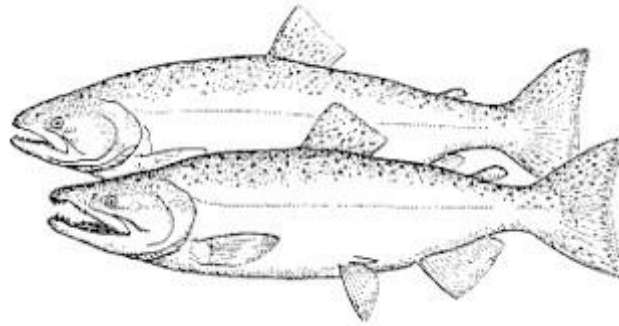

Willapa Bay Chum Salmon Investigation

FINAL REPORT
August 27, 2007



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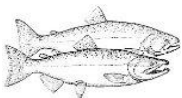
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1 INTRODUCTION

1.1 Study Purpose

Steward and Associates was contracted to assist the Willapa Bay Regional Fish Enhancement Group (WBRFEG) in the investigation of the chum salmon population within the Willapa Basin. Both groups entered into the agreement with an understanding that the overall purpose of this study and future chum studies undertaken by the WBRFEG is to increase the number of naturally spawning chum salmon in Willapa Bay. This study will lay the foundation for future actions the WBRFEG could take to play an active role in the effort to increase the number of chum salmon returning to Willapa Bay waters.

We approached the Willapa Bay chum salmon investigation with the following set of objectives:

1. Model the threat of Willapa Bay chum salmon extinction in the near future based on existing data;
2. Model the potential effect of changes to hatchery, harvest, and habitat management to Willapa Bay chum salmon;
3. Explore several key factors potentially limiting Willapa Bay chum salmon production;
4. Review and critique existing Willapa Bay chum salmon management; and
5. Provide a suite of recommendations for the WBRFEG and for Willapa Bay chum salmon management in general.

1.2 Willapa Bay

Willapa Bay, located along the southwest coast of Washington State within Water Resource Inventory Area (WRIA) 24, encompasses approximately 120 square miles at mean high water (Suzumoto 1992). The bay drains approximately 1060 square miles of upland habitat within Pacific, Grays Harbor, Lewis, and Wahkiakum counties and includes 745 rivers and streams with over 1470 linear miles of streambed (Phinney and Bucknell 1975; Smith 1999). The Willapa Basin receives water from numerous freshwater sources, including six major watersheds that produce salmon: the North, Willapa, Palix, Nemah, Naselle, and Bear rivers (Figure 1). In the spring, the most significant source of freshwater is the Columbia River plume which is drawn into the Bay by the tides (Hickey and Banas 2003, Banas et al 2004).

1.3 Chum Salmon

1.3.1 Distribution

Chum salmon (*Oncorhynchus keta*) are the most widely distributed Pacific salmon species, ranging in North America from the Sacramento River north to the Mackenzie River (Salo 1991). Although not the most abundant Pacific salmon species (chum rank 3rd behind pink and sockeye salmon), chum salmon may have historically constituted nearly 50% of the



annual biomass of the seven Pacific salmon species due to the combination of their large size and abundance.

On the Washington coast, chum salmon occur in each of the large river systems from the Columbia River north to the Strait of Juan de Fuca. The largest chum salmon populations along the Washington coast are found within the rivers of Grays Harbor and Willapa Bay (WDFW 2000). Willapa Bay historically offered excellent chum salmon habitat due to the presence of large, low gradient freshwater tributaries in combination with a pristine, productive estuary. Each major Willapa Bay tributary supports runs of chum salmon, with the North, Palix, Nemah, Naselle, and Bear rivers producing significant chum runs (WDFW 2000).

1.3.2 Genetic Stock Delineation

Several studies have employed genetic techniques to examine and delineate distinct chum populations throughout their range (Taylor et al. 1994, Wilmot et al. 1994, Winans et al. 1994, Beacham 1996). In general, three major groups of chum salmon exist in the North Pacific: Japanese; Russian/Yukon River; and southeastern Alaska/British Columbia (Taylor et al. 1994). In a more focused regional study, significant allele frequency differences were found between chum stocks of Oregon, Washington and southern British Columbia that reflected geographic and run-timing differences (Phelps et al. 1994). Evolutionarily Significant Units (ESUs), used for management in the United States, were determined based on a comprehensive review of chum salmon genetic research in the Pacific Northwest (Johnson et al. 1997). The four ESUs identified are: 1) Puget Sound/Strait of Georgia; 2) Summer-run Hood Canal; 3) Pacific coast; and 4) Columbia River. Willapa chum populations (6 stocks sampled) were grouped with Strait of Juan de Fuca and other coastal Washington and Oregon chum populations – a group more closely related to Fraser River and Georgia Strait chum, than to Puget Sound chum stocks (Johnson et al. 1997). According to SaSSI reports (2002), North River chum are genetically distinct from Naselle chum, but documentation of the original research was not available for review. Conclusive genetic evidence of distinct stock structure within Willapa Bay is not currently available, although distinctive genetic diversity has been shown between chum spawning in different parts of the Columbia River (Small et al. 2006).

