinook rearing capacity in palustrine wetlands within the floodplain based on usable area in summer range from 710,000 to 1.54 million pre-smolt chinook. Based on the same usable area estimates, Marshland and French Creek marshes could have produced between 770,000 and 1.7 million coho smolts in summer and between 4.3 and 7.4 million smolts in winter. All estimates assume full dispersal by juveniles within the basin to occupy available rearing habitat.

Currently, no chinook and coho production occurs in Marshland because of anthropogenic barriers, with the exception of years when the levees overtop or flow control structures fail. It is highly probable but undocumented that floodwaters transport juveniles into off-channel rearing areas behind levees during 5-year+ peak flow events. A pump-station on French Creek also blocks access for adult chinook and all juvenile salmonids. Some coho pass the pump-station via a fish ladder and spawn upstream. It is likely that some of their progeny rear in ditched floodplain streams, prior to exiting the French Creek sub-basin.

Floodplain isolation and modifications to accommodate commercial agriculture also reduced the quantity of habitat available to juvenile salmonids in small tributaries, side-channels, beaver ponds associated with these habitat types, and side-channel sloughs. Pre-smolt chinook rearing capacity in these habitats decreased from an estimated 80,000 to 40,000. Coho smolt production capacity decreased from an estimated 300,000 smolts prior to development to 140,000 currently. Winter coho smolt production potential dropped from approximately 780,000 to 360,000.

Production in the Main stem

Change in coho and chinook rearing capacity in the main stem is estimated using edge survey results and preference ratios for various edge habitat types (Beamer and Henderson, 1998). Historic rearing capacity relative to current rearing capacity was estimated for the Snohomish River under several scenarios (Figure 4-26). We calculated a weighted average of usage coefficients for current conditions in the channel margin and compared them to weighted averages of usage coefficients calculated for historic condition scenarios.

In scenario 1, current edge cover conditions along natural banks are extrapolated over the entire length of hydro-modified channel edge. Historic production for chinook, summer coho parr and winter pre-smolt coho was 39, 20 and 4 percent greater than current production potential, respectively. Scenario 2 addresses the loss of rootwads due to attrition and lack of new recruitment by applying the ratio of wood debris with rootwads found in racked members of debris jams in the Nisqually (54%) to the Snohomish River. Historic production estimates for chinook, summer coho parr and winter pre-smolt coho are 76, 161 and 52 percent greater than current production potential, respectively. These estimates are very conservative because they account only for the change in rootwads abundance and not overall wood abundance; the “pristine” reach of the Nisqually River had 8.8 times the wood loading per channel width as the Snohomish.

The future condition scenario examines the potential consequence of the decay of old-growth remnants in the future if new large wood is not recruited. Unless dikes are breached and the river is allowed to migrate through its floodplain, old-growth remnants may not be replaced with new wood debris as they decay or become mobilized. Therefore, it is likely that conditions will worsen before they get better in the absence of restoration. If old-growth remnant logs decay and are not replenished through new recruitment then future production potential for chinook, summer coho parr, and winter pre-smolt coho in the main stem will decrease by 39, 54, and 35 percent, respectively, in addition to losses experienced to the present.

Summary and Production Implications

Significant production losses since the mid-19th century (>50% for each habitat area), presented in relative terms, occurred across estuary, floodplain and main stem habitat types for chinook salmon (Figure 4-27) and coho salmon (Figure 4-28). The largest relative change in chinook smolt production capacity (-96%) occurred in the floodplain, primarily within Marshland and French Creek marshes. Main-stem and estuary habitat types lost 76 and 50 percent, respectively. The substantial losses within the freshwater component of Snohomish River valley have likely had the greatest impact on stream-type chinook. The loss of off-channel habitat has also likely impacted survival of chinook exhibiting other life history strategies that may have used these areas as refuge during peak flow events.

