LINKING FRESHWATER REARING HABITAT TO SKAGIT CHINOOK SALMON RECOVERY

Appendix C of the Skagit Chinook Recovery Plan

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1. CHINOOK SALMON LIFE HISTORY STRATEGIES THAT DEPEND ON FRESHWATER HABITAT FOR EXTENDED REARING

In the Skagit River basin, Chinook salmon fry exhibit a variety of rearing strategies before migrating to Skagit Bay and beyond. While many Chinook salmon fry migrate rapidly to tidal delta and nearshore habitats to rear, trapping studies have shown that on a given year 20% to 60% of Chinook salmon fry spend enough time rearing in freshwater habitats to exhibit growth (see Figure 3.1 below). These freshwater-rearing fry can be divided into two general groups: parr migrants and yearlings. Both of these life history strategies are described below.

1.1. PARR MIGRANTS

The fry of parr migrants emerge from egg pockets and rear for a couple of months in freshwater to achieve a similar size as their tidal delta rearing cohorts over the same time period. Following freshwater residence, parr migrants move through the tidal delta and into Skagit Bay, usually starting in late May or June at the average size of 75 mm fork length (observed range from mainstem trapping is 57-92 mm fork length). Parr migrants do not reside in tidal delta habitats. We observe an extended freshwater rearing region and no tidal delta rearing region on their otolith. Some of these fish may reside in off-channel habitat within the large river floodplain areas of the Skagit River (Hayman et al. 1996).

1.2. YEARLINGS

The fry of yearlings emerge from egg pockets and rear in freshwater for a period of over one year. The movement patterns of yearlings and their habitat preferences within freshwater habitats are largely unknown. Yearlings migrate to the estuary generally from late March through May at the average size of 120 mm fork length (observed range is 92-154 mm fork length). Yearlings do not reside in tidal delta habitats for an extended period of time like tidal delta rearing migrants. Yearlings seem to pass through tidal delta habitats, possibly lingering briefly, on to nearshore areas. Yearlings are rarely found in shallow intertidal environments, but are most commonly detected in deeper subtidal or offshore habitats. Residence time in nearshore areas of Skagit Bay for yearlings appears to be shorter than for ocean type life histories.

1.3. PRESENCE IN THE SKAGIT RIVER BASIN

Yearling and parr migrant life history strategies are consistently observed in Skagit Chinook populations. We observe them via outmigration data collected at the WDFW Mainstem trap located in Burlington and the estuary, using timing and length data to infer life history strategy. We also observe both life history strategies using otolith analysis. Scale samples from returning adult spawners also show consistent evidence of yearlings in Skagit Chinook salmon populations.

1.4. MARINE SURVIVAL

Marine survival estimates for parr migrants and yearlings are discussed in Appendix D of the Skagit Chinook Recovery Plan. Parr migrant survival was estimated at 0.518% for a high marine survival climate regime and 0.109% for low survival regimes. Yearling survival was estimated at 1.191% for a high marine survival climate regime and 0.251% in low survival regimes.

2. FRESHWATER HABITATS USED BY LIFE HISTORY STRATEGIES

In this section we discuss what is known about habitat preferences of yearling and parr migrant life history strategies while rearing in freshwater and the implications for Skagit Chinook salmon recovery.

2.1. YEARLINGS

Habitat preferences for yearlings by life stage are largely unknown for the Skagit River Basin. Yearlings are present in all Skagit Chinook populations (as reported in the section 3.4 of the Skagit Chinook Recovery Plan). We assume that yearling fry exhibit the same habitat preferences of other age 0+ Chinook salmon fry through early summer when most ocean-type individuals have migrated seaward. Habitat preferences of yearling Chinook salmon in interior rivers, such as upper Snake River tributaries, are similar to juvenile coho salmon habits (G. Pess, NOAA Fisheries, personal communication), which include off-channel sloughs, wetlands, beaver ponds, and other ground-water fed floodplain habitats.

The implication is that projects such as restoring habitat access, reconnecting side channels, and restoring the natural process of habitat formation through channel migration would benefit the yearling life history strategy.

2.2. PARR MIGRANTS

Murphy et al. (1989) showed that subyearling Chinook salmon in a large Southeast Alaska river system preferred off-channel habitat and mainstem shoreline habitats with low velocity, such as backwaters, over other mainstem habitats. Skagit-specific studies have identified similar trends for sub-yearling Chinook salmon. Many of the fish captured in the Skagit studies would be parr migrants so we assume that these results describe the habitat preferences of this life history strategy.

Hayman et al (1996) showed that backwaters were also preferred habitat by sub-yearling Chinook and were used in higher densities than other mainstem edge habitats. Hydromodifications and floodplain disturbances that hinder river movement (riprap, dikes, unneeded roads and fills) reduce the formation of backwaters and other complex natural habitats. Projects that remove or relocate these kinds of structures should increase parr migrant capacity. The riprap study (Beamer and Henderson 1998) showed that sub-yearling juvenile Chinook use natural banks with complex wood cover at a density 5 times greater than riprap (hydromodified) banks. The salmon recovery inference from this study is that wherever riprap banks exist, they should be converted to natural banks (either through removal or mitigation measures like adding complex wood to riprap areas). These types of projects should increase capacity for parr migrant and stream type life history strategies. They should also improve habitat quality for fry of other life history strategies that are migrating seaward yet are still using these habitats on a more temporary basis.

Hayman et al. (1996) also showed that juvenile Chinook (probably parr migrants) were consistently found in the lower ends of off-channel habitat along the Skagit River. This phenomenon was not found in off-channel habitat along the Sauk and Suiattle Rivers. The data were opportunistically collected at coho smolt trapping sites operated during the 1980s and early 1990s, so caution should be used in drawing conclusions. The finding implies support of the Chinook salmon recovery action to reconnect off-channel habitat, especially along the Skagit River, for the benefit of parr migrants. Certainly, increased off-channel area would provide short-term refuge for juvenile Chinook salmon during flood events, even if these habitats were not heavily used (i.e. high fish density) for rearing throughout the freshwater rearing season.

3. CURRENT BIOLOGICAL MECHANISMS INFLUENCING JUVENILE CHINOOK SALMON IN FRESHWATER HABITAT

In this section we examine estimates of juvenile Chinook salmon populations in the Skagit River Basin to determine whether we have evidence of freshwater rearing limits. The results suggest that freshwater habitat may be limiting for both parr migrant and yearling life history strategies. This indicates that increasing freshwater habitat capacity or quality in the Skagit River basin will increase the production of Chinook salmon.

3.1. PARR MIGRANTS

By examining the freshwater outmigration data we can break the migrating population into early and late migrants based on the population’s weekly length trend (Figure 3.1A). Early migrants are smaller, while late migrants are larger. The later migrants are larger in size because of their longer rearing period in the freshwater environment. The proportion of population that exhibits early migration strongly fluctuates as a result of overall population size (Figure 3.1B). Conversely, the number of late migrants does not appear to fluctuate as a function of overall population size if we assume the function is linear (Figure 3.1C). However, if we assume the relationship is a Ricker function, then Figure 3.1C suggests freshwater habitat capacity is achieved at approximately a total wild Chinook subyearling outmigration of 4.5 million. Either way, these figures indicate a limitation in freshwater habitat capacity; as freshwater habitat fills up, the excess fish respond by moving downstream. The number of late migrants is a good surrogate for the number of parr migrants. The number of parr migrants per year has averaged 1,320,419 over the period of record (1997-2002).

