FISCAL YEAR 1999 SKAGIT RIVER CHINOOK RESTORATION RESEARCH

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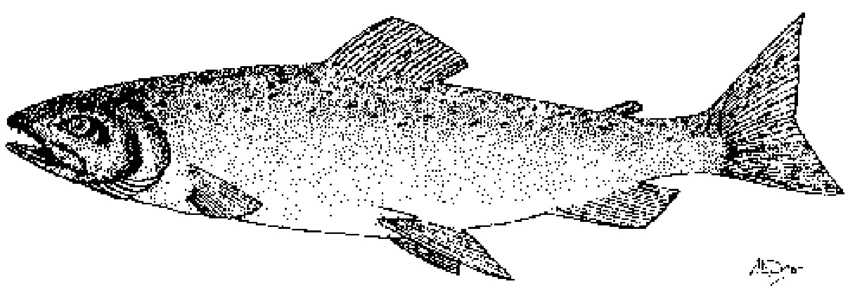

Project Performance Report

In compliance in part with
Northwest Indian Fisheries Commission Contract #3902 for FY 1999

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Introduction

Overview of Skagit Chinook Restoration Study

Started in 1995, the Skagit Chinook Restoration Study is a work in progress to be provisionally complete in 2001, using fish input data through one complete brood year (BY94), and modified as additional data become available. The intent is to model the production of Skagit River origin chinook according to discrete chinook life-stages and habitat preferences, so that: 1) the likely effects of different proposed restoration actions can be evaluated; and 2) our assumptions about chinook limiting factors can be tested. Juvenile and adult life history patterns are identified from patterns observed on chinook otoliths that are collected in various habitat types or zones within the Skagit River basin or estuary. Fish use and habitat parameters are inventoried throughout the river basin and estuary to estimate capacity and survival during the following lifestages: spawning, freshwater rearing and estuary rearing. Adult recruitment rates are estimated by using coded wire tag data from Skagit River origin indicator stocks. Model inputs, sources of data, and analytical methods used to generate initial inputs and outputs for Chinook Restoration Analysis Model are shown in Table 1.

Table 1. Inputs, and sources of data and analytical methods used to generate initial inputs and outputs for Chinook Restoration Analysis Model.

OUTPUT	MODEL INPUTS	SOURCE OF DATA FOR INPUTS	ANALYTICAL METHOD TO GET INPUTS & OUTPUTS
Total Eggs	Initial Escapement (by stock & age) Spawning Habitat Capacity (by stock)*	User discretion Measured redd densities by habitat variable (e.g., pool spacing)*	Eggs = Σ(Fec*Esc) by age and stock + Egg supplementation. Esc is ceilinged at a maximum spawner capacity (limited by spawning area) = f(pool spacing, area);
	Fecundity (by age)*	Broodstock collection	
	Egg box supplementation (by stock)**	User discretion	
Total Emergent Fry	Egg -> Emergent Fry survival (by stock)**	Literature Flood return interval by spawning range of a stock* Life history study for residence time	Literature values of egg survival (S_E) modified by calculated relative survival from flow -> smolt relation. Or egg->smolt survival minus (lit value of daily fry mortality * freshwater residence time from otoliths). Potential land use effects (changes that affect sediment supply & peak flow) could be incorporated. Fry = Σ(Eggs*S_E +fry supplementation) by stock.
	Fry supplementation (by stock)**	User discretion	
Smolts Leaving River	1/b in river for 0+ fry by freshwater habitat type.** 1/a for 0+ fry (fry->scoop trap) by freshwater habitat type. 1/b in river for 1+ fry by freshwater habitat type.** 1/a for 1+ fry (fry->scoop trap) by freshwater habitat type.	Scoop trap population estimate. Total area by habitat type.* 0+/grid pt by habitat type.* 1+/grid pt by habitat type.*	Beverton-Holt plots of smolt #s by habitat type vs. total fry. Smolt #s by habitat type (N_{Ri}) = A_iK_id where A_i & K_i are the area & preference coefficient of habitat i, and d is the density in natural banks. Total River Smolts (N_R) = ΣN_{Ri}
Smolts in Estuary	1/b in estuary for 0+ smolts by estuary habitat type.** 1/a for 0+ smolts (scoop->estuary) by estuary habitat type. 1/b in estuary for 1+ smolts (if any) by estuary habitat type.** 1/a for 1+ smolts (scoop->estuary) by estuary habitat type.	Total area by habitat type.* 0+ density by habitat type.* 1+ density by habitat type.* Residence time by habitat type (from otoliths).*	Beverton-Holt plots of smolt #s by habitat type vs. total scoop trap smolts. For estuary, smolt #s by habitat type (N_{Ei}) = $A_i(fd)_i/T_i$ where $(fd)_i$ is the number of fish-days/sampled area, and T_i is average residence time. Total Estuary Smolts (N_E) = ΣN_{Ei}
Smolts in Bay	1/b in Bay for 0+ smolts that <u>don't</u> rear in estuary, by life history type. 1/a (scoop->bay) for 0+ smolts that <u>don't</u> rear in estuary by life history type. 1/b in Bay for 1+ smolts that don't rear in estuary. 1/a (scoop->Bay) for 1+ smolts that don't rear in estuary.	Life history composition in Bay (from otolith samples)* Estuary smolt number (N_E).	Beverton-Holt parameters from plots of smolts by life history type in Bay vs. total scoop trap smolts. For Bay smolts of life history type X, $\%N_{BX} = (fd_x/T_x)/\Sigma(fd_i/T_i)$, and $N_{BX} = N_E * (\%N_{BX}/\%N_E)$, where $\%N_{BX}$ and $\%N_E$ are the respective percents of the Bay samples composed of smolts with life history X, and of estuary-reared smolts, and i is each life history type. Total Bay Smolts (N_B) = $\Sigma N_{BX} + N_E$ Stock % of 0+ smolts = stock % of fry. 1+ smolts all added proportionately to spring stocks, giving stock % leaving Bay ($\%_S$).
Age 3 Recruitment	Marine Survival (S_M) by life history type* Post-Recruitment Natural Mortality (M)	Life history composition in terminal run from adults in test fishery.* CWT Indicator Stock Exploitation Rates.* M from literature.	Recruitment (R) from cohort analysis.*** Recruitment of life history X (R_X) = R * %X from test fishery otoliths. Survival of X (S_{MX}) = R_X/N_{BX}. Recruitment by stock (R_S) from cohort analysis.
Preterminal Catch & Terminal Run Size	Instantaneous preterminal fishing mortality (F) by age & stock.** Maturity rates by stock.	F set by user. Current rates from indicator stock CWTs. Maturity rates from terminal age composition data.***	Catch by age & stock (C_{AS}) from Baranov Catch Equation (C = FAN/Z). Total Preterminal Catch = ΣC_{AS}. Term RS by age & stock (TRS_{AS}) = $N_{AS}e^{-(F+M)}matrate_{AS}$
Terminal Catch & Escapement	Terminal harvest rate by stock.** Terminal poaching rate by stock.**	User discretion.	Terminal catch by age & stock = TRS_{AS} * HR_S # Poached by age & stock = (TRS_{AS} * HR_S) * PR_S Escapement by age & stock = TRS_{AS} - $catch_{AS}$ - # $poached_{AS}$

NOTES TO TABLE 1

* Data generated from SSC's Chinook Restoration Project proposal.

** Inputs that could be directly manipulated by restoration actions. The habitat quality values (1/a's) could be manipulated by indirect actions.