Although the largest relative change occurred in floodplain habitat types, habitat loss in the estuary resulted in a larger production capacity change (1.0-1.6 million smolts). This analysis suggests that the estuary is commonly the bottleneck to chinook production in the Snohomish River basin. From 1968 to 1999, the mean escapement for the Snohomish was 4,671 adults (STDEV = 1,274). In the Skagit River basin (freshwater survival estimates are not available in the Snohomish at this time), Skagit System

Cooperative estimated freshwater survival at 280 smolts/spawner in an average flow year and a maximum freshwater survival of 400 smolts/spawner under optimal conditions (Beamer *et al*., 1999). At the mean escapement level in the Snohomish, with freshwater survival comparable to the Skagit in an average flow year, 1.3 million smolts would enter the estuary, an amount equal to the mean carrying capacity we calculated for the Snohomish estuary. This suggests that in years when escapement and/or freshwater survival are higher than the mean, the estuary, through density-dependent constraints, caps the chinook outmigration at roughly 1.3 million smolts.

Assuming comparable freshwater survival in the Snohomish to the Skagit (280-400 smolts/spawner) and a carrying capacity for the estuary of roughly 1.3 million smolts, between 1968 and 1999, chinook experienced density-dependent constraints on production in the estuary between 45 and 87 percent of the time. These estimates are based on an assumption that all chinook smolts use the estuary, the same assumption made by Beamer *et al*. (1999) in the Skagit based on otolith sampling from chinook in Skagit Bay, which indicated that nearly all fish used estuary habitat. In the Snohomish, however, approximately one-quarter of chinook are thought to exhibit the stream-type life-history strategy. Although these fish have been documented in blind tidal channels within the estuary, it is believed that many pass through quickly. Even if it is assumed that 25 percent of the population passes straight through, the estuary would still have exerted density-dependent constraints 10 percent of the time at a 280 smolts/spawner and 55 percent of the time in years when freshwater survival was high since 1968. In addition to offspring from natural spawners, the Snohomish estuary is seeded each year by millions of 1+ chinook from the Wallace Hatchery. To the extent that these fish use estuary habitats, density-dependent constraints are increased.

Like chinook, coho experienced the greatest relative loss of production capacity in off-channel habitats in the floodplain (95%). Main-stem production capacity decreased by 62 and 34 percent in summer and winter, respectively. Production capacity in the estuary also decreased by over 50 percent.

Given the severe drop in summer and winter rearing capacity identified throughout the Snohomish River valley and the relatively small amount of spawning habitat necessary to seed large areas of rearing habitat, it is likely that rearing habitat, either summer or winter, is the production bottleneck in the Snohomish River basin. Coho limiting factors analysis in the Skagit and Stillaguamish river basins identified summer rearing as limiting followed by winter rearing (Beechie *et al*. 1994; Pess *et al*., 1999).

A complementary report, Ecosystem restoration opportunities in the Snohomish River valley, Washington (Haas, 2001), identifies restoration opportunities to address production bottlenecks and the potential production gains associated with their implementation.

CONCLUSION

Key Findings

- **Habitat Changes in the Lower Estuary** – Prior to human induced changes, the Snohomish River basin included approximately 3,950 hectares of tidal marsh (not including mudflats) between Priest Point and the divergence of Ebey Slough from the main stem. The marsh was composed of 5 percent within the estuarine emergent marsh (EEM) zone, 29 percent within the emergent/forested transition (EFT) zone, and 66 percent within the forested riverine/tidal (FRT) zone. Only one sixth of the historic marsh area remains. Sixty-one blind tidal channel networks greater than six meters wide at the mouth have been lost, and only one-forth of the blind tidal slough area remains intact and connected to the channel network. Distributary slough and main-stem channel area and position have changed little, but near continuous diking, riparian clearing and wood removal have significantly modified habitat condition in the channel margins.
- **Habitat Changes in the Floodplain** – Prior to timber harvest and clearing in the late 19th century, one-fifth of the floodplain riparian forest was coniferous, and it contained trees up to 4 meters in diameter. Currently, 70 percent of the Snohomish River has no riparian forest greater than or equal to one site-potential tree height (56 m) in width. The remaining floodplain riparian forest, which is almost entirely comprised of cottonwood (*Populus trichocarpa*), contains only 2 percent coniferous trees. Very few trees exceed 1 meter in diameter. As a result of these changes to the riparian forest coupled with extensive diking, the river receives limited recruitment of wood that is large enough to function as cover or influence the channel morphology. Land-use impacts also reduced off-channel habitat. Settlers drained and/or isolated approximately 3,370 hectares of palustrine marsh in the floodplain upstream of Ebey Slough. Flow control devices isolates or restrict access to tens of kilometers of channels from the river. Diking and bank armoring has also contributed to a 2-kilometer decrease in the total length of side-channels and a 55 percent reduction in