Our analysis shows evidence of a density dependent migration for the parr life history strategies in freshwater habitat. We propose that as freshwater rearing habitat “fills up,” the excess fish respond by moving downstream. Clearly, freshwater conditions will affect the proportion of each life history strategy being produced by the population. Although we are fundamentally measuring this response at the population level, the density dependent processes that result in fry moving downstream to the estuary likely occur at multiple scales of space and time. For example, different portions of the watershed will vary in their capacity to support fish based upon the habitat conditions and stream flows that are present there. Similarly, within one part of a basin, the outcomes of the interactions of individual fish as defined by food supply, physical habitat conditions, and environmental conditions will determine what fish and how many of them ultimately move downstream.

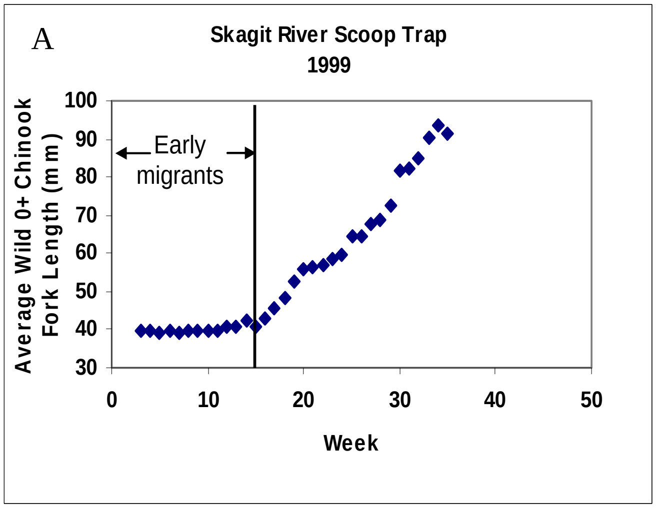
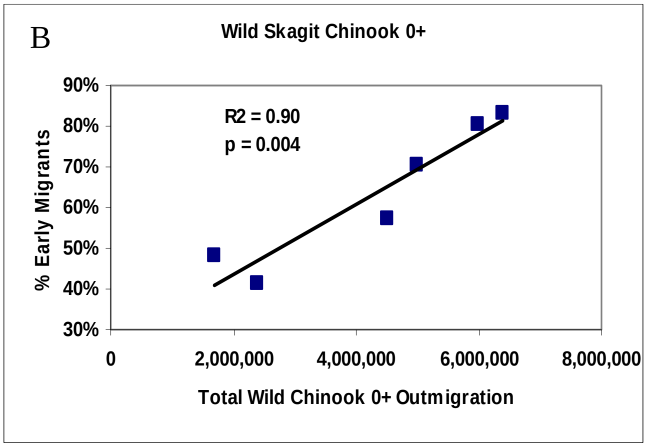
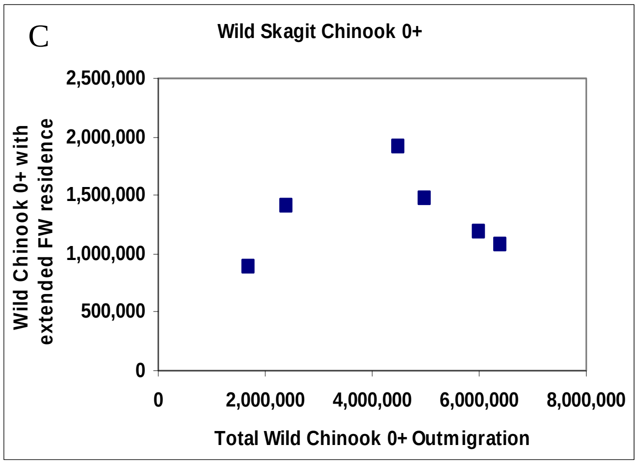


Figure 3.1. *Freshwater Outmigration Data.*

(A) Average length trend of subyearling Chinook salmon moving through the lower Skagit River in example year 1999. Fish captured before week 15 (mid-April) were similarly sized, reflecting a population that migrated relatively quickly following emergence. After week 15, the average length of juvenile Chinook salmon steadily increased, reflecting a population that delayed in riverine habitat long enough to exhibit growth.



(B) The relationship between total freshwater wild Chinook salmon population size and the proportion of the population that are early migrants (those fish that do not exhibit significant growth in freshwater).



(C) The relationship between total freshwater wild Chinook salmon population size and the number of late migrants (those fish that do exhibit significant growth in freshwater).

3.2. YEARLINGS

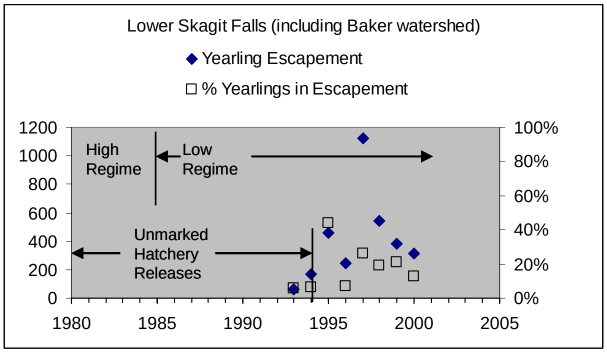
Yearling smolts are detected by various sampling efforts of Skagit Chinook salmon. In this section we investigate evidence of their recent smolt population size and whether their freshwater habitat is limiting. Also, we explore the likelihood of unmarked hatchery releases confounding any conclusions drawn about wild yearling smolts.

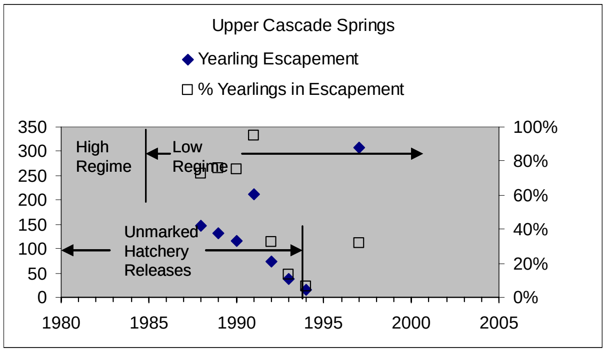
3.2.1 Contribution of Yearling Smolts to Escapement

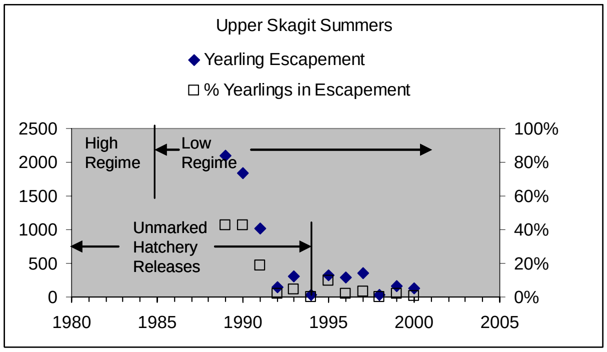
We have enough data to examine whether wild yearling smolts have contributed to the escapement in five of the six Skagit Chinook stocks (Lower Sauk Summer are lacking data) (Figure 3.2). Yearling smolts have consistently contributed to the escapement of all stocks evaluated, but some stocks show consistently higher proportions of their escapement attributed to yearling productions. The stocks with higher yearling contribution are the spring stocks. Also, there is a large decline in the number and proportion of yearlings found within the Upper Skagit Summer population. The decline coincides with both changes in flow management and cessation of unmarked hatchery releases from the Skagit Hatchery program (Figure 3.3). There is a significant positive correlation ($P = 0.029$, $R^2 = 0.39$) between the number of unmarked hatchery yearlings released and our current estimate of the number of yearlings that contribute to the escapement. While the correlation is statistically significant with only limited data, the amount of variation explained is low, leaving us to believe there are errors in our estimation process or that other variables (like a change in flow management) are responsible for the drop in yearling contribution starting around brood year 1992. Both issues (unmarked hatchery yearlings straying into the wild escapement and flow management effects on yearling productivity) should be studied in the future.