The effect of hatchery supplementation on the genetic diversity of chum within Willapa Bay watersheds is also unknown. Transfers have primarily been between Willapa sub-basins; however, there have been instances when Hood Canal-origin chum were released (see hatchery section). The potential for reduced population fitness, resulting from the introgression of non-native genetic material, is a concern, but the scale of such a problem is uncertain. LeClair et al. (1999) found evidence that the genetic distance between hatchery and wild chum in south Puget Sound had not been reduced over time (i.e. gene flow and loss of wild genetic diversity was minimal). Similarly, since not many chum salmon have been transferred into Willapa Bay from other stocks, we suspect that the genetic profile still largely reflects Willapa Bay stocks, the effects of within-basin transfer notwithstanding.

1.3.3 Life History

Chum salmon are a semelparous anadromous fish species, meaning they live out most of their 3-5 year life cycle within the productive marine waters of the North Pacific Ocean



followed by a short spawning run into freshwater river systems before they die. Willapa chum salmon adults begin entering the bay as 3, 4, or 5 year old fish in late September, and spawn from mid-to-late October through November. Fry emerge from the spawning gravels in March and April and migrate downstream to the estuary within a few weeks of emergence. Chum salmon are heavily dependant on estuaries since they offer an excellent source of food for rapid smolt growth and development (Smith 1999). Chum smolt residence time within the estuary ranges from two weeks to 40 days and is typically driven by food availability; as food supplies (i.e., zooplankton) decline in the estuary, chum salmon migrate to offshore waters and switch diets accordingly.

1.3.4 Abundance

As indicated in Figure 2, typical Willapa Bay chum runsizes in the past 40 years range between 25,000 and 100,000 fish, although certain return years have produced very large (>225,000 chum in 1988) and very small (<14,000 in 1979) returns.



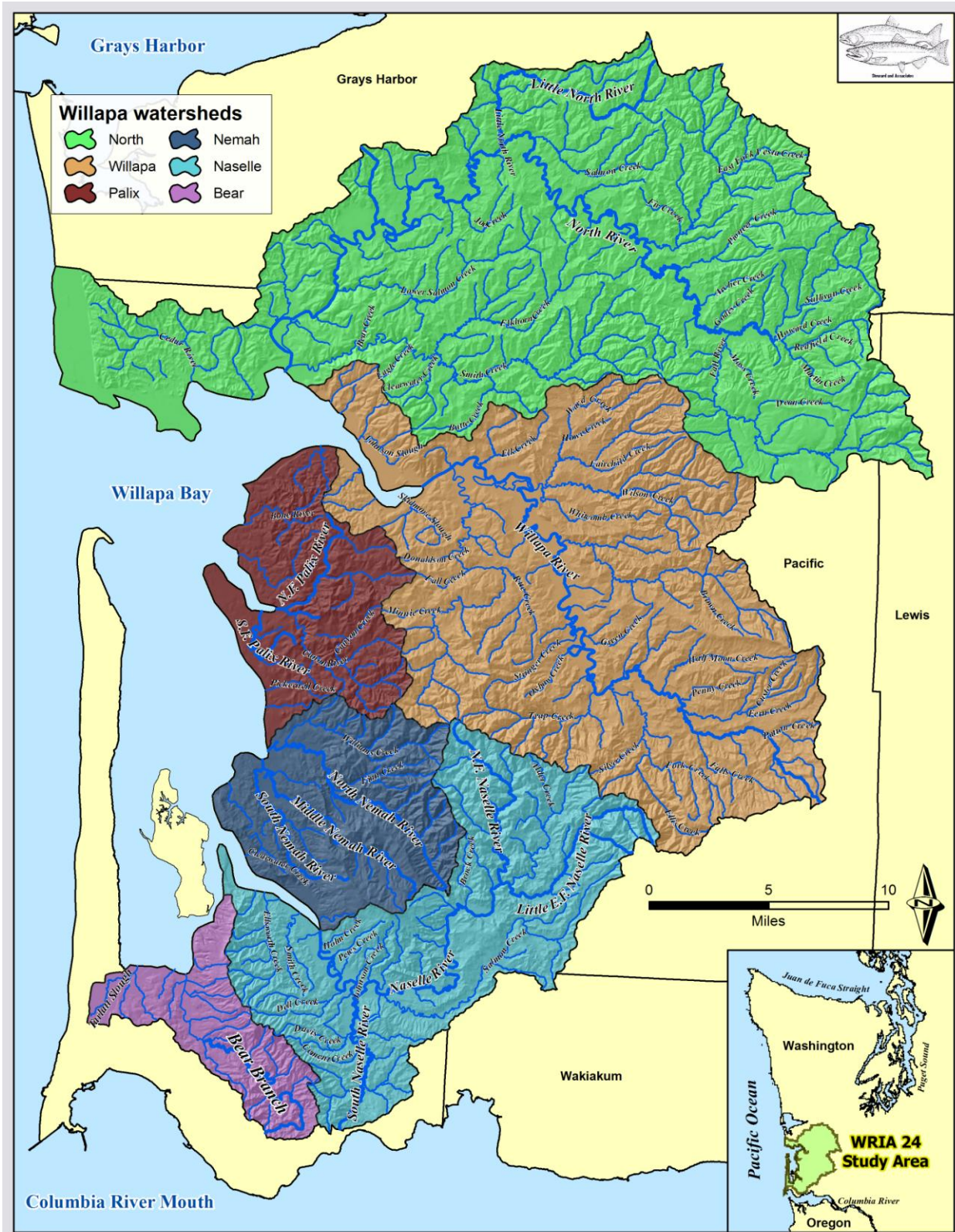
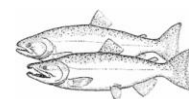


Figure 1. Project site map showing the six major watersheds draining to Willapa Bay.