*** Recruitment of a year-class will be calculated by cohort analysis, using Pope's (1972) approximation to Gulland's (1965) formula. Adapted to chinook, this formula would be:

$$N_t = PTC_t e^{M/2} + (N_{t+1} + TRS_t)e^M$$

where, for the cohort, N_t is the population size at the beginning of year t, PTC_t is the preterminal catch during year t, TRS_t is the terminal run size in year t, and M is the instantaneous annual natural mortality rate. For this model, age of recruitment is defined as age 3; thus, N_3 is the total recruitment (R). If CWT data indicate that age 2 catches are significant, recruitment can be redefined as N_2. To do this calculation, an estimate of the population at the oldest age (age 5) is needed. The population at the beginning of age 5 will be calculated as:

$$N_5 = PTC_5 e^{M/2} + TRS_5 e^M$$

Since the spring and summer/fall stocks may have different PTC_t rates, the recruitments will be run-timing specific. Within each run timing, it will be assumed that all stocks have the same PTC_t rates.

For a given stock, the percent of a cohort that matures in year t (MR_t) is:

$$MR_t = TRS_t/(N_{t+1} + TRS_t)$$

If age composition data are insufficient to break out each stock by age, then maturity rates will be calculated for each run-timing component (i.e., spring vs summer/fall), and it will be assumed that each stock within that component has the same maturity rate.

Summary of Results

Through 1999, the Skagit Chinook Restoration Study has helped identify:

- different ocean type chinook juvenile life history types and detail in estuarine habitat use by Skagit chinook (reported in Hayman et al. 1996; Beamer et al. 2000b)
- four types of developmental otolith checks, and tentative identification of the sections of the river from which they originate (reported in Skagit System Cooperative and Western Fisheries Research Center 1998 and 1999)
- preference of channel type (tributary level) for spawning (reported in Montgomery et al. 1999),
- a starting point for quantifying of the effects of peak flow on egg to fry survival (reported in Beamer 1998; Beamer and Pess 1999; Pess et al. 2000)
- rearing preferences of juvenile chinook in mainstem edge habitat (reported in Hayman et al. 1996; Beamer and Henderson 1998)
- support for hypotheses regarding an overall estuary habitat rearing constraint (reported in Hayman et al. 1996 and this report)
- a sub-watershed scale understanding of habitat loss or change, and sensitivity to various land uses throughout the Skagit River basin, mainly related to a change in capacity or egg to fry survival (reported in Hayman et al. 1996; Beamer et al. 2000a).

The major strengths of this approach to identifying chinook limiting factors is that we are using real fish density, life history, and habitat data collected from the Skagit specifically for building this model. The model framework is based on isolated lifestages and testable hypotheses, which can be revised over time as validation monitoring information warrants. The entire model does not need to undergo revision if one part is improved.

However, we can not predict fish production changes in some habitat quality parameters (e.g., changes due to nutrient levels or water quality) and there are limitations in our current results including:

- The model does not include nearshore habitat, which may have an impact on Skagit chinook production. We will begin to address the habitat side of this data gap with a study component that inventories nearshore habitat conditions starting in the summer of 2000. Collection of juvenile chinook to assess use within each major nearshore habitat type will begin in 2001.
- Validation monitoring will require a long time period, and the model's confidence may not be in the same scale as the estimated benefits of specific restoration actions.
- There is likely to be wide variance in population estimates of juvenile chinook at specific sites within the Skagit estuary, based on the expansion of means from each habitat type.

Results from Fiscal Year 1999

This section reports results from our collections during the 1999 field season and applies the major findings of the Skagit Chinook Restoration Research Study in a simplified limiting factors analysis.

Juvenile Chinook Sampling – Skagit Estuary

In 1999, we sampled with fyke traps from February through July at eight different small blind channel sites (Table 2, Figure 1). Trapping methods were those described in Hayman et al. (1996). To calculate juvenile chinook density at each site, we multiplied the raw catch by the recovery efficiency (RE), which was estimated by doing a mark and recapture procedure at least one time per season. RE for each site is shown in Table 2. Juvenile chinook density (fish per hectare of blind channel) is plotted by time to generate a curve for each site (example shown in Figure 2). The area under each curve (fish-days per hectare of blind channel) is then divided by an estimate of estuarine rearing residence time for chinook, and then plotted against the outmigration population passing through the lower Skagit River at Burlington (Figure 3). The average estuarine resident period for Skagit juvenile chinook is 34.2 days (Beamer et al. 2000b). Outmigration population is estimated by WDFW and reported in Seiler et al. (1999).

Table 2. Juvenile chinook recovery efficiency by sampling site in the Skagit Estuary.

Fyke Trap Site	Recovery Efficiency (RE)
Freshwater Slough Pond	If ending gauge ht is between 61 cm and 72 cm, then RE = -0.0195 (ending gauge ht) + 1.6645 If ending gauge ht < 61 cm, then RE = 45% If ending gauge ht > 72 cm, then RE = 24%
Ika Saltmarsh Channel	For the lower gauge: If ending gauge ht is between 21 cm and 57 cm, then RE = -0.0092 (ending gauge ht) + 0.6439 If ending gauge ht < 21 cm, then RE = 46% If ending gauge ht > 57 cm, then RE = 13%
Tom Moore Saltmarsh Channel	If ending gauge ht is between 3 cm and 63 cm, then RE = -0.0109 (ending gauge ht) + 0.8368 If ending gauge ht < 3 cm, then RE = 80% If ending gauge ht > 63 cm, then RE = 15%
Deepwater Slough Channel	If ending gauge ht is between 2 cm and 38 cm, then RE = -0.015 (ending gauge ht) + 0.6244 If ending gauge ht < 2 cm, then RE = 59% If ending gauge ht > 38 cm, then RE = 4%
Grain of Sand	If drop in water level during trapping is between 14 cm and 124 cm, then RE = 0.004 (drop) + 0.0828 If ending gauge ht < 14 cm, then RE = 10% If ending gauge ht > 124 cm, then RE = 58%
Browns Slough - Diked Side	If drop in water level during trapping is between 3.1 ft and 4.8 ft, then RE = 0.1493 (drop) - 0.3825 If ending gauge ht < 3.1 ft, then RE = 7% If ending gauge ht > 4.8 ft, then RE = 33%
Browns Slough – Barrow Channel	For 1995 season RE = 97%, For 1996 season RE = 91%, For 1997 season RE = 82%, For 1998 season RE = 74%, For 1999 season RE = 58%
Cattail Channel	No temporal or tidal variable is evident. Therefore, we use the average RE of 34% (range 28%-38%)