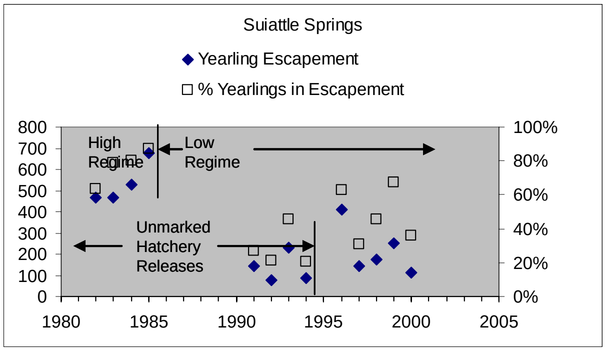
Average values of yearling contribution to escapement are:

- Upper Skagit Summers - 2.6% (brood year 1994 and later to avoid possible influence of unmarked hatchery fish on our estimate)
- Lower Skagit Falls – 17.8%
- Upper Cascade Springs – 50.3%
- Upper Sauk Springs – 44.3%
- Suiattle Springs – 51.3%









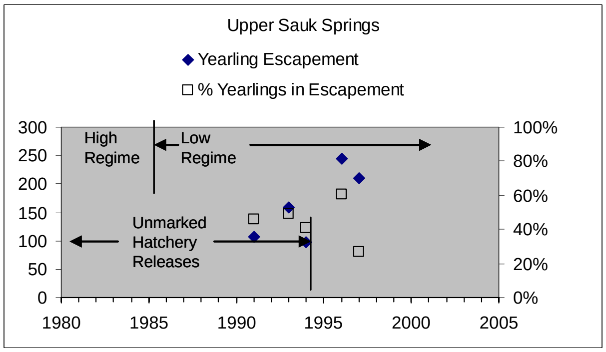


Figure 3.2. *The contribution of the yearling juvenile life history strategy in escapement by brood year for Skagit Chinook stocks.* A marine survival regime shift from high survival to low survival occurred after the 1985 brood year. Also, unmarked hatchery yearling releases ceased, starting with brood year 1994. Changes in flow management for the Upper Skagit River occurred in the mid 1980s and again in 1991 due to the Seattle City Hydropower relicensing.

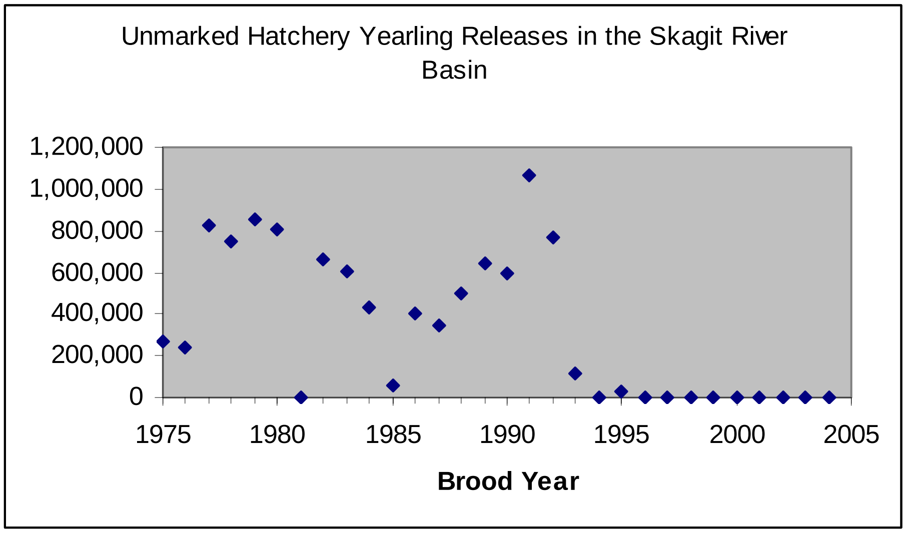


Figure 3.3. *Unmarked hatchery yearling releases from the Skagit River Basin by brood year.*

3.2.2 Yearling Outmigration Population Estimates

Trapping efforts within the Skagit River Basin do catch yearling Chinook salmon. However, efficiency of gear on yearling capture has not been determined. Also, very few yearlings are captured, making our ability to directly estimate a yearling smolt population size problematic at this time.

We made very rough yearling smolt population estimates by back calculation through escapement estimates for years where we know we have no influence of hatchery yearlings confounding our estimates. The years we could use were after the 1994 brood year (1996 smolt outmigration year). We estimated the yearling smolt population by using the yearling escapement contribution and dividing it by their expected marine survival for low survival climate regime (0.518%). These results are presented in Table 3.1. We then used only data with a low risk of estimator error and summed the yearling smolt contribution for each of the six Chinook salmon stocks. We obviously had gaps in data for all years except the smolt outmigration year 1999. However we assumed that the average for each stock was a reasonable starting point for estimating a recent average yearling smolt outmigration population size. The average is 107,000 (Table 3.2). It appears that the recent range in outmigration size for yearlings may range from approximately 40,000 smolts in 1996 to 187,000 smolts in 1999. Future work will refine these estimates, exploring methods to estimate the data gaps.

Table 3.1. *Preliminary yearling smolt population estimates of wild Skagit Chinook populations.* Determination of risk for estimator error was based on the number of escapement samples used to expand to yearling smolts. High risk of error was assumed with < 10 samples; moderate risk of error was assumed with 10-20 samples; low risk of error was assumed with > 20 samples.

Stock	Brood Year	Smolt Year	Total Escap. of Yrlg. Smolts	% Yrlgs Smolts	# Escap. Samples by BY	Risk of Error in Estimate	Yrlg. Smolt Population Estimate
Lower Skagit Falls (including Baker)	1994	1996	170	6.3%	75	low	14,228
Suiattle Springs	1994	1996	86	20.7%	46	low	7,257
Upper Cascade Springs	1994	1996	15	6.2%	29	low	1,232
Upper Sauk Springs	1994	1996	97	40.8%	35	low	8,100
Upper Skagit Summers	1994	1996	26	0.3%	309	low	2,205
Lower Skagit Falls (including Baker)	1995	1997	459	44.1%	38	low	38,494
Upper Skagit Summers	1995	1997	318	10.0%	151	low	26,666
Lower Skagit Falls (including Baker)	1996	1998	242	7.3%	70	low	20,323
Suiattle Springs	1996	1998	411	62.7%	44	low	34,495
Upper Sauk Springs	1996	1998	244	60.4%	24	low	20,499
Upper Skagit Summers	1996	1998	291	2.0%	420	low	24,429
Lower Sauk Summers	1997	1999	85	9.1%	22	low	7,122
Lower Skagit Falls (including Baker)	1997	1999	1127	26.3%	152	low	94,600
Suiattle Springs	1997	1999	146	30.7%	42	low	12,264
Upper Cascade Springs	1997	1999	307	31.9%	41	low	25,784
Upper Sauk Springs	1997	1999	210	26.5%	52	low	17,668
Upper Skagit Summers	1997	1999	354	3.0%	370	low	29,707
Lower Skagit Falls (including Baker)	1998	2000	545	19.0%	72	low	45,715
Suiattle Springs	1998	2000	173	45.7%	30	low	14,525
Upper Skagit Summers	1998	2000	25	0.2%	314	low	2,083
Lower Skagit Falls (including Baker)	1999	2001	384	21.3%	103	low	32,224
Suiattle Springs	1999	2001	254	67.5%	28	low	21,293
Upper Skagit Summers	1999	2001	164	1.7%	259	low	13,765
Lower Skagit Falls (including Baker)	2000	2002	312	12.5%	134	low	26,194
Suiattle Springs	2000	2002	111	35.9%	31	low	9,327
Upper Skagit Summers	2000	2002	125	0.9%	220	low	10,490
Upper Sauk Springs	1995	1997	66	57.4%	13	moderate	5,566
Upper Cascade Springs	1996	1998	76	36.1%	12	moderate	6,397
Upper Sauk Springs	1998	2000	193	50.2%	12	moderate	16,199
Upper Cascade Springs	2000	2002	27	9.1%	11	moderate	2,278
Suiattle Springs	1995	1997	35	32.2%	8	high	2,910
Upper Cascade Springs	1995	1997	57	53.0%	6	high	4,758
Lower Sauk Summers	1998	2000	0	0.0%	1	high	0
Upper Cascade Springs	1998	2000	0	0.0%	2	high	0
Upper Cascade Springs	1999	2001	102	33.3%	6	high	8,531
Upper Sauk Springs	1999	2001	130	70.6%	4	high	10,878