the area of side-channel sloughs. Beaver pond area occupies only three-fifths of its historic extent (not including habitat loss in vast floodplain marshes).

- **Habitat Changes in the Snohomish River –** Main-stem channel position and area have changed little from 1884 through 1998, presumably because of diking and bank armoring. Pools within the main stem (upstream of RK 24.5) are currently large and spaced on average every three channel-widths. Wood debris in the Snohomish consists of individual pieces of old, relict cedar on the bed of the river, and secondarily, smaller-diameter, younger pieces on the banks. It averages 0.42 meters in diameter and 8 meters in length. Only 22 percent of logs have rootwads. The Snohomish River contains an average of 18 debris pieces per channel width. In contrast, a largely undisturbed reach of the Nisqually River contains 140 debris pieces per channel width (Collins *et al.*, 2001, submitted). In the Snohomish River, wood as a percentage of channel edge habitat in the slack-water channel margin along hydromodified banks is less than 50 percent of wood abundance in the slackwater channel margin of natural banks.
- **Changes in Chinook and Coho Salmon Production Potential –**

  Lower Estuary **–**Prior to development, the estuary (between the head of Ebey Slough and Priest Point) could support approximately 2.6 million chinook smolts. Current smolt production capacity is between 1.0 and 1.6 million smolts, a decrease of 40 to 61 percent. The greatest loss in production potential by habitat zone (56%) has occurred in the emergent/forested transition (EFT) zone followed by the estuarine emergent marsh (EEM) zone and the forested riverine/tidal zone, respectively. By habitat type, the greatest loss has occurred in blind tidal channel networks, where chinook salmon smolt production potential has decreased by 68 percent. Coho salmon production potential in the forested riverine tidal (FRT) zone (freshwater component of estuary) has decreased by approximately one-half.

  Floodplain **–**Disconnection and destruction of off-channel habitat has eliminated approximately 95 percent of chinook salmon rearing capacity and coho salmon smolt production capacity in the floodplain. Pre-smolt chinook rearing capacity in the floodplain decreased from a mean estimate of approximately 1.2 million in the mid-19th century to 36,000 in 1998. Summer coho smolt production potential decreased from a mean estimate of 3.4 million smolts in the mid-19th century to 155,000 smolts currently. Winter coho smolt production potential dropped from approximately 7.4 million to 376,000. While significant losses occurred through the isolation of side-channel sloughs, the vast majority of habitat loss occurred through the draining and diking of Marshland and French Creek marshes.

Main stem - Historic production estimates for chinook salmon, summer coho salmon parr, and winter pre-smolt coho salmon in the main stem are 76, 161 and 52 percent greater than current estimates, respectively. If old-growth remnant logs decay and are not replenished through new recruitment, then future production potential for chinook, summer coho parr, and winter pre-smolt coho in the main stem could decrease by 39, 54, and 35 percent, respectively, in addition to losses experienced to the present.