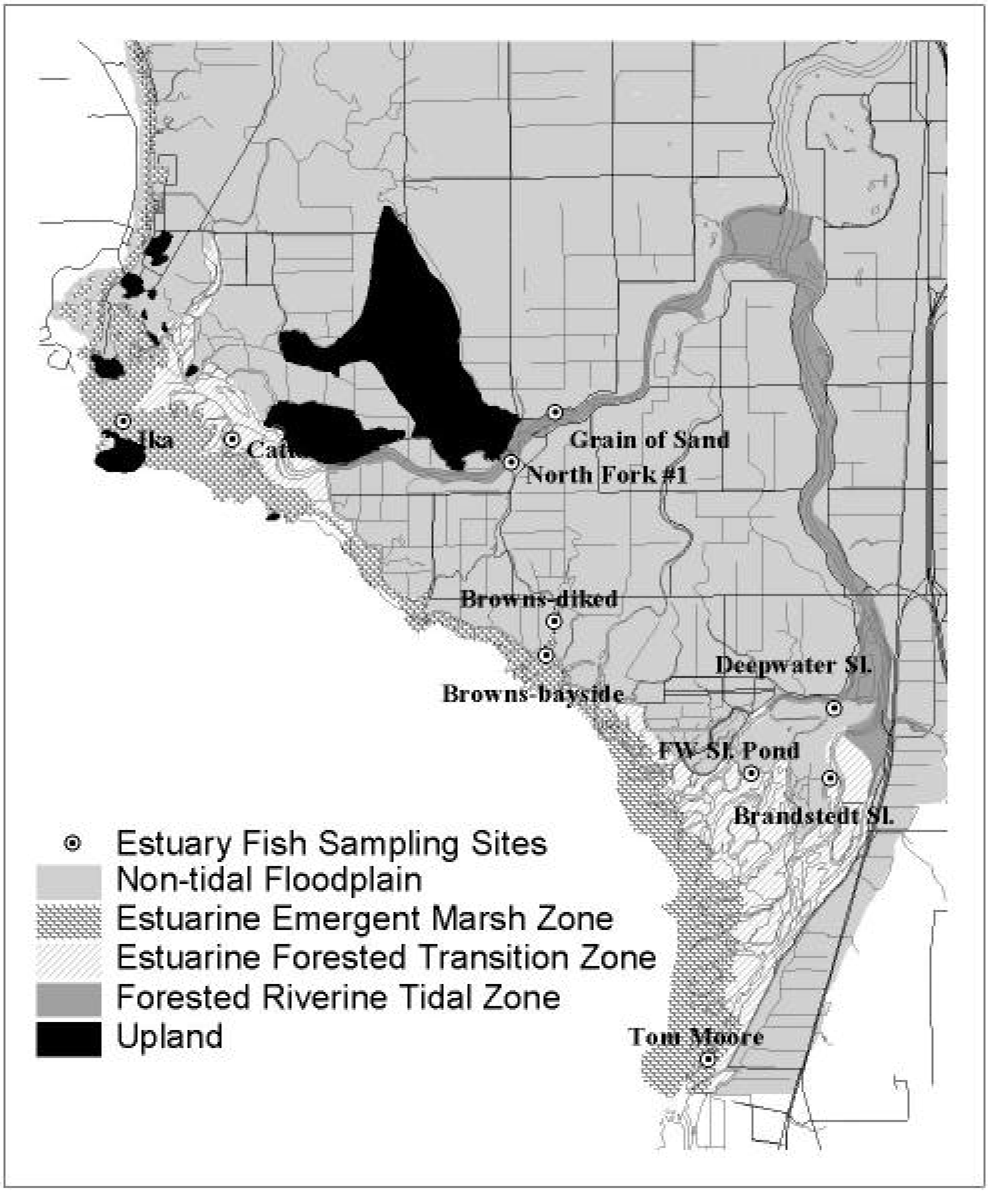

Figure 1. Map of the Skagit and Samish River Delta showing the current (~1991) extent of the estuarine habitat zones and the location of fish sampling sites.

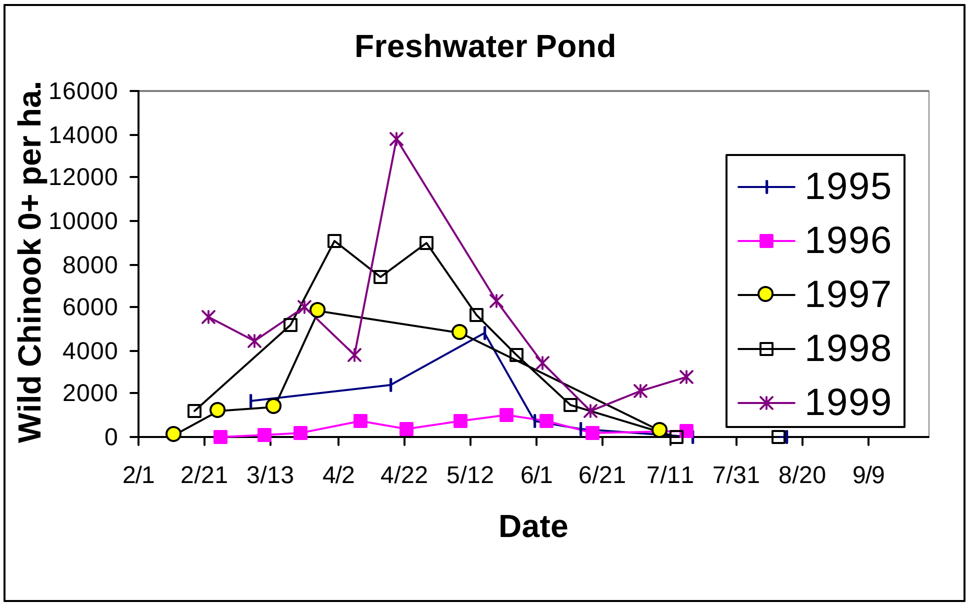

Figure 2. Seasonal density of sub-yearling wild chinook in a blind channel site within the Skagit Estuary.

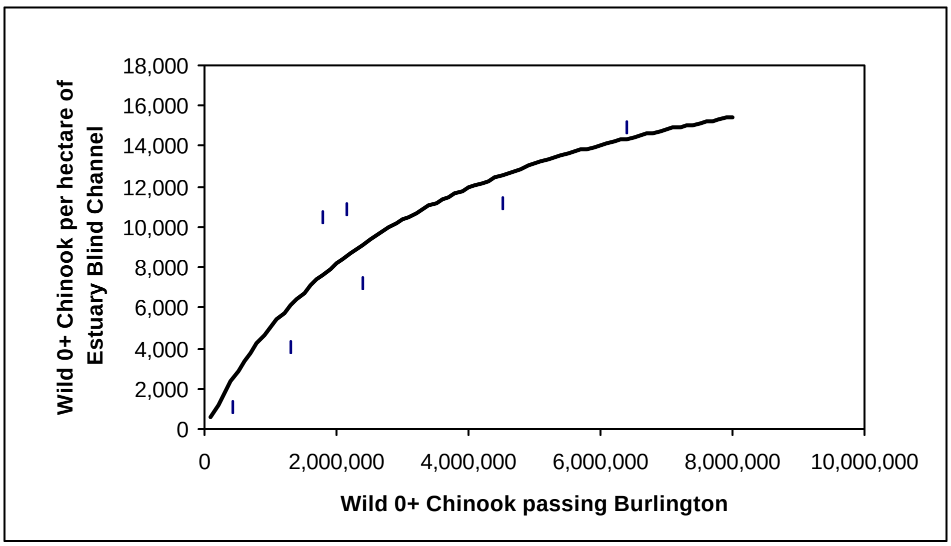

Figure 3. Beverton-Holt relationship between the number of sub-yearling wild chinook that could potentially occupy estuarine habitat and the density of sub-yearling wild chinook observed in blind channel habitat of the Skagit Estuary (R^2 = 0.81). Ocean-type chinook smolt capacity in blind channel habitat (i.e., at infinite outmigration size) is calculated at 21,916 fish per hectare.

Juvenile Chinook Sampling – Nearshore Habitat of Skagit Bay

Beach seining was conducted using a 100-foot by 12-foot beach seine set from a 20-foot outboard skiff. The net mesh was 1/8-inch. Normally, three seine sets, of approximately four minutes duration, were made at each site. All fish caught were identified and enumerated. Salmon were measured (twenty of each species, when available) and juvenile chinook were kept for otolith analysis.

Generally, up to twenty chinook were kept from each site. All chinook in the sample were kept if less than twenty were caught at a site.