Upper Sauk Springs	2000	2002	108	22.2%	9	high	9,039

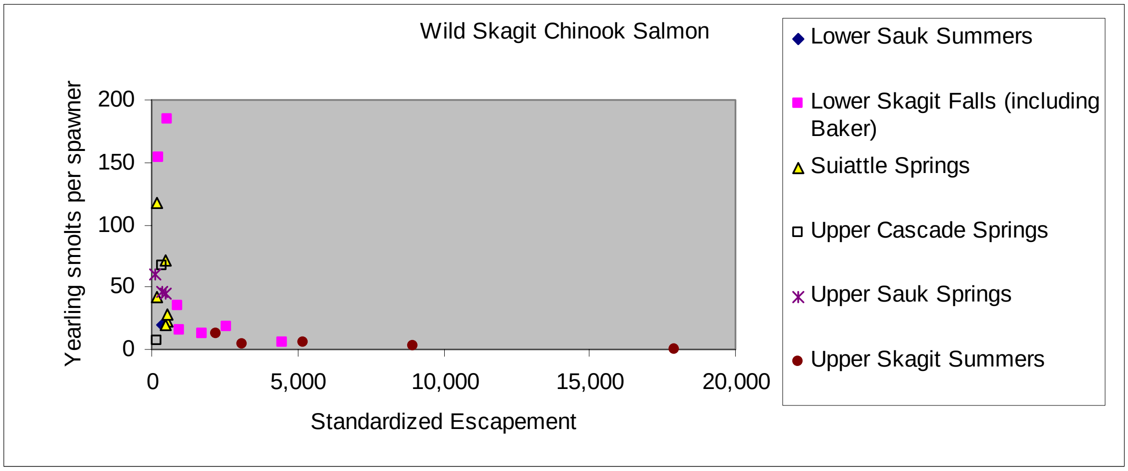
Table 3.2. *Summary of preliminary yearling smolt population estimates of wild Skagit Chinook populations.*

Smolt migration year	Lower Sauk Summers	Lower Skagit Falls (including Baker)	Suiattle Springs	Upper Cascade Springs	Upper Sauk Springs	Upper Skagit Summers	Grand Total
1996		14,228	7,257	1,232	8,100	2,205	33,022
1997		38,494				26,666	65,160
1998		20,323	34,495		20,499	24,429	99,746
1999	7,122	94,600	12,264	25,784	17,668	29,707	187,145
2000		45,715	14,525			2,083	62,323
2001		32,224	21,293			13,765	67,282
2002		26,194	9,327			10,490	46,011
Average	7,122	38,825	16,527	13,508	15,422	15,621	107,025

3.2.3 Evidence of Yearling Habitat Filling Up

Next, we examined the existing data for evidence of yearling habitat filling up to capacity. We plotted yearling per spawner for each stock against the standardized escapement for each stock. Standardized escapement removes the flood-induced variability on the egg to fry survival stage and is therefore a better metric to analyze for possible density dependence in a juvenile salmon population. This method of standardizing escapement is explained in Appendix B of the Skagit Chinook Recovery Plan. While the data are limited (only 4 of the 6 stocks have sufficient data to establish a trend), our results indicate there is a negative relationship between escapement and yearling productivity (Figure 3.4). This suggests that yearling habitat may be filling to capacity and that increasing freshwater habitat capacity or quality that could be used by yearlings may increase overall Chinook production. Figure 3.4 also indicates that there may be real stock differences which may be due solely to large differences in their population size or possibly differences in habitat opportunity. We have preliminarily concluded that yearling habitat is limiting but we also recognize that much research needs to be conducted in yearling populations to best understand how to recover them.

Future work should compare yearling smolt estimates with WDFW mainstem trapping results and estuary sampling results. We can also compare yearling smolt population as a density, by dividing the population size by the area of habitat available in the stock’s rearing range. Lastly, the plots in Figure 3.4 should be re-calculated by standardizing the escapements by the stream gage data (in flood recurrence interval) unique to these watersheds, to eliminate any possible variability caused by using the Skagit River gage. We could use these methods to monitor yearling smolt yield on an annual basis.



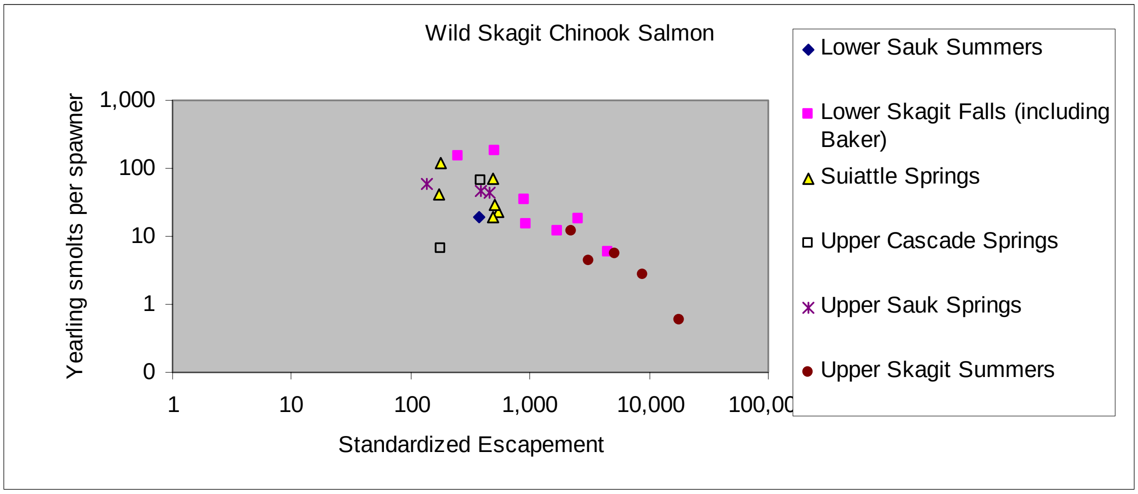


Figure 3.4. *Relationship between yearling productivity (smolts per spawner) and escapement by Skagit Chinook salmon stock.*

4. FRESHWATER HABITAT CONDITIONS

Analyses of current and historic freshwater habitat conditions demonstrate that freshwater rearing habitats have changed and are likely limiting juvenile Chinook freshwater rearing capacity because the changes have reduced habitats preferred by juvenile Chinook salmon. This section presents estimates of the types and amount of habitat that has been lost in non-tidal delta, mainstem, and floodplain habitats.