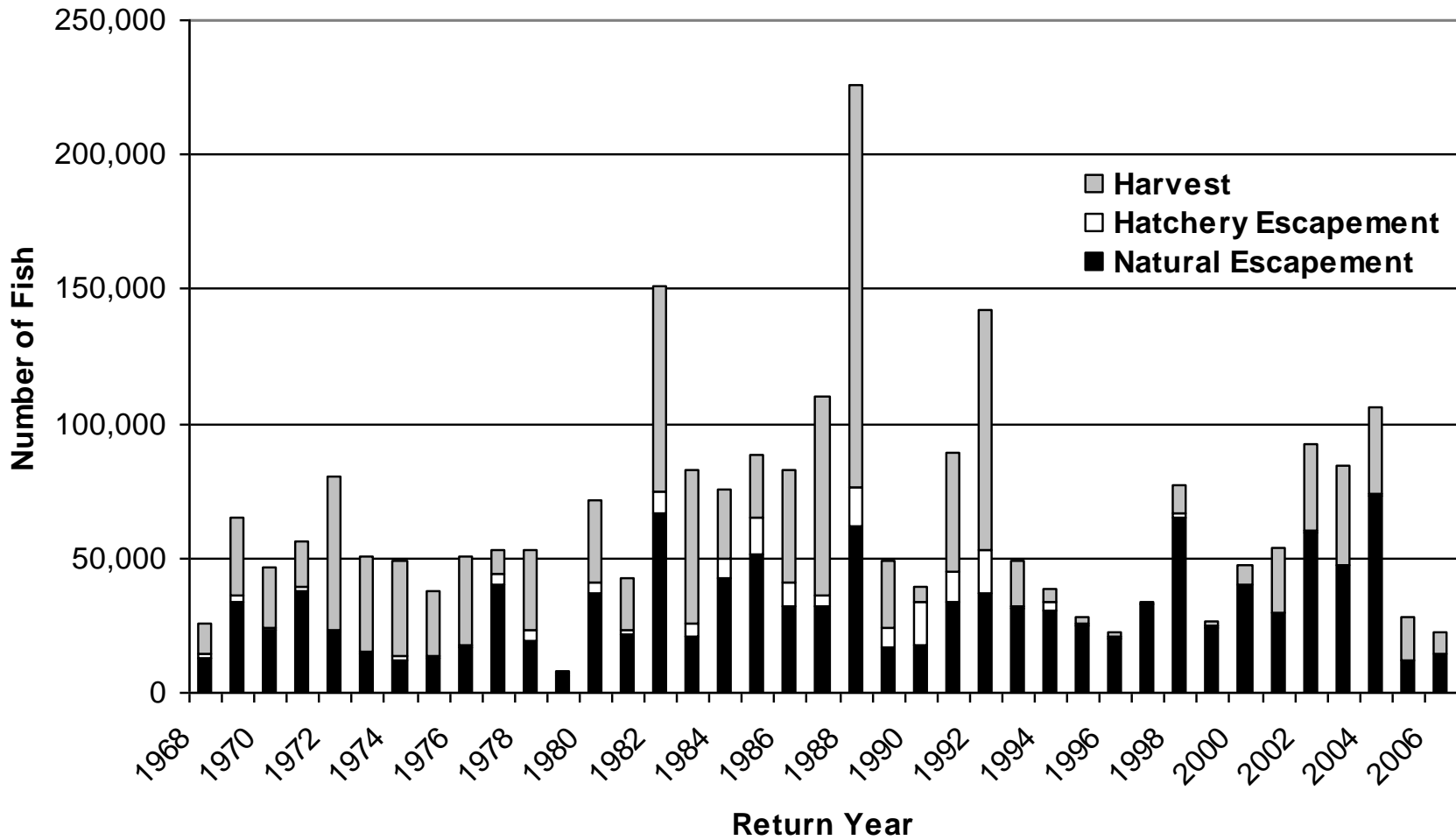


Figure 2. Willapa Bay chum salmon natural escapement, hatchery escapement, and harvest from 1968 to 2006 (Data source: WDFW).



2 POPULATION MODELS

Two different types of quantitative models were used to address some of the general concerns regarding the status of Willapa Bay chum salmon. First, the Salmon Population Analyzer (SPAZ) was used to describe the population based on available data and to calculate the risk of extinction over a certain period of time. This information regarding the long-term viability of the population helped to frame subsequent questions. Second, the All-“H”-Analyzer (AHA) was used to project the population over 100 generations under hypothetical management scenarios. The AHA model thereby provided a framework for management decision-making and determining what types of future research may be needed.

The results from any modeling exercise, including this one, are limited by the quality of the initial data. Willapa Bay chum salmon data were provided by the WDFW as the best data available. Due to limited resources for sampling and the inherent difficulty of fisheries population monitoring, there is substantial potential for error to be introduced. Expanding observed data to estimate statistics for the entire population requires many assumptions and can potentially further multiply the error. Potential improvements to data collection methods are beyond the scope of this section, but are discussed in Sections 4 and 5 of this report.

2.1 Salmonid Population Analyzer (SPAZ)

Recent assessments of other salmon populations’ viability have analyzed four characteristics to determine whether a population can persist over the long-term. These include abundance, productivity, spatial structure, and genetic diversity (McElhany et al. 2000). The Salmon Population Analyzer (SPAZ) model was developed at NOAA Fisheries’ Northwest Fisheries Science Center to address the first two characteristics. Analysis of the latter two characteristics is not presented in detail in this report due to the limited amount of available information within the Pacific Northwest region.