Sampling Frequency

The sampling frequency for each of the eight main sampling sites is presented in Table 3, below. Sampling frequency at the Hope Island site was reduced after 1995 due to low catches, but was still sampled, infrequently. Sampling at Kiket Island was discontinued after an encounter with two large guard dogs and an armed resident of the island.

In 1999, we sampled five different sites approximately twice each month. More sets were made at some sites than others because of available time and weather conditions affecting accessibility. From February 11th through October 22nd we made 217 beach seine sets (Table 3); 122 of those sets resulted in the collection of at least one juvenile chinook salmon.

More sets were made at Strawberry Point (in south Skagit Bay) as samples were taken from both the southern and northern portions of the same beach, both of which were considered the same site. These locations are less than 500m apart. This resulted in about twice as many sets from Strawberry Point as from the other sites.

Table 3. Primary sampling sites for collection of juvenile chinook salmon in Skagit Bay.

	Number of beach seine sets					
Site	1995	1996	1997	1998	1999	Total
1. Ala Spit	48	44	65	53	47	257
2. Hoypus Point	31	29	43	51	38	192
3. Snee-oosh	26	27	43	38	29	163
4. Hope Island	22	2	3	0	3	30
5. Lone Tree Point	24	40	48	48	37	197
6. Kiket Is. / Similk Bay	7	0	0	0	0	7
7. Skagit Island	13	1	0	0	0	14
8. Strawberry Point	0	44	39	56	63	202
Total Sets	171	187	241	246	217	1,062

Catch and Relative Abundance of Juvenile Chinook

Juvenile chinook were present in Skagit Bay in February and had essentially left Skagit Bay (were absent or seldom taken by beach seining) by late October of 1999. Because sampling effort was relatively constant within and between years, the mean CPUE for a year may prove to be a comparative index of abundance in the bay. Calculations of the catch per minute (catch per unit of effort, or CPUE), for juvenile chinook only, are presented in Table 4. Peak abundance (as measured by beach seine CPUE) occurred in both February and in mid-June of 1999. Relatively high abundance was observed early in other years, but not to this degree. In other years (1995 - 1998), peak abundance occurred between May and July (McClure et al. 1999; Hayman et al 1996).

Catches of juvenile chinook were often associated with substantial numbers of other species of fish, particularly sandlance, smelt, and herring. There has been no formal analysis to determine if salmon utilize these forage fish, but later in the sampling season we observed salmon with juvenile sandlance or herring protruding from their mouths.

Changes in abundance were observed throughout the year, each year. However, the annual pattern of juvenile chinook abundance appeared to follow a similar pattern each year. Early in the year (February) the abundance of chinook was low, followed by a period of variable abundance, until the abundance peaked sometime between May and July. In 1999, a high abundance of juveniles was observed in February but fell back to levels observed in previous years. Subsequently, abundance followed the pattern of previous years, with peak abundance in June.

Juvenile Collection for Otolith Examination

Sampling effort in 1999 resulted in the capture of 662 unmarked and 78 adipose marked juvenile chinook. A total of 495 juvenile chinook were retained for otolith examination (including the adipose marked fish).

Juvenile Chinook Lengths

From February through the end October 1999, a total of 662 juvenile chinook were captured and measured. Since the inception of the project, a total of 3,138 juvenile chinook have been captured from Skagit Bay. Of these, juveniles were captured as early as February at lengths ranging from 36 to 52mm and a mean fork length of 41mm. The lengths of fish generally increased throughout the sampling season when, in September, fork lengths ranged from 98mm to 268mm, with a mean of 155 mm (Table 5.).

Table 4. Chinook beach seine catches from Skagit Bay, 1999. Catch per Unit of Effort, expressed in catch per net set. nm = no marks, ad = adipose fin clipped. The majority of adipose fin clipped fish are from the Upper Skagit Summer Chinook Indicator Stock Program.

Sample Date	Total Sets	Chinook CPUE nm	Chinook CPUE Ad
11-Feb-99	9	0.0	0.0
25-Feb-99	6	22.2	0.0
11-Mar-99	18	3.8	0.0
16-Mar-99	18	3.7	0.0
13-Apr-99	18	0.6	0.1
23-Apr-99	15	1.5	0.0
10-May-99	18	0.3	0.0
24-May-99	18	1.4	0.9
08-Jun-99	6	22.2	3.8
22-Jun-99	9	11.8	2.8
06-Jul-99	14	1.6	0.1
20-Jul-99	13	3.5	0.5
09-Aug-99	10	1.7	0.3
17-Aug-99	15	0.1	0.0
07-Sep-99	3	0.0	0.0
21-Sep-99	15	0.3	0.1
22-Oct-99	12	0.1	0.1
Average catch/set		3.1	0.4

Table 5. Average fork lengths and collection data for juvenile chinook from Skagit Bay, 1995 - 1999**.**

	1995		1996		1997		1998		1999	
Month	Avg. FL (mm)	*n*	Avg. FL (mm)	*n*	Avg. FL (mm)	*n*	Avg. FL (mm)	*n*	Avg. FL (mm)	*n*
Feb		--	42.0	1	40.1	28	42.4	14	44.7	111
Mar		--	41.5	6	41.3	74	41.5	4	41.3	131
Apr		--	44.0	1	45.6	74	59.3	16	44.3	32
May	90.5	82	82.0	8	65.7	89	69.5	222	81.3	32
Jun	83.2	192	92.6	140	87.9	169	89.2	168	89.2	168
Jul	99.3	63	104.9	53	94.5	256	98.2	189	102.6	73
Aug	118.4	24	112.3	10	101.1	81	118.9	11	114.8	19
Sep	115.3	3	195.1	14	127.9	8	135.1	12	129.5	4
Oct							150.0	1	128	1

Preliminary Application of Findings

With data from the Skagit Restoration Study, we have developed methods to evaluate productivity and capacity for Skagit chinook.

Freshwater Productivity:

A basic assumption in our analysis is that there exists some relationship between the size of a stock (e.g., number of spawners) and resulting recruitment (e.g., number of smolts). However, at first glance, this does not always appear to be true for Skagit chinook over the freshwater part of their life cycle (Figure 4). Seiler et al. (1999) has shown that for Skagit chinook, the factor with by far the greatest effect on freshwater survival is the peak flow level that occurs during the intragravel life stage (i.e., egg deposition to emerged fry) (Figure 5). Pess et al. (2000) generalized this relationship (Figure 6) and illustrated how egg to fry survival is reduced by increases in peak flows and sediment supply. Beamer et al. (2000a) analyzed the sub-basins in the Skagit River basin in terms of sediment level and peak flow hydrology, and rated them "functioning" or "impaired" for each factor (Figures 7 and 8). With these data, and in the somewhat longer term, we intend to determine the freshwater smolt production that can be attributed to the functioning sub-basins, and estimate the productivity that could be achieved in the impaired sub-basins, if they became functioning (e.g, through restoration actions). In the short term, we assumed that having an incubation flow that averages the 2-year flood return frequency (which is a mean peak flow of about 56,000 cfs at Mt. Vernon, vs. the recent average peak flow of 80,000 cfs) is as good as it can get.

To determine the smolts/spawner level under this average flow, we standardized each of the spawning escapements observed since 1989 for its corresponding incubation flow, using the relationship shown in Figure 6 (e.g., if the escapement was 20,000, but the incubation flow would have given an incubation survival that was only 10% of the 2-year flood level, then the flow-adjusted escapement would be 2,000), and plotted the observed freshwater smolt outmigration against this flow-adjusted escapement (Figure 9). The slope of the regression line through the origin is about 320 smolts/spawner; however, the 1998 point, which had the highest smolt outmigration, is not shown in that figure (because the USGS flow data have not yet been finalized). Assuming that flow was about the same as that of 1997, we would then get a regression line slope of about 380 to 400 smolts/spawner. Our preliminary rough estimate of the maximum possible average freshwater survival rate would therefore be about 400 smolts/spawner.