4.1. HISTORICAL RECONSTRUCTION OF NON-TIDAL DELTA AREAS

A large loss in freshwater rearing habitat opportunity has occurred in the non-tidal area of the Skagit geomorphic delta. Collins (2000) reconstructed the historic distribution and types of habitat for this area. We present results of this in Chapter 10 of the Skagit Chinook Recovery Plan (see section 10.3). We identified a 98% loss in area where lower river delta (non-tidal) habitat can form greatly limiting freshwater rearing and refuge habitat available to parr migrant and yearling Chinook salmon.

4.2. HYDROMODIFICATION OF MAINSTEMS AND ISOLATION OF FLOODPLAINS

Hydromodifications such as riprap bank armoring structures, dikes, floodplain roads, and other floodplain modifications degrade mainstem habitat conditions by reducing the complexity of bank habitat. In addition, hydromodifications isolate floodplain areas from the mainstem river channel, which changes the distribution and type of habitats that form within both the mainstem and floodplains. In this section we present results from a study that indicates how much natural bank habitat has been lost directly to hydromodifications and analyze floodplain conditions to estimate how much mainstem and off-channel habitat has been lost as a result of floodplain isolation caused by hydromodifications.

We conducted a hydromodification inventory for 31 large river mainstem reaches (channels > 50 meters bankfull width) that identified areas of riprap and isolated floodplains. We reported the results of this inventory in Chapter 10 of the Skagit Chinook Recovery Plan. We found 31% of the floodplain area has been isolated from the river (see Table 10.1 in Chapter 10 of the Skagit Chinook Recovery Plan). We also found over 98 km of hardened streambank throughout the river network (see Table 10.2 in Chapter 10 of the Skagit Chinook Recovery Plan). These modifications to the freshwater habitat system have reduced habitat capacity and opportunity for juvenile Chinook salmon and have constrained the natural formation of new habitats during flood events.

4.3. INFLUENCE OF FLOODPLAIN CONDITION ON OFF-CHANNEL AND MAINSTEM EDGE HABITATS

As discussed above, hydromodifications such as riprap bank armoring, diking, floodplain roads or other floodplain disturbances can degrade mainstem habitat conditions and reduce connectivity between floodplain areas and the river, which can reduce the formation of off-channel habitats. In addition to direct effects to bank conditions, hydromodifications isolate the river from the floodplain, which changes the distribution and type of habitats that form within both the mainstem and floodplain areas. Unfortunately, the amount of habitat lost through floodplain isolation has not been documented in the existing scientific literature. In this section we report findings from an analysis linking floodplain characteristics and floodplain disturbance to mainstem and off-channel habitat conditions.

4.3.1 Methods

1998 black and white aerial photographs and GIS were used to estimate the total area of floodplain along mainstem channels (width > 50 m) used by Chinook salmon in the Skagit River basin. The floodplain was defined as the area that would be flooded during a 100-yr flood event and extended out to the first terrace break to include areas that might be subject to channel migration and habitat formation in the absence of floodplain modification. Floodplain areas were delineated into reaches based on valley topography, channel gradient and extent of hydromodification. Some reaches were excluded from the analysis due to a lack of data on habitat conditions, which left 31 reaches in the Skagit, Sauk, Suiattle, Cascade, and Whitechuck rivers. 1998 black and white aerial photographs, GIS, and field surveys were used to locate roads, dikes and other hydromodifications that might influence habitat conditions in each floodplain reach. Each floodplain reach was subdivided into areas based on level of disturbance: (1) isolated areas were surrounded on all sides by roads or hydromodifications, (2) shadowed areas were located behind roads or hydromodifications, but were not completely disconnected from the river, and (3) connected areas were not directly influenced by roads or hydromodifications (see example in Figure 4.1). The area of each disturbance category was estimated for each floodplain reach.

Mainstem channel length, channel gradient, valley length, valley gradient were calculated for each floodplain reach based on 1998 black and white aerial photographs and the 10 m DEM. Average floodplain width was calculated for each floodplain reach by dividing the floodplain area by floodplain length. Effective floodplain width was calculated, which is the average width of the floodplain that is connected to the river and NOT isolated or shadowed by roads and hydromodifications. This is the area where habitat formation is most likely to occur. We standardized effective floodplain width by dividing it by the average channel width of the mainstem, which enabled us to compare reaches with different mainstem channel widths. Mainstem and floodplain habitat conditions were also measured for each floodplain reach. This included the length of off-channel habitat, shoreline perimeter of backwater habitat, length of bank and bar habitat on mainstem edges, and total area of mainstem habitat. Off-channel habitat was classified as to whether it was flowing in a connected portion of the floodplain or an isolated or shadowed portion of the floodplain. Off-channel habitat density was calculated as the length of off-channel habitat per area of floodplain in each floodplain reach. This was used to compare the amount of off-channel habitat in reaches with differing characteristics.

These data were used to compare total amount of habitat in floodplain reaches with differing characteristics and levels of impairment and to compare the amount of habitat found in connected versus isolated/shadowed floodplain areas. A simple summary of these data shows the degree in which floodplains are isolated and the amounts of various habitats found in each reach (see example in Table 4.1). These data are reported for all 31 reaches in Chapter 10 of the

Skagit Chinook Recovery Plan. We used paired T-tests and regression (single and multiple variable) analysis to determine whether floodplain conditions predicted aquatic habitat used by juvenile Chinook salmon.

Table 4.1. *Summary of floodplain habitat conditions within the rearing range of all Chinook populations.*

Rearing Range	Floodplain Reach	Floodplain Habitat		Mainstem Habitat		Backwater Habitat Perimeter (m)	Density of floodplain channels per mainstem length	Mainstem Edge Habitat	
		Total Area (ha)	% Isolated From River	Length (m)	Area (ha)			% Hydro-modified Bank	% Natural Bank
All Stocks	SK060A	3312.6	35%	18,972	287.1	13,346	4.04	11.8%	30.3%
	SK060B	1275.2	68%	10,201	170.3	2,204	1.59	24.7%	32.2%
	SK070A	136.6	29%	2,546	43.5	292	0.25	13.8%	53.5%
	SK070B	341.3	25%	5,026	78.7	641	1.29	9.6%	44.1%
	SK080A	409.1	33%	7,686	103.2	1,075	0.45	5.3%	59.1%
	SK080B	332.3	14%	5,764	91.7	1,295	0.40	14.1%	39.7%
	SK080C	225.4	12%	7,843	103.4	378	0.26	19.4%	57.4%
	SK090	151.4	8%	5,133	72.0	1,759	0.12	7.0%	53.7%
	SK100	267.6	10%	5,784	65.8	2,545	1.74	7.9%	41.7%