Summary and Implications – The largest relative change in chinook smolt production capacity (-96%) occurred in the floodplain, primarily within Marshland and French Creek marshes. The largest production capacity change (1.0-1.6 million smolts) occurred in the estuary. Our analysis suggests that the Snohomish estuary is commonly a bottleneck to chinook production. Assuming comparable freshwater survival in the Snohomish to the Skagit (280-400 smolts/spawner), Snohomish escapement estimates and a carrying capacity for the estuary of 1.3 million smolts, between 1968 and 1999, chinook experienced density-dependent constraints on production in the estuary between 45 and 87 percent of the time. To the extent that competition with hatchery fish, habitat fragmentation and temperature reduce capacity, production may be constrained further. For coho salmon, the greatest relative and actual change in production capacity occurred through the disconnection and draining of larger palustrine marshes within the floodplain.

Data Gaps and Next Steps

Temperature Modeling

Water temperature in the Snohomish estuary has been documented at stressful and lethal levels for salmonids in main stem, distributary slough and blind tidal channel habitats during the outmigration period. Pentec (1992) documented a temperature of 27^o C on May 15th in Union Slough and found temperatures as high as 28^o C in Spencer Marsh in late May and June. Average temperatures in main-stem habitats ranged from 4.9^o C in December to 17.9^o C in August in main channels and from 4.2^o C to 24^o C at individual off-channel sites over the same time period (Pentec 1992).

Temperature sampling and modeling could be used to identify locations where high temperatures are a concern, the root cause of temperature problems and areas of thermal refuge. The data would benefit restoration and mitigation projects design and the development of an overall restoration strategy for the estuary.

Distribution of Coho and Chinook in the Estuary

Data suggest that juvenile chinook, even within the same habitat zone, are not evenly distributed within the Snohomish estuary (Beauchamp, 1986). A substantially greater abundance of juvenile chinook were captured in the main-stem Snohomish than at sites along Steamboat and Ebey sloughs (Beauchamp, 1986). It is unclear whether the uneven distribution is related to a preference for the main stem over distributary sloughs, inability of fish to locate high quality habitat areas on the North and East sides of the estuary due to habitat fragmentation or perhaps simply differential catch efficiency among the sites.

Further investigation into this issue is critical because rearing habitat in the estuary has been identified as a bottleneck to chinook production in the Snohomish River basin, and a development footprint has been proposed in the estuary that includes several hundred acres of chinook habitat and several hundred acres of restoration opportunities, mostly along the main stem. Mitigation sites for the proposed impacts are located along Ebey, Steamboat and Union sloughs. Better information on juvenile distribution and movement in the estuary is critical to restoration, mitigation and development planning.

Habitat Requirements of Stream-type Chinook

Chinook salmon exhibit several different life history strategies in the Snohomish River basin, but the habitat requirements of each are poorly understood. In particular, little is known about the stream-type life history pattern, which involves a freshwater rearing residence time of up to 18 months and comprises roughly one-quarter of the population. Snorkel surveys and smolt trappings could be used to identify key habitat areas and the timeframe over which they are used, and in turn provide guidance to restoration and conservation actions.

Basin-wide Limiting Factors and Historical Analyses

A basin-wide quantitative limiting factor analysis should be completed for coho and developed for chinook. Several potential limiting factors have been identified, but there is still much uncertainty about the relative contribution of individual limiting factors to reduced salmon habitat productivity without a basin-wide quantitative analysis.

Limiting factor analysis should be coupled with a historical analysis of the Skykomish and Snoqualmie rivers. Techniques developed in this project and other studies (Beechie *et al.,* 1996, Pess *et al.* 1999) can be applied throughout the basin to develop guidelines and reasonable goals for restoration. A better understanding of limiting factors and the historical context would aid in the prioritization and design of restoration projects and approaches for multi-species salmon recovery efforts.

Feasibility and Design Work to Evaluate Restoration Opportunities

Twenty-nine restoration opportunities have been identified within the Snohomish River valley. The next steps are to investigate landowner interest at potential restoration sites, analyze restoration feasibility and develop an overall restoration strategy. A preliminary feasibility analysis would answer the following questions:

1. Which restoration sites have cooperative landowners or willing sellers?
2. How would restoration impact adjacent properties?
3. What are the hydrologic flow pathways and characteristics of each site?