After adjusting for the effect of flow on freshwater productivity, it appears that, consistent with our basic assumption, more spawners do tend to yield more smolts (compare Figures 4 and 9), over the range of flow-adjusted escapements observed to date. River smolt numbers do appear to increase linearly with flow-adjusted escapement, without any indication of density-dependence (Figure 9). It therefore appears that, for the range of flow-adjusted escapements observed since 1989, freshwater capacity does not have a measurable effect on freshwater smolt production.

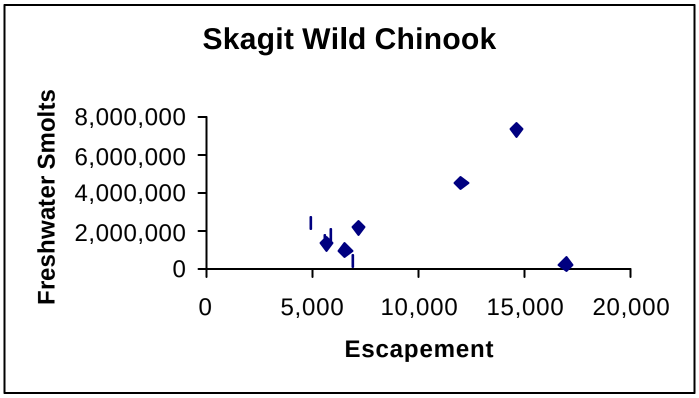

Figure 4. Relationship between Skagit Chinook escapement and resulting number of sub-yearling chinook passing through the lower Skagit River at Burlington.

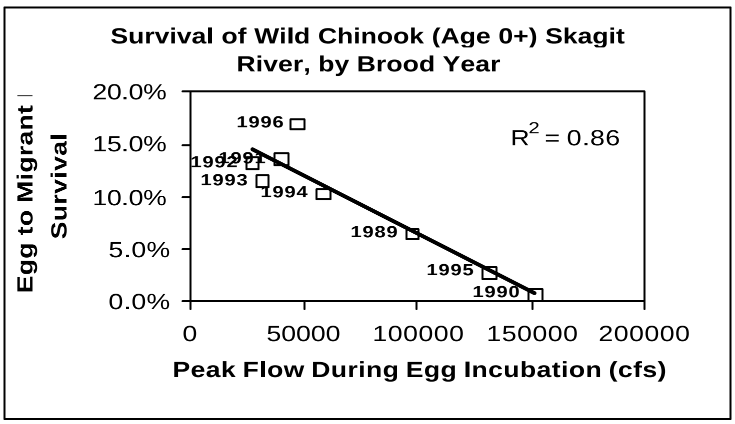

Figure 5. Survival from egg to migrant fry for sub-yearling Skagit Chinook (data from Seiler et. al. 1998).

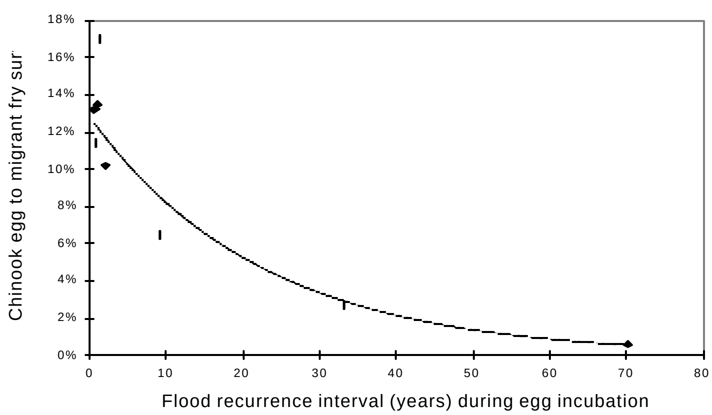

Figure 6. Chinook egg to migrant fry survival versus flood recurrence interval (years) during egg incubation in the Skagit River, Washington from 1989 to 1996 (from Pess et al. 2000). Regression equation is chinook egg to fry survival = $0.1284e^{-0.0446(\text{flood recurrence interval})}$ (r^2 = 0.97, P = 0.007).

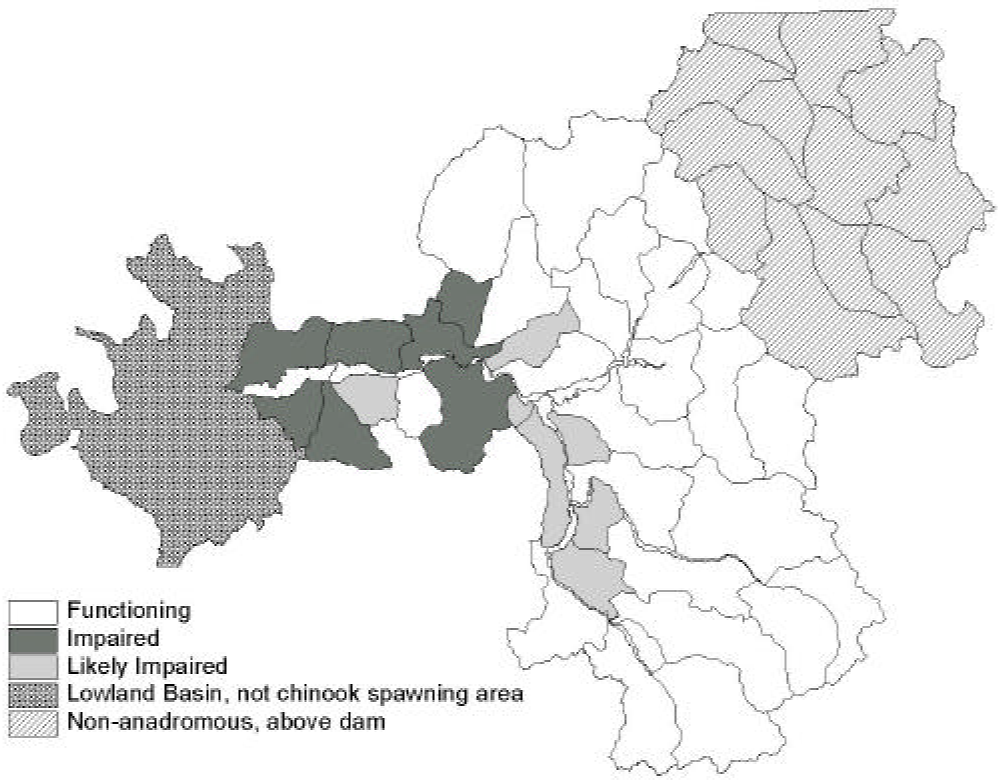

Figure 7. Sub-basins where peak flows are functioning or impaired (i.e., significantly increased over the estimated natural rate) (from Beamer et al. 2000a).