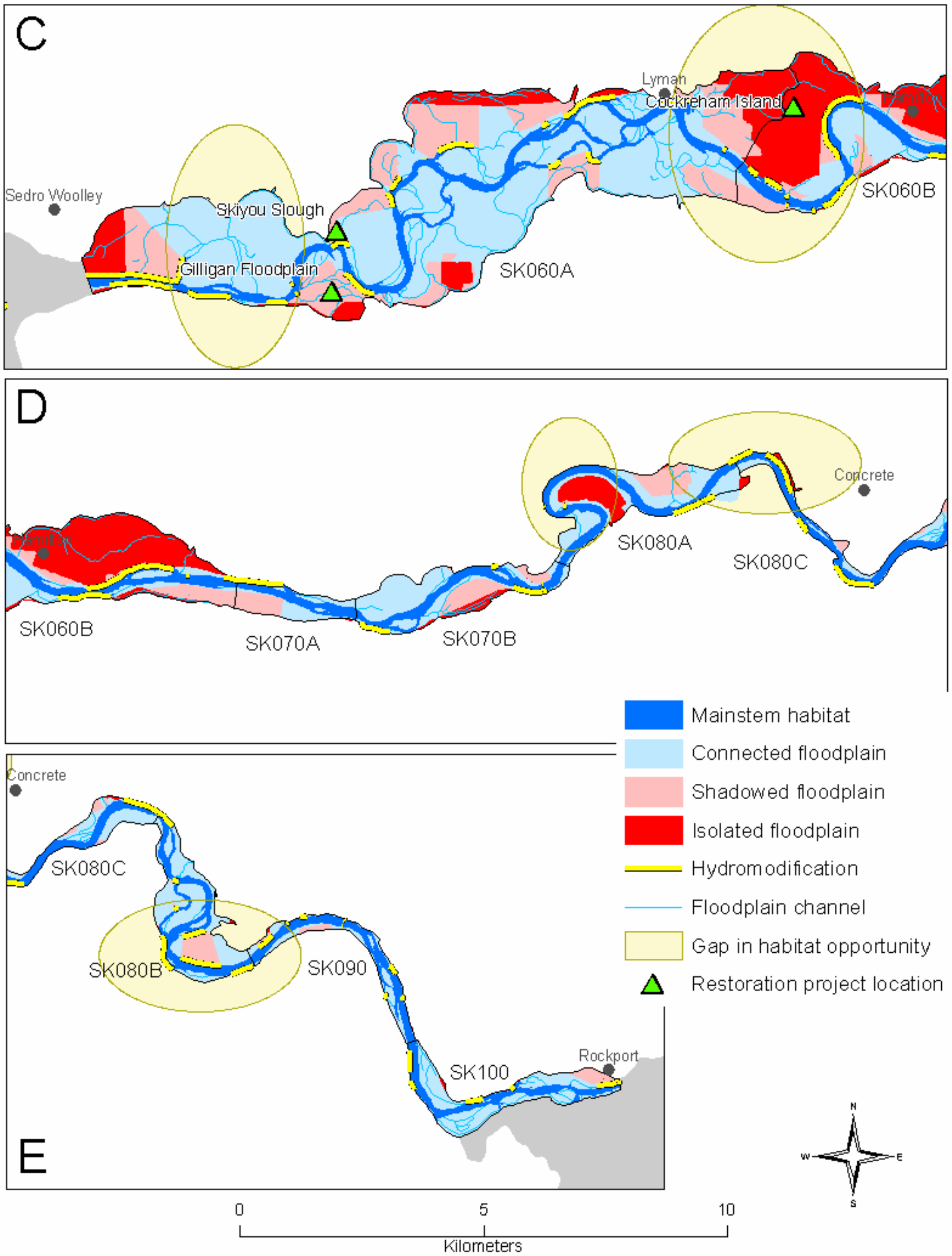


Figure 4.1. Floodplain areas for the Skagit River from (C) Sedro Woolley to Hamilton, (D) Hamilton to Concrete, and (E) Concrete to Rockport. The map shows floodplain areas that are connected to river hydrology (light blue), isolated from river hydrology through roads or dikes (red), or shadowed from river hydrology through hydromodification or roads (pink). Restoration project areas are shown as triangles.

4.3.2 Results

Our analysis shows there has been significant modification to floodplains and this has translated to a loss in habitat areas used by juvenile Chinook salmon.

Floodplain width and gradient appear to be important variables controlling the amount and type of mainstem edge habitat and the amount of off-channel habitat found within floodplain reaches. Modifications to floodplains isolate areas from river hydrology and reduce the effective floodplain width, thus changing the habitats within that floodplain reach. Our results show that standardized effective floodplain is significantly less than historic conditions and has been reduced by an average of 28.6% (Figure 4.2.).

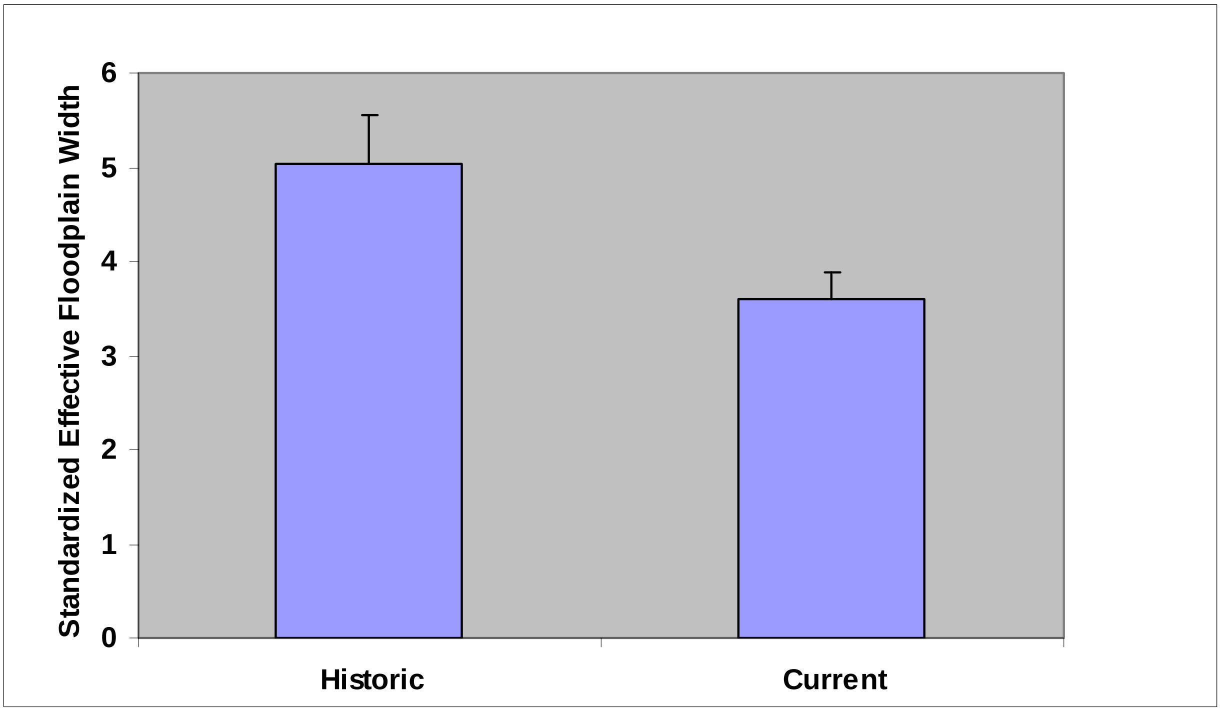


Figure 4.2. *Average (and standard error) standardized effective floodplain width.* Data from 31 large mainstem reaches in the Skagit River Basin. Effective floodplain width has been significantly reduced by floodplain modifications (paired T-test, P > 0.0002). Standardized effective floodplain units are effective floodplain width in meters divided by channel width in meters.

This change in effective floodplain width as a result of floodplain modifications has had a dramatic effect on the amount of off-channel habitat available to juvenile salmon because the density of off-channel habitat in areas connected to the river (within the effective floodplain area) is approximately double the density found in areas that are isolated or shadowed (outside the current effective floodplain area but within the historic floodplain) (Figure 4.3). Multiple regression analysis showed that floodplain gradient and effective floodplain width were significant in determining how much off-channel habitat was available in each reach (see Table 6.1 for regression model equation and results).