The general concept behind the SPAZ model is to determine whether a particular population of salmon will be able to sustain itself over the long-term, given anticipated variability in recruitment and environmental conditions. The model projects the population size over time based on the recruitment dynamics of the particular species and population in question and stochasticity estimated from the data provided, assuming that underlying factors such as the quality and amount of habitat remain the same. The term population is defined as an independent group of one salmon species that is not significantly affected by its neighboring populations; in other words, where extinction of one population would not degrade the population of the other. Viability is defined as the population having negligible risk of extinction over 100 years. This model has been used for multiple salmonid species in the Lower Columbia and Willamette Rivers (McElhany et al 2004, 2006a).

In the SPAZ model, historical data relating to abundance and productivity are used to project the population into the future and determine the population’s risk of extinction over a given time line. In order to run this assessment, certain types of information are needed including: time-series’ of escapement and catch, the age structure of spawners, and the influence of any hatchery programs.



The SPAZ model provides several useful outputs. It reconstructs annual returns from each brood year, which allow an assessment of spawning success over time, and fits several different recruitment functions to the data. The main output from SPAZ is a “viability curve” which summarizes the extinction risk model and provides a graphical way to compare the current stock status to various long-term risk thresholds.

2.1.1 Methods

2.1.1.1 Basic Statistics

Data were loaded into the model as a tab-delineated text file that contains columns with the following headers:

- “Year” - representing each year of record;
- “Spawners” - referring to total escapement numbers;
- “Fracwild” - is a fraction between 0 and 1 representing the proportion of spawners that were of natural origin;
- “Catch” - the number of adults harvested;
- “Age1”, “Age2”, “Age3”, “Age4”, “Age5” - each represent the fraction of that year’s escapement that was made up of 1, 2, 3, 4, or 5 year old fish respectively; and
- “Regime” - is a multiplier (set at 1.0 as a default) that adjusts results according to information available about basin-scale environmental patterns.

These data were compiled from various sources within WDFW. Willapa Bay chum escapement data represent estimates made from stream surveys and the application of extrapolation methods (see Section 4.3). Annual hatchery reports supplied information on past levels of chum hatchery production from which the fraction wild was calculated as:

$$\text{FracWild} = (\text{Wild Escapement}) / (\text{Wild} + \text{Hatchery Escapement}).$$

Chum catch in Willapa Bay for sport and commercial fisheries was available from harvest records. Spawner age distributions used were the same distributions used in the WDFW run reconstruction workbook from 1969 to 2006. The regime column was left at the default value because a standard index was not available and a specific mechanism for its impact on chum has not been documented.

From these numbers, SPAZ performed runsize reconstructions, calculated spawner/recruit statistics, and fit specified production models to the data. Based upon review of these summary statistics and in comparison with previously published chum population parameters in other regions, we selected a recruitment function with which to best simulate the population dynamics for the risk analysis.

2.1.1.2 Viability Analysis

Assessing viability with the SPAZ model consisted of overlaying results from a sensitivity analysis of the population’s estimated growth and abundance parameters with results from an



extinction risk analysis. The sensitivity analysis used a Markov-Chain Monte-Carlo approach to fit a specified production model to the data. Based on the priors defined by the user, SPAZ calculated a posterior likelihood distribution of the growth and abundance parameters. The risk analysis projected the population's size over 100 years using the spawner-recruit model and process error terms. If during this time the number of returning spawners fell below a certain threshold (referred to as the "Quasi-Extinction Threshold" or QET) for an average generation (4 years for chum), then the population was considered extinct. This projection was iterated several thousand times to determine the probability of extinction under a range of productivity and abundance values. Based on the user-defined time horizon (100 years), QET (600 spawners), and acceptable extinction risk (5%, 25%, and 50% chance that extinction will occur), a viability curve is generated. Ultimately the posterior growth and abundance distributions are plotted together with the viability curves. If the population is located above and/or to the right of the curve, it is considered viable. If it is below and/or left of the curve, it is considered non-viable.

At very low numbers of spawners the spawner-recruit process often does not behave according to the production model (known as the depensatory or "Allee" effect). The QET is a precautionary way to address uncertainty regarding depensatory effects. In essence, if the projected population drops below the QET during the risk analysis projections then recruitment for that year is set to 0. Determining the QET is difficult and is ultimately based on expert opinion. In the Willamette/Lower Columbia viability assessment for coho, logical discussion based on the limited empirical evidence led to using a value of 2.0 spawners per mile (McElhany 2006a). In this assessment of Willapa chum, we used a value of 100 fish per each of the 6 defined stocks (SASI) and set the QET equal to 600.

The Salmon Population Analyzer model offers a wide range of settings that define how data will be used in the different types of analyses. Corrections are available to adjust the data for 1) the potentially reduced success of hatchery origin spawners, 2) any harvest that occurred after escapement was estimated, and 3) to apply a weighting system to mean ages. We chose to use the correction for hatchery spawners but did not discount their chance of successfully spawning in the wild because for the most part, broodstock were of local, natural origins. The other options were unnecessary for the Willapa chum data. Next we specified the preferred production model and set the priors for the critical parameters (growth rate, carrying capacity, and variance) to represent a sufficiently large range of possibilities.