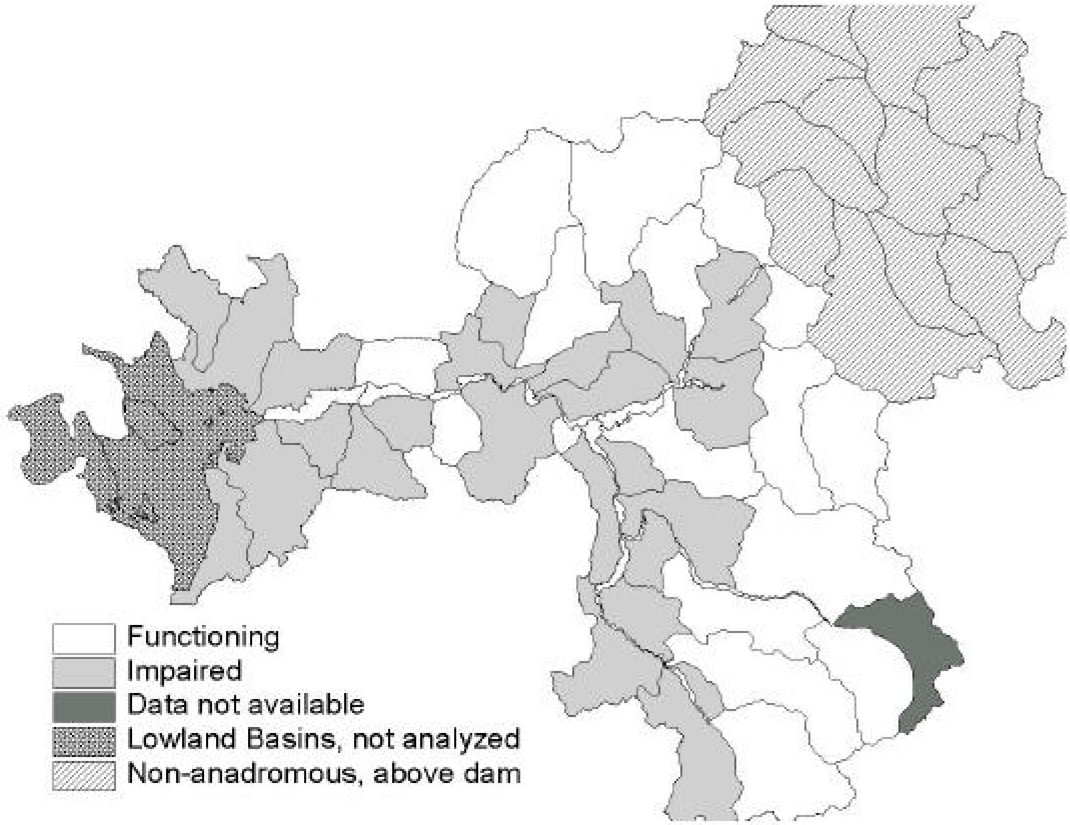

Figure 8. Sub-basins where watershed sediment supply is functioning or impaired (i.e., significantly increased over the estimated natural rate) (from Beamer et al. 2000a).

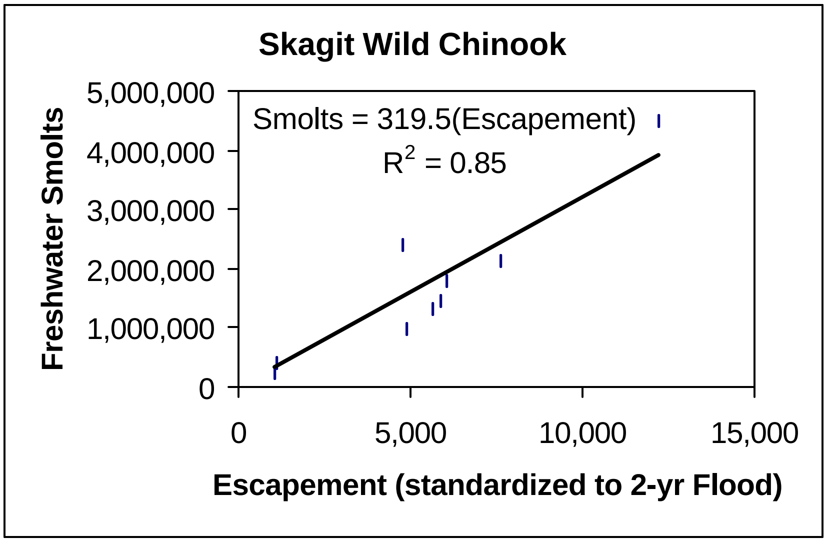

Figure 9. Relationship between Skagit Chinook escapement and the resulting number of sub-yearling chinook passing through the lower Skagit River at Burlington. Chinook escapement was standardized to the number of spawners needed to produce an equivalent number of migrant fry under a 2-year flood event, according to the predicted survival rates shown in Figure 6.

Estuarine Channel Productivity:

Preliminary analysis of chinook otoliths collected in Skagit Bay indicated that nearly all the fish sampled had reared in estuary channel habitat (Beamer et al 2000b). While we have a lot more samples to examine (collected from a lot wider time period than during our first 2 sample years), and logic tells us that there must have been some fish that moved right into the bay without rearing in the estuary channels, we assumed for this exercise that all chinook must rear in estuary channels. To the extent that some don't, we will be underestimating potential productivity.

We expressed estuarine channel productivity as the number of smolts leaving the estuary channels per smolt produced from the river. Since there have to be more smolts produced by the river than leave the estuary, this productivity must be less than one.

We calculated this number by plotting the measured smolts/ha of blind channel habitat against the number of river smolts that outmigrated that year (see Figure 3). In contrast to the freshwater graph, this figure showed a density-dependent relation (i.e., the best fit of the data is not linear). The Beverton-Holt parameters for a line through these points were: α = 4.56E-05; β = 153. This results in a slope at the origin (productivity value) of 6.54E-03 estuary smolts/ha per river smolt[1], and a maximum estuary capacity (i.e., number of smolts at infinite river outmigration – note that this is not a replacement

[1] At 117.7 ha of estuary channel habitat (current habitat estimate from Hayman et al. 1996), that's a river-through-estuary survival rate of about 77% at the origin.

level, because it doesn't produce infinite river smolts in the next generation) of 21,916 smolts/ha.

Marine Survival:

This is the survival from *leaving* the estuary to adult recruitment (in AEQ's), which is different from how we usually express it (i.e., from smolt release or migration past a river trap to adult recruitment).

Since we don't have direct estimates of this survival rate, we used the Beverton-Holt relation derived above to calculate the theoretical number of smolts that would have left the estuary under a given river outmigration, and divided that number by the AEQ adult recruitment (Puget Sound Salmon Salmon Stock Review Group 1997). This gave us marine survival values for brood years 1989-93 of 3.9%; 13.1%; 1.7%; 1.6%; and 3.0%, respectively. Ignoring the 13.1%, which could be a calculation quirk caused by using a very low outmigration number, the mean is 2.6%, with a range of 1.6% to 3.9%. We assumed that these rates were density-independent.

Freshwater Capacity:

It appears that, for the range of flow-adjusted escapements observed since 1989, freshwater capacity does not affect river smolt production (Figure 9). At some level of escapement, freshwater capacity will undoubtedly limit production; we just don't have direct evidence of what that population level is yet. However, we can infer what some of the freshwater capacity constraints would be through an understanding of fish use and habitat inventory. For example, sub-yearling chinook use of stream edge habitat with natural wood cover (common to unmodified stream edges) is over 5 times greater than their use of riprap cover (common to modified stream edges) (Beamer and Henderson 1998). We have strong evidence that stream bank hardening changes the distribution and extent of the stream edge habitat types from the preferred to non-preferred types for sub-yearling chinook (Hayman et al. 1996). Within freshwater habitat of the Skagit, 97 kilometers of stream edge has been modified (either rip-rapped or diked within 60 meters of the channel, or both) along the large main river channels (Beamer et al. 2000a).