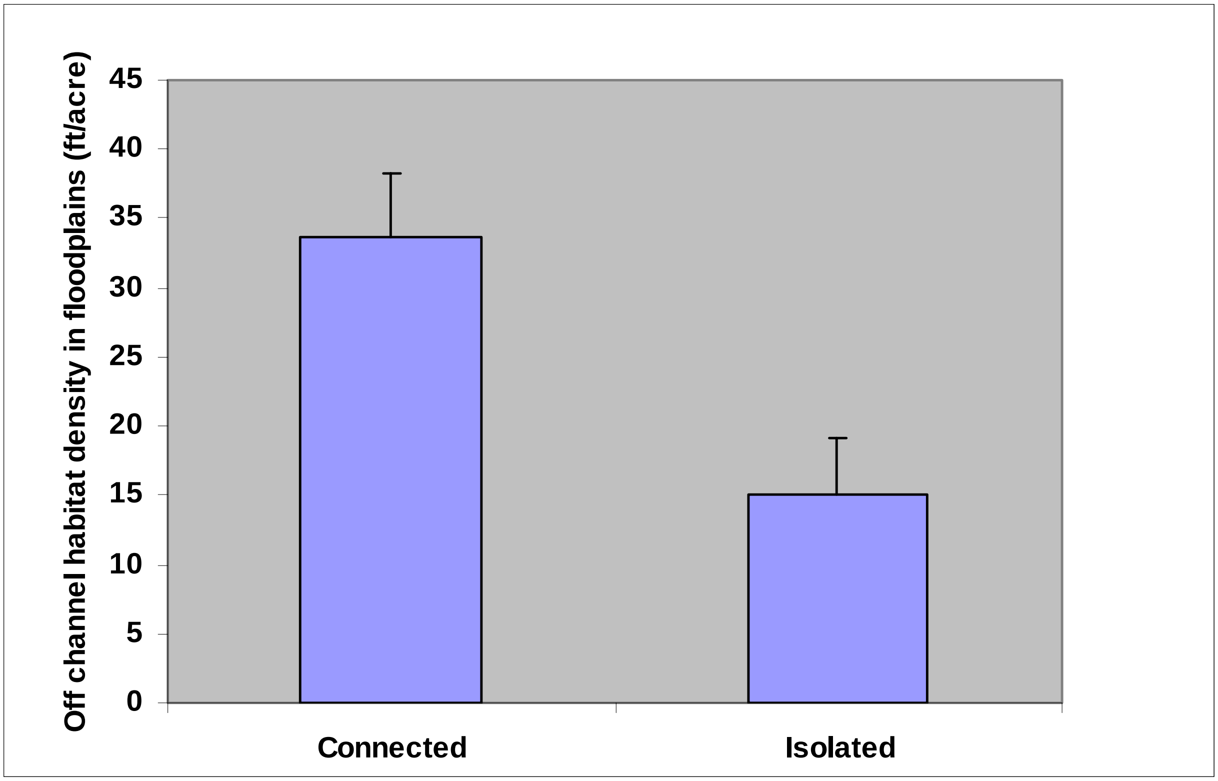


Figure 4.3. *Average (and standard error) off-channel habitat density in connected and isolated floodplains.* Data from 31 large mainstem reaches in the Skagit River Basin. Off-channel habitat density is significantly lower in isolated floodplain areas (paired T-test, P = 0.0015).

Floodplain modifications that have reduced effective floodplain width have also had a substantial effect on the amount of mainstem habitat. Regression analysis showed that effective floodplain width predicts the amount of mainstem edge habitat. Wider (and lower slope) floodplains allow the mainstem channel to form greater amounts of backwater edge (Figure 4.4A). Wider floodplains also allow the mainstem channel to form greater amounts of bar edge habitat (Figure 4.4B) while narrower floodplains constrain the mainstem channel and allow for only bank edge habitat as channels become progressively straighter (Figure 4.4C). These results show that a higher diversity of mainstem edge habitats occurs in channels with less floodplain modification and wider effective floodplains. It is true that naturally constrained mainstem reaches naturally lack much backwater, bar, or off-channel habitat. Naturally constrained river reaches are dominated by natural bank habitat. However, floodplain reaches that have been dramatically reduced in effective floodplain width will be dominated by bank edge – likely hydromodified bank edge which has the lowest value for juvenile Chinook salmon of any mainstem edge habitat type

These results clearly indicate that in addition to the direct effects on bank habitat conditions from hydromodifications, floodplain modifications that reduce effective floodplain width significantly reduce both mainstem and off-channel habitats used by Chinook salmon. Removing or relocating roads and hydromodifications in large river floodplains that increase the effective floodplain width should also increase the amount of rearing habitat available to Chinook salmon. Because freshwater habitat can limit Chinook populations as discussed earlier, these types of restoration projects should increase overall Chinook populations. The regression results can also be used to estimate how much habitat may be gained by removing floodplain modifications as described in section 6.