2.1.2 Results

Input to the SPAZ model is displayed in the table below. Data were acquired from various sources within WDFW.

Table 1. "Spawners" represents total escapement, "FracWild" is the proportion of the escapement that came from natural origins as opposed to hatchery origins, "Catch" is the number of adults harvested that would have spawned. Age structure data from Suzumoto (1992). Regime value is a multiplier, thus 1.0 results in no effect.

Year	Spawners	FracWild	Catch	Age1	Age2	Age3	Age4	Age5	Regime
1968	14200	0.93	11700	0	0	0.380	0.550	0.070	1



1969	35900	0.94	29300	0	0	0.800	0.200	0.000	1
1970	23900	0.97	22900	0	0	0.291	0.705	0.004	1
1971	39000	0.96	17100	0	0	0.697	0.300	0.003	1
1972	23600	0.95	56400	0	0	0.235	0.765	0.000	1
1973	15500	0.94	35400	0	0	0.210	0.650	0.140	1
1974	13300	0.92	35700	0	0	0.475	0.508	0.017	1
1975	14000	0.9	23600	0	0	0.807	0.193	0.000	1
1976	17400	0.95	33500	0	0	0.108	0.889	0.003	1
1977	44600	0.9	8500	0	0	0.880	0.120	0.000	1
1978	23200	0.82	29700	0	0	0.079	0.921	0.000	1
1979	7000	0.91	1200	0	0	0.650	0.230	0.120	1
1980	41300	0.9	30550	0	0	0.529	0.471	0.000	1
1981	23200	0.95	19500	0	0	0.315	0.625	0.057	1
1982	75000	0.89	76000	0	0	0.119	0.877	0.004	1
1983	25400	0.82	57400	0	0	0.280	0.333	0.387	1
1984	49500	0.86	26350	0	0	0.507	0.460	0.029	1
1985	64900	0.79	23700	0	0	0.665	0.327	0.008	1
1986	41300	0.79	41350	0	0	0.072	0.915	0.013	1
1987	36400	0.88	73500	0	0	0.614	0.317	0.069	1
1988	76420	0.81	149558	0	0	0.015	0.947	0.037	1
1989	23817	0.72	25253	0	0	0.140	0.345	0.515	1
1990	33983	0.52	5704	0	0	0.031	0.888	0.075	1
1991	45028	0.75	44280	0	0	0.252	0.591	0.157	1
1992	52700	0.7	89676	0	0	0.016	0.930	0.051	1
1993	32334	0.96	17029	0	0	0.072	0.329	0.595	1
1994	34045	0.9	4780	0	0	0.242	0.605	0.144	1
1995	25501	0.97	2922	0	0	0.282	0.554	0.158	1



1996	20553	0.97	2306	0	0	0.100	0.857	0.031	1
1997	33922	0.98	192	0	0	0.431	0.539	0.030	1
1998	66416	0.98	10447	0	0	0.133	0.791	0.075	1
1999	25005	0.98	1875	0	0	0.505	0.293	0.198	1
2000	40233	1	6970	0	0	0.255	0.734	0.010	1
2001	29970	0.98	23573	0	0	0.360	0.587	0.052	1
2002	60275	0.99	32427	0	0	0.484	0.433	0.083	1
2003	47797	0.99	36960	0	0	0.079	0.887	0.033	1
2004	73827	0.99	32587	0	0	0.124	0.758	0.118	1
2005	11983	1	16142	0	0	0.165	0.605	0.227	1
2006	14717	1	8064	0	0	0.260	0.660	0.060	1

We first used SPAZ to generate summary statistics and calculate spawners per recruit for the time series (Figure 3). Then, a variety of recruitment function models were fit to these data (Figure 4).

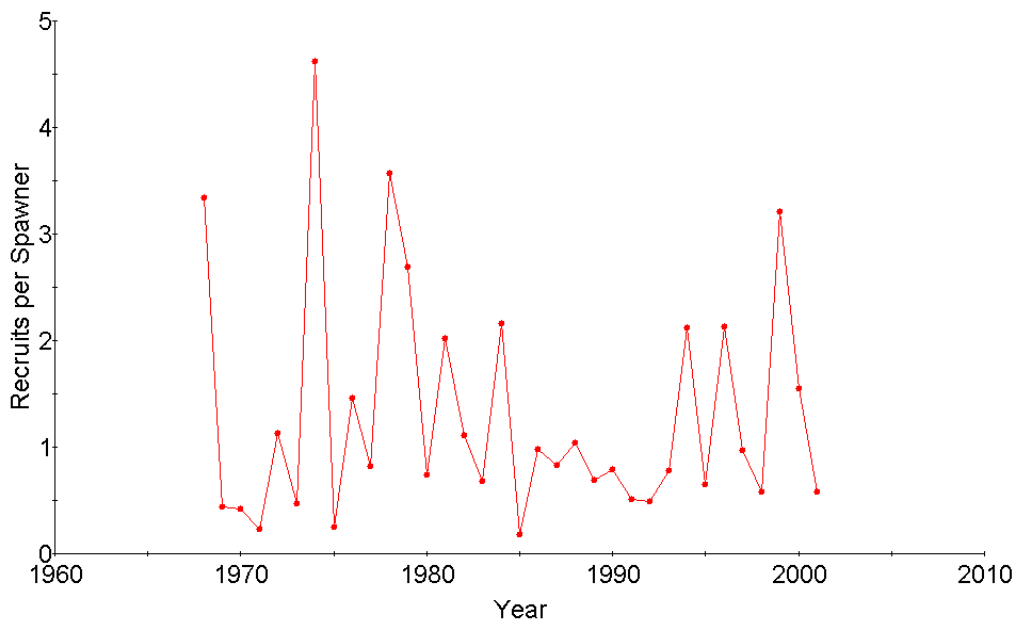


Figure 3. Recruits per Spawner calculated by SPAZ for Willapa chum salmon from 1968 to 2001.