Estuarine Channel Capacity:

As noted above, we calculated that there is a density-dependent relation between river smolts and estuary smolts, and that the maximum capacity of estuary blind channel habitat, at infinite river smolt outmigration, is about 21,916 smolts/ha. Since current blind channel habitat is 117.7 ha, this means that total estuarine capacity (at infinite smolt outmigration) is about 2.6 million estuarine smolts; at mean current marine survival (2.6%), maximum adult recruitment (with *infinite* escapement), under current estuary habitat levels, would therefore be about 67,000. Since this is above the replacement level (infinite spawners would not produce infinite recruits), the replacement carrying capacity would be even less. Because annual chinook catches in Skagit Bay alone during the

1930's approached 50,000 in some years (Ward *et al.* 1975), which means that total recruitment was likely to have been much higher, it is likely that capacity has been reduced significantly since that time. The possibility that estuary capacity has presented a gradually tightening bottleneck on chinook production is logical when considering the extent of habitat loss in this part of the river basin. Under historic conditions the Skagit had large areas of the estuarine and freshwater habitat in its delta (compare Figure 1 with Figure 10).

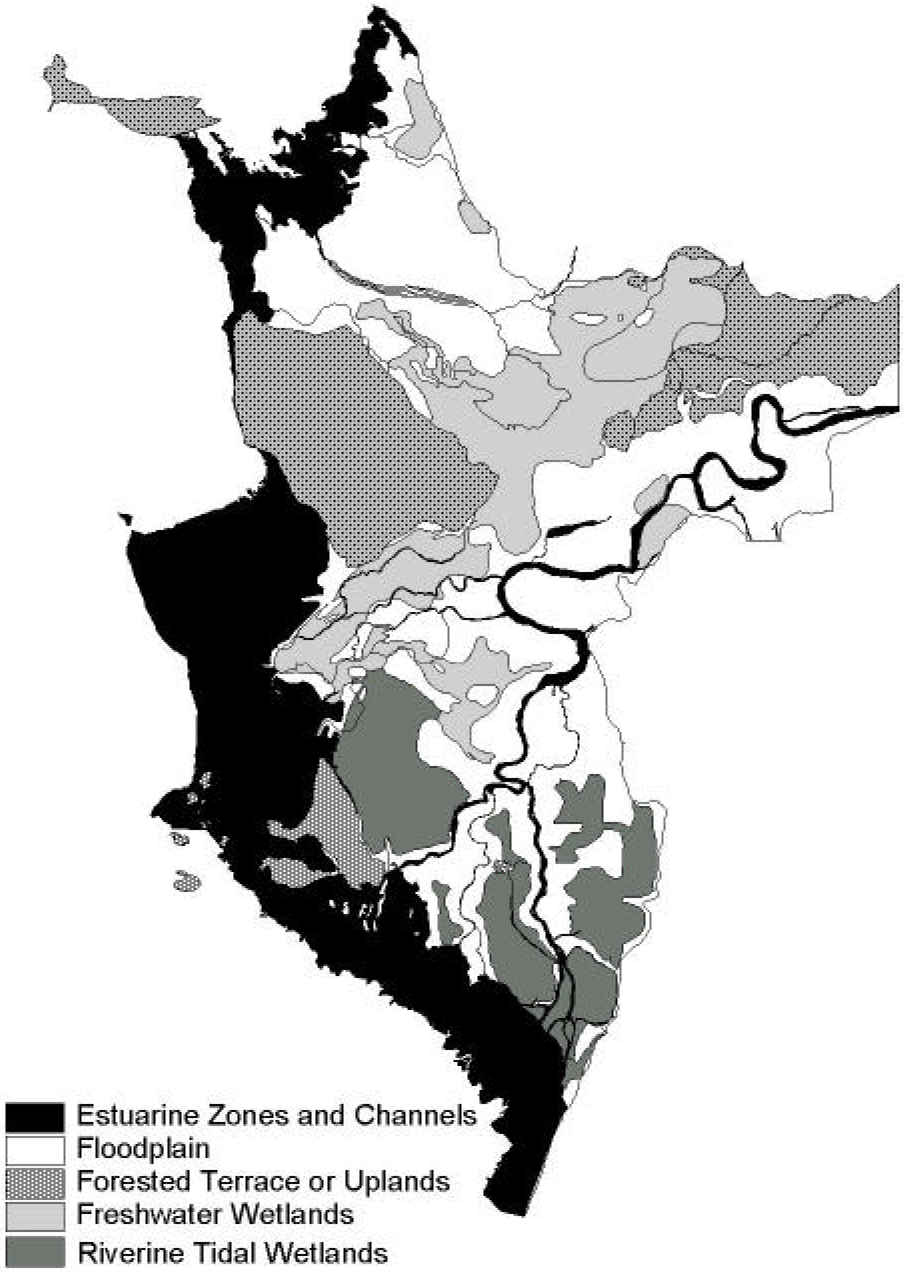

Figure 10. Location of channels, major wetlands, and limits of estuarine habitat zones of the Skagit Rivier Delta in the late 19th Century (from Collins 2000).

Marine Capacity:

We assumed no capacity constraint in the marine environment.

Illustration of Productivity Constraints (Simplified Limiting Factors Analysis)

The biological results (Figures 3, 4, 5) and habitat loss or impairment results (Figures 1, 7, 8, and 10) support the idea of two major constraints to chinook production in the Skagit:

(1) lower than expected egg to fry survival and
(2) density dependence during the estuarine rearing life stage.

Using these productivity and capacity parameters, we can predict the effect of changes to these parameters. Assuming current starting conditions of 280 river smolts/spawner, 117.7 ha of estuary blind channel habitat, an estuary-to-adult survival rate of 2.6%, and the Beverton-Holt river-to-estuary parameters described above, we could examine the effect of different restoration actions in the Skagit.

The maximum restoration of freshwater survival was estimated to be to 400 smolts/spawner, an increase of 120 smolts/spawner. Beamer et al. (2000a) estimated that 299 ha of estuary blind channel habitat, which are currently inaccessible to fish because of diking or other flood control measures, could be reclaimed for fish production. Thus, the maximum possible restoration of estuary area would be to 417 ha (117.7 + 299).

Using the productivity and capacity estimates above, we illustrated the production curves for Skagit ocean-type chinook under current habitat conditions (Figure 11), maximum restoration to increase freshwater survival (Figure 12), maximum restoration of estuarine blind channels (Figure 13), and both (Figure 14). In each case we modeled the production curve with the range of possible marine survival rates (1.6% - 3.9%).

This analysis indicated that restoration of peak flow and sediment supply to "functioning" levels would provide limited benefits, unless estuary capacity, or whatever factor it is that limits survival from freshwater smolt to estuary smolt, is also increased. If this is borne out by future studies, it would mean that our first restoration priority should be increasing the estuary capacity.