4. What is the site elevation and topography?
5. Is there any site contamination?
6. Is the site fully or partially filled?
7. How is the site oriented in relation to existing channel geometry and other conservation properties?
8. Does the site contain utility crossings, transportation right-of-ways or other infrastructure?
9. What length of cross-dike (if any) would be necessary to construct relative to the length of dike that could be breached and acreage restored?
10. What are the restoration design alternatives?
11. What is the total project cost?
12. What is the smolt per unit cost estimate of restoration?

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GLOSSARY

Estuary – that part of a river or stream or other body of water having unimpaired connection with the open sea, where the sea water is measurably diluted with freshwater derived from land drainage (Armantrout, 1998). For the purpose of this report, “estuary” refers to the portion of the estuary downstream of the head of Ebey Slough.

Tidal Marsh Habitat Zones

Estuarine emergent marsh (EEM*)* zone – a habitat zone dominated by low and high saltmarsh vegetation. Other habitat types commonly occurring within this zone in small patches include channel, mudflat, estuarine openwater, estuarine scrub shrub and freshwater emergent marsh (Hayman *et. al.,* 1996)

Emergent/forested transition (EFT) zone – a mosaic of estuarine scrub shrub wetland and tidally influenced emergent marsh encompassing the range of vegetation between the saltmarsh-dominated and forest-dominated wetlands. Other habitat types commonly occurring within this zone in small patches include channels, wetland forest, gallery forest, palustrine openwater and mudflat (Hayman *et. al.*, 1996).

Forested riverine/tidal (FRT) zone – tidally influenced, forested wetlands is the dominant vegetation community. Other habitat types commonly occurring within this zone in small patches include channels, mudflat, gallery forest, and tidally influenced emergent marsh and scrub shrub habitats (Hayman *et al.*, 1996).

Blind Tidal Channel Networks - the capillary-like channels within the estuarine marsh, which fill and drain with the tides.

Distributary Slough – estuary channels which branch off the main stem and flow directly into the bay.

Floodplain – Land beyond a stream channel that forms the perimeter for the maximum probability flood (Armantrout, 1998). For this analysis, the floodplain is defined as the100-year floodplain upstream of the divergence of Ebey Slough from the main stem to the confluence of the Snoqualmie and Skykomish rivers.

Palustrine wetlands– nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and all such wetlands that occur in tidal areas where salinity due to ocean-derived salts is below 0.5% (Cowardin, 1979). For the purpose of this report the term "palustrine wetlands" is used to describe wetlands within the floodplain upstream of the head of Ebey Slough.

Small Tributaries – streams with average summer wetted widths less than 6 m.

Side-Channels - secondary or overflow channels, which are connected to the main stem at both ends.

Side-Channel Sloughs - perennially flooded former paths of the main river that are predominately pool habitat

Beaver Ponds – surface water impounded by beaver dams.

Main stem – principal, largest, or dominant stream or channel in any given area or drainage system (Armantrout, 1998).

Channel Migration Zone – the lateral extent of likely movement along a stream reach. The channel migration zone includes the meander amplitude, remnant channels and oxbows.

Constrained Channel Migration Zone – the channel migration zone excluding areas behind continuous dikes designed to withstand a 100-year flow event.

Edge Habitat – the slack water channel margin between the shear line of the thalweg and the bank edge.

Riparian Zone – Those (areas) on or by land bordering a stream, lake, tidewater, or other body of water. For the purpose of this report is defined as the channel migration zone plus 1 site potential tree height (56 m).

Other Terms

Rearing capacity - the usable habitat area multiplied by the parr rearing density estimate for a given season.

Smolt production capacity - the expected number of smolts produced from available habitat during a given season (Beechie *et al.*, 1994); It is the rearing capacity multiplied by the survival to smolt stage factor.