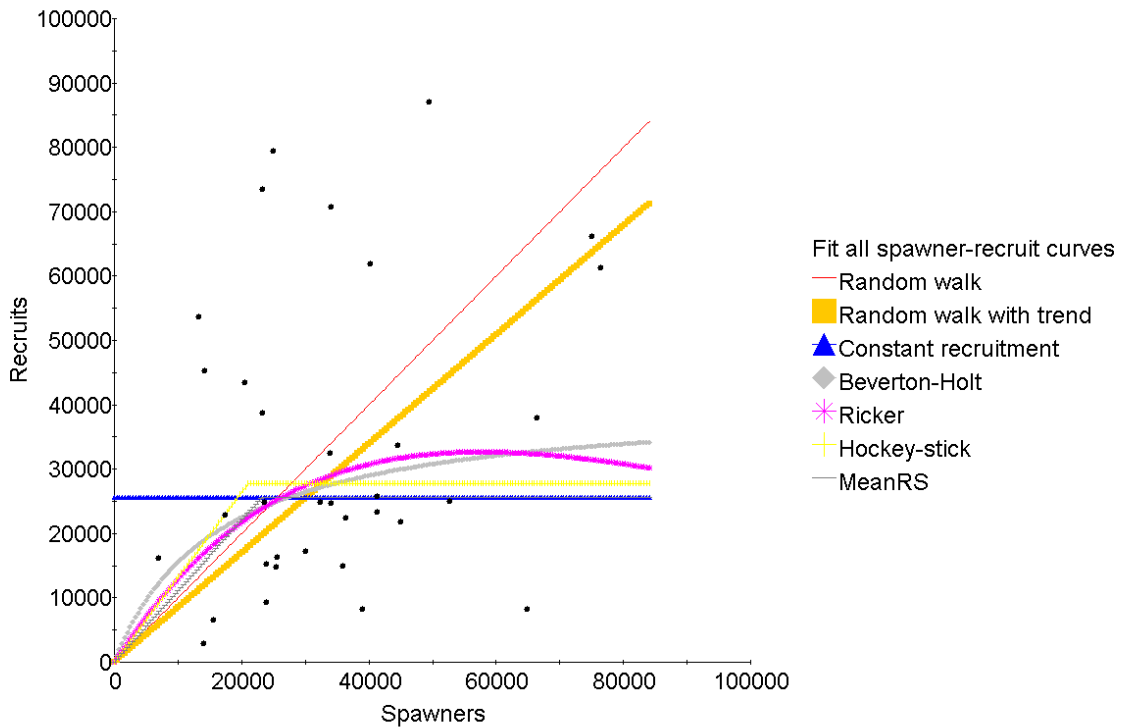


Figure 4. Best fit of 7 different production models to the Willapa chum recruits per spawner data.

As can be seen by the wide spread in data (Figure 4), the spawner-recruit relationship was not well-defined for these data, therefore selecting the best model was challenging. Ultimately we chose the Beverton-Holt function because it had the lowest value for the Aikake Information Criteria (AIC) and the estimated growth rate was similar to those of other chum populations (Table 2).

Table 2. A comparison of the results from fitting several commonly used recruitment models to the Willapa chum data using a Bayesian approach. Maximum likelihood estimates (MLE) and confidence intervals of growth rate (A) and carrying capacity (B) parameters. AIC = Aikake Information Criteria (C) and relAIC is the relative distance from the lowest AIC value.

(A) Table of results			
Model	Growth rate LowerCI	Growth rate MLE	Growth rate UpperCI
Random walk	0	0	0
Random walk with trend	0.67938	0.84743	1.10650
Constant recruitment	0	0	0
Beverton-Holt	1.48911	2.49619	18.11389
Ricker	0.90353	1.53503	2.48361
Hockey-stick	1.17097	1.31890	18.93096
MeanRS	0.77990	1.10349	1.55067

(B) Table of results			
Model	Carrying capacity LowerCI	Carrying capacity MLE	Carrying capacity UpperCI
Random walk	0	0	0

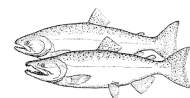


Random walk with trend	0	0	0
Constant recruitment	20781	25586	32873
Beverton-Holt	23675	40862	69874
Ricker	27125	32635	85742
Hockey-stick	20835	27699	35336
MeanRS	20516	25574	31799

(C) Table of results

Model	AICc	relAIC
Random walk	83.23526	2.89389
Random walk with trend	85.37078	3.5164
Constant recruitment	83.59357	0..2606
Beverton-Holt	83.21695	0
Ricker	84.01843	0.7727
Hockey-stick	84.6231	0.8113
MeanRS	90.76368	6.6217

A sensitivity analysis of the population status using the Beverton-Holt model showed a high degree of uncertainty regarding the maximum likelihood estimate (MLE) for the growth rate and carrying capacity parameters (Figure 5). The MLEs for production and abundance were above all three of the defined risk thresholds (5%, 25%, and 50% over 100 years).



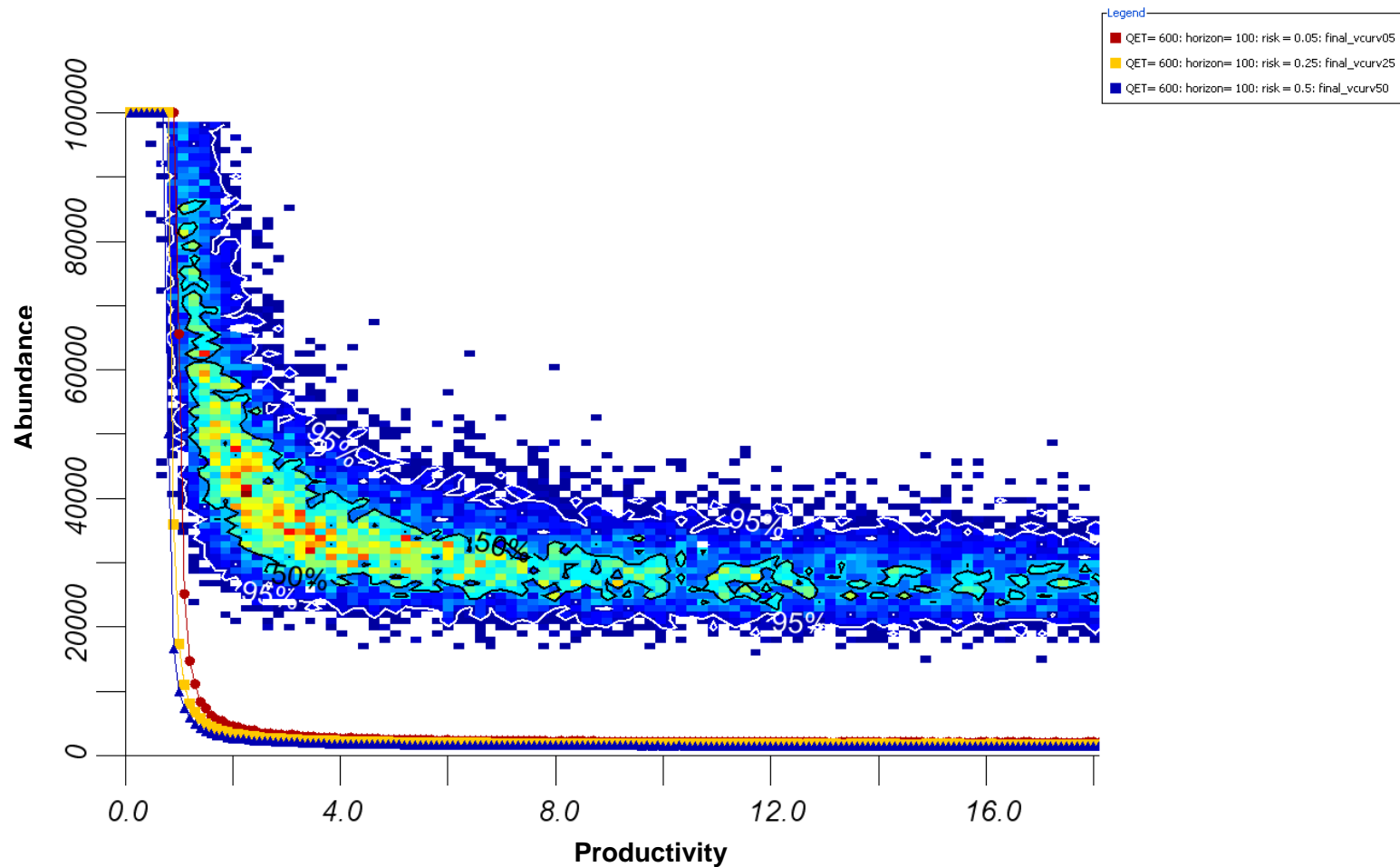


Figure 5. Viability of Willapa Bay chum population expressed in terms of productivity and abundance. Lines represent different extinction risk isopleths (red=5%, yellow=25%, blue=50%) and “blob” represents the likelihood of estimated values of the population’s productivity and abundance. For all likely combinations of current productivity and abundance parameters, the Willapa Bay chum population has less than 5% chance of going extinct over the next 100 years. The exception to this statement is illustrated on the left side of the chart where productivity is 1.0 or less: intuitively, this “growth” rate is less than needed for the population to replace itself and would lead to eventual extinction.



2.1.3 Discussion

Since 1968, the average number of recruits per spawner has been slightly above replacement (1.17), however, in 22 out of 34 broods (65%) the population failed to replace itself (recruits per spawner < 1.0). These statistics are a result of the highly variable recruitment success of chum from year to year. These data also show that the relative number of returns in a particular cohort is on average higher in brood-years when the number of spawners is lower. Conversely, relative returns are lower in brood-years when there are a large number of spawners in the streams (Figure 6). This pattern supports our decision to use the Beverton-Holt recruitment model, which can incorporate population dynamics such as density dependence and carrying capacity, rather than a simpler model that uses constant or mean recruitment.

Using the Beverton-Holt function, SPAZ estimated a Willapa Bay carrying capacity of approximately 40,000 chum. While uncertainty around this value was high (upper and lower confidence intervals were 23,700 and 70,000 respectively), probably due to the wide scatter in the data (Figure 2), the capacity seemed low considering historical catch records reported by Suzumoto (1992). For example, the average number of chum caught in Willapa Bay between 1913 and 1959 was 83,400. Escapement was not estimated at that time, but one can imagine that the total run-size (harvest + escapement) was significantly greater than more recent chum run-sizes. Several examples of large run-sizes can be found over the last 30 years: over 100,000 natural origin chum returned to Willapa in 1982, 1988, 1992, and 2004; but it is difficult to determine the factors that led to this success or whether the current habitat conditions and access in the Willapa Basin is sufficient to provide opportunity for all returning fish to spawn.

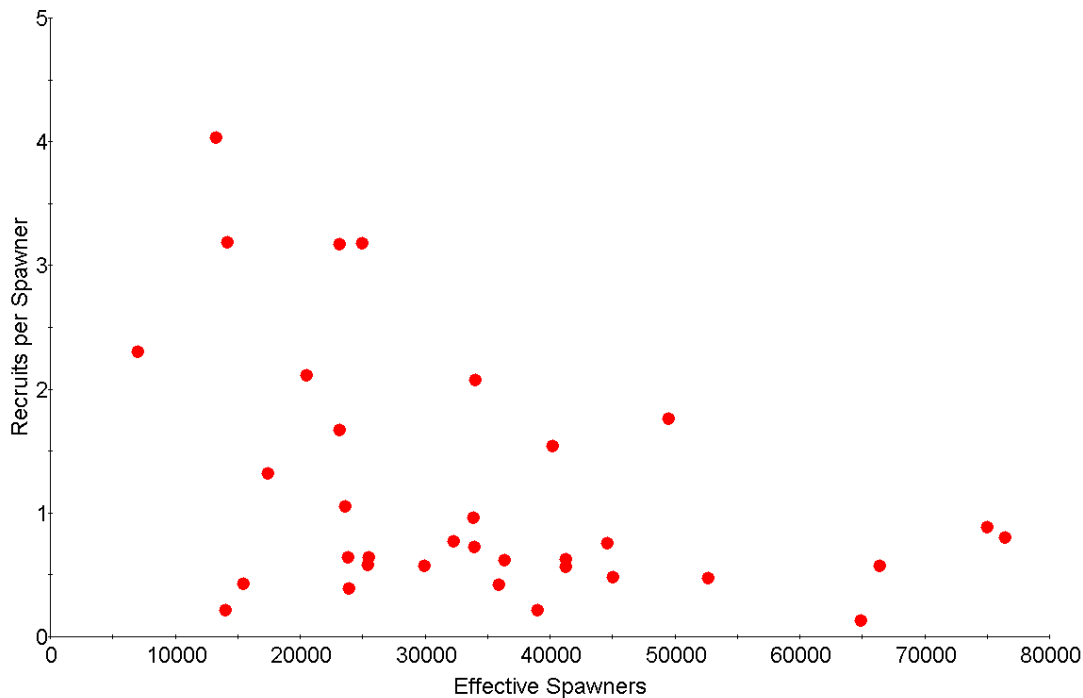
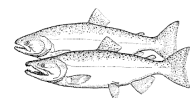


Figure 6. Relative success of chum spawning compared to the total number of spawners.



Results from the SPAZ model indicate that, despite a high degree of uncertainty around the estimated productivity and abundance of Willapa Bay chum, the population as a whole is at a negligible risk of extinction in the near term (Figure 5). However, we feel this type of analysis would be more useful on a stream by stream basis where capacities are not as large and more stream-specific factors could be considered. Unfortunately, sufficient data is not available for more specific analyses that would assess the viability of the six stocks delineated by SaSI.

It is also important to note that this chum population is viable in the sense that at least some chum will persist in these streams. The model does not address whether a persistent level of chum is sufficient to fill its historical ecological role in the Willapa Bay ecosystem. The model also assumes that overall, the current habitat condition and availability will remain the same over the next 100 years. If significant alterations occur such that the carrying capacity is reduced, then these results will no longer be valid.

2.2 All “H” Analyzer (AHA)

The AHA model is a spreadsheet model that allows users to explore the tradeoffs and decisions inherent in the management of fish populations. It provides a way to incorporate “what-if” scenarios into the context of changes to habitat, harvest rate, and hatchery production. The model can run multiple scenarios simultaneously and provides a user-friendly comparison of management options and goals. Optional components include simulated variability in ocean conditions and loss of genetic fitness due to hatchery effects.

Population dynamics are defined with a Beverton-Holt recruitment relationship, which is conveniently comparable to the output from SPAZ. The AHA model is deterministic, meaning results do not include a distribution of uncertainty and/or variability. No sensitivity analyses have been performed.

A few basic parameters are required as inputs in three main sections of the AHA model. For the habitat section, values are needed for productivity (i.e., recruits per spawner absent competition), and capacity (i.e., max # recruits accommodated by habitat). To define harvest, exploitation rates of both hatchery and wild fish are needed. In the hatchery section, a separate R:S value is needed along with values for the size and characteristics of the broodstock. Several of the inputs are used to define the goals as determined by managers, but are not necessarily requisite data to run the model.

Multiple tables and charts display the results in two basic categories: realized spawning composition, and realized run composition. A Proportion of Natural Influence (PNI) chart shows “the degree to which the natural environment is driving the adaptation of the hatchery and natural population components.” Stacked bar charts represent the number and composition of fish returning to the hatchery