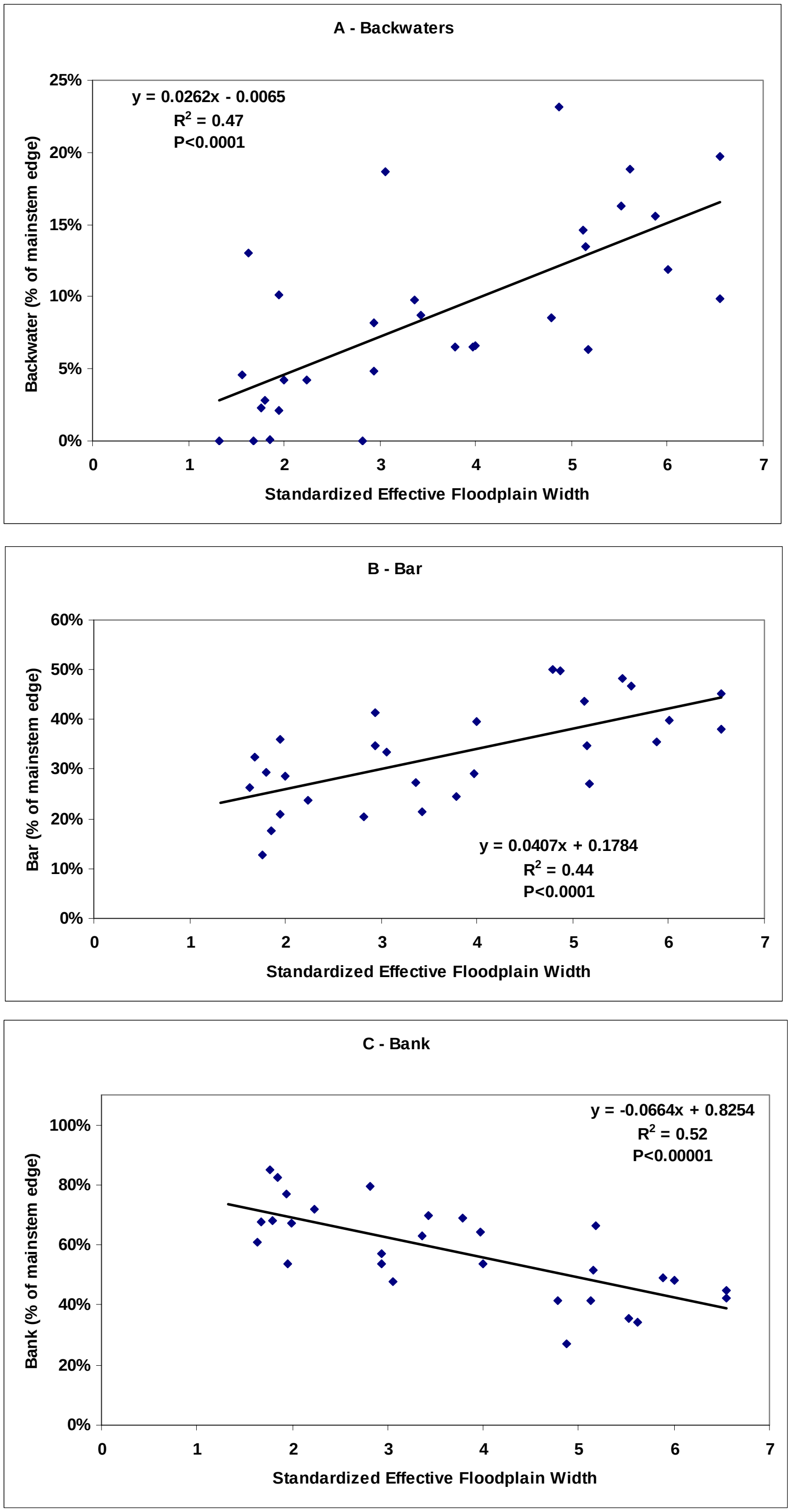


Figure 4.4. *Relationship between standardized effective floodplain width and mainstem edge habitat.*

A - Percent of mainstem edge that is backwater. The best model is a multiple regression using standardized effective floodplain width and floodplain gradient. Wider and lower slope floodplains allow the mainstem channel to form greater amounts of backwater edge.

B - Percent of mainstem edge that is bar habitat. Wider floodplains allow the mainstem channel to form greater amounts of bar edge. There was no improvement in the model by adding floodplain gradient, likely due to the limited range of gradients in our dataset.

C - Percent of mainstem edge that is bank habitat. Narrower floodplains constrain the mainstem channel and allow for only bank edge habitat as channels become progressively straighter. There was no improvement in the model by adding floodplain gradient, likely due to the limited range of gradients in our dataset.

5. RESTORATION IMPLICATIONS

The biological (Section 3) and habitat (Section 4) evidence discussed in this document leads us to conclude that increases in the freshwater habitat capacity for parr migrants and yearlings will benefit Skagit Chinook salmon populations. Since the dominant density dependent mechanism within the freshwater rearing life stage appears to be density dependent migration, increases in freshwater habitat capacity should also reduce the number of fry migrants produced by Skagit river origin Chinook salmon.

In the freshwater system, juvenile Chinook salmon rearing habitats formed within large river floodplain areas are especially important to the success of parr migrants and yearlings because they spend a long period of time in the freshwater environment compared to the other life history strategies known to exist with the Skagit watershed. The availability of complex mainstem edge habitat, backwaters, and off-channel habitat is essential for foraging and refugia of juvenile Chinook salmon. Land uses that degrade or eliminate these habitats include hydromodifications such as dikes and riprap bank armoring structures that reduce mainstem edge complexity and limit the formation of backwaters, and hydromodifications or any floodplain structure (dikes, riprap, roads, fills, etc.) that reduces lateral channel migration and the formation of off-channel habitat.

The restoration strategy for increasing freshwater rearing habitat focuses on restoring mainstem edge habitat and reconnecting isolated floodplain areas by removing, relocating, or improving hydromodifications and floodplain structures. Where hydromodifications are in reaches with narrow floodplains or where the structures are located near the outer edge of the floodplain, restoration actions should focus on increasing edge habitat complexity by incorporating wood or complex structures into the bank protection projects. Where floodplain modifications isolated portions of the floodplain, restoration actions should focus on removing or relocating structures to increase effective floodplain width. The proposed actions target significant portions of isolated floodplain habitat that have either been recently acquired by conservation interests, or have near term support from interests that are interested in protecting social and political investments.

The same principles apply to tributary watersheds, although at a smaller scale due to their size relative to the large mainstem rivers. Significant increases in juvenile Chinook freshwater rearing capacity can be gained in tributaries (especially their alluvial fans) where floodplain or riparian disturbance is high.

Specific restoration projects and restoration strategies for the varying reaches within the Skagit River Basin are presented in Chapter 10 of the Skagit Chinook Recovery Plan. We assume that actions listed in the Plan also benefit yearling life history strategies. However, because we lack a good understanding of the preferences of yearlings within freshwater habitat after early summer, we have listed this gap as a research priority in the Plan. Results of future research may show us where and how to direct restoration more directly to the benefit of yearlings.

6. PREDICTING THE BENEFITS OF RESTORATION

The analyses discussed in Section 4 of this report yielded significant relationships between floodplain characteristics and habitats used by juvenile Chinook salmon. These relationships were used as modeling tools to predict the change in parr migrant capacity for each freshwater rearing habitat project listed in Chapter 10 of the Skagit Chinook Recovery Plan because each project influences either floodplain area or channel habitat. We used floodplain disturbance regression equations and average habitat widths shown in Tables 6.1 and 6.2 to predict the area of each habitat type that would likely be gained over time as a result of each freshwater habitat project. We then multiplied the areas of habitat by type for each project by the parr migrant capacity values shown in Table 6.3, making sure the area units (e.g. meters squared or hectares) were converted if the regressions used different units. We then summed these values for each project to estimate the total change in parr migrant capacity for each project. The results for each freshwater rearing habitat project have been reported in Chapter 10 of the Skagit Chinook Recovery Plan.

Table 6.1. *Regression equations for estimating mainstem edge and off-channel habitat areas in large river floodplains.*

Freshwater Habitat Parameter	Model Equation	R^2	P
% mainstem edge that is backwater habitat	y = (-6.47522 * FPGrad) + (0.043484 * StdFPwidth) + 0.187184	0.57	<0.00001
% mainstem edge that is bar habitat	y = (0.040717 * StdFPwidth) + 0.178352	0.44	<0.0001
% mainstem edge that is bank habitat	y = (0.825398 * StdFPwidth) - 0.06635	0.52	<0.00001
Backwater area (m^2)	y = (0.0009 *Bwperimeter^2) + (1.9836 * Bwperimeter) + 2587.1	0.98	<0.00001
Off-channel density in floodplain (ft/ac)	y = (2107.531 * FPGrad) + (7.335358 * StdFPwidth) - 0.77032	0.39	0.0011

StdFPwidth = standardized effective floodplain width calculated as effective floodplain width divided by channel width
FPGrad = floodplain gradient in percent
Bwperimeter = backwater perimeter in meters

Table 6.2. *Habitat width values used to estimate the area of each habitat type.*

Freshwater Habitat Parameter	Average width (m)
Width of bank edge habitat (from Hayman et al 1996)	2.6
Width of bar edge habitat (from Hayman et al 1996)	15.6
Average width of off-channel habitat (from Beamer et al 2000)	7.8

Table 6.3. *Assumed capacity for parr migrant Chinook salmon by habitat type.*

Habitat type for large rivers (channels > 50 m wide)	Assumed capacity (fish/m^2)	Source
Natural backwater	1.780	Hayman et al. 1996
Hydromodified backwater	0.639	Hayman et al. 1996 (scaled by bank ratio)
Natural bar	0.440	Hayman et al. 1996
Hydromodified bar	0.158	Hayman et al. 1996 (scaled by bank ratio)
Natural bank	0.970	Hayman et al. 1996
Hydromodified bank	0.348	Hayman et al. 1996
Mid-channel areas	0.001*	NOAA, unpublished
Off-channel habitat	486 (per hectare)	Hayman et al. 1996

*This value was for riffles. We believe this represents the appropriate juvenile Chinook density in the larger channels because velocities are high and our limited data from mid channel habitat does not find rearing sub yearling Chinook salmon.

7. REFERENCES

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