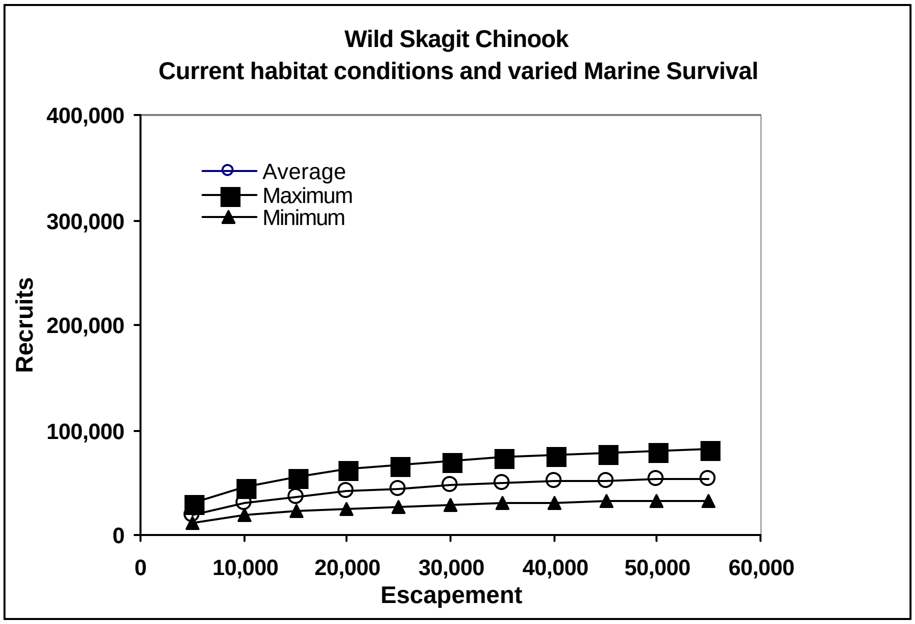

Figure 11. Estimated Skagit chinook (ocean-type only) production curve under current habitat conditions. Recruits are expressed as adult equivalent recruitment (AEQ).

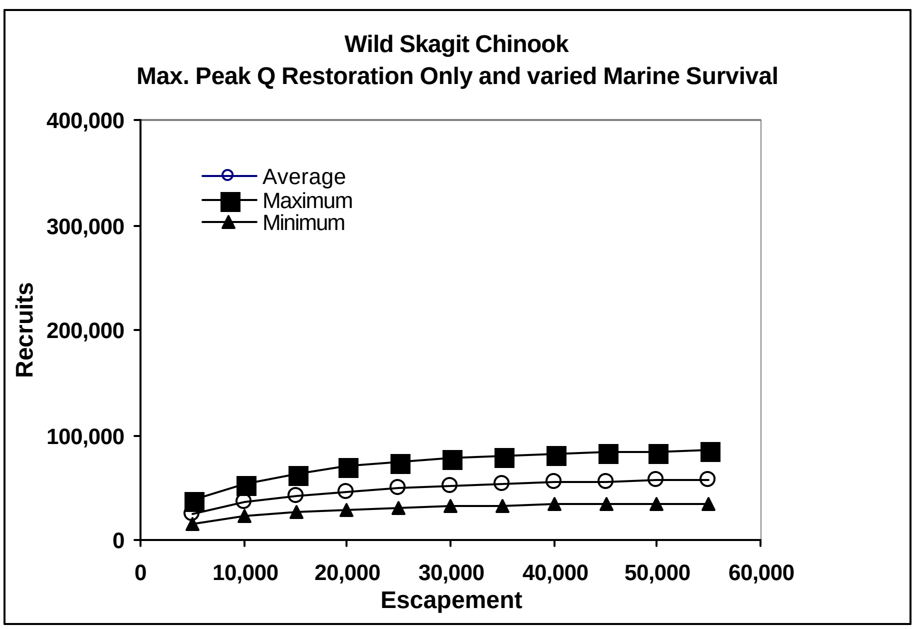

Figure 12. Estimated Skagit chinook (ocean-type only) production curve estimated after maximum restoration is completed for peak flow and sediment supply impairment (see Figures 7 and 8). Recruits are expressed as adult equivalent recruitment (AEQ).

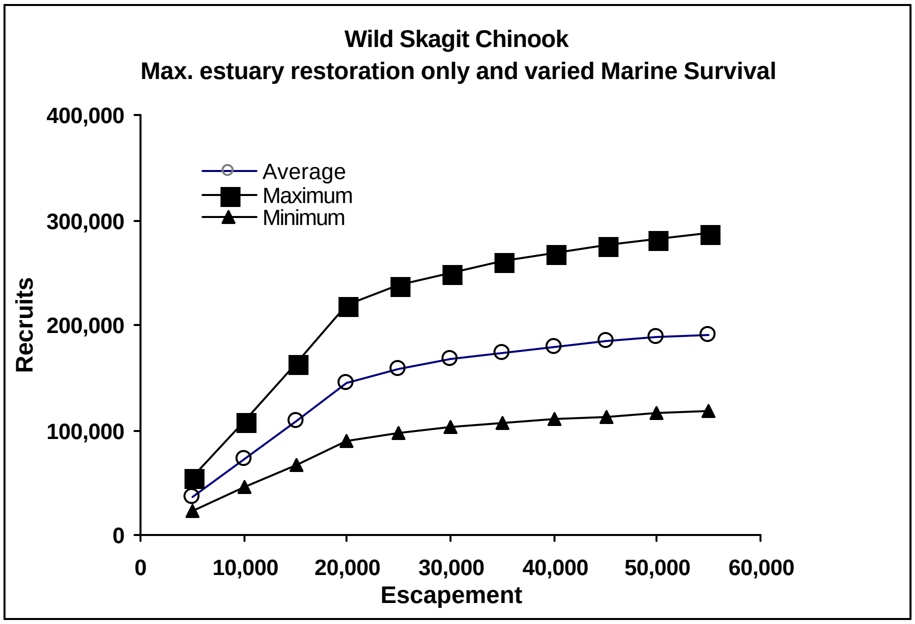

Figure 13. Estimated Skagit chinook (ocean-type only) production curve estimated after maximum estuary restoration is completed. Recruits are expressed as adult equivalent recruitment (AEQ).

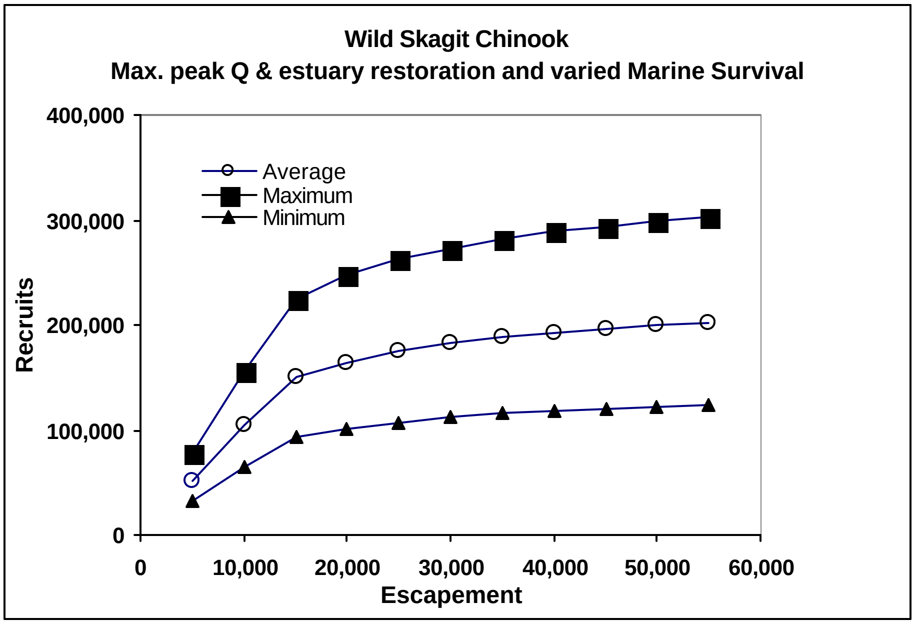

Figure 14. Estimated Skagit chinook (ocean-type only) production curve estimated after maximum restoration of freshwater survival and estuary capcity. Recruits are expressed as adult equivalent recruitment (AEQ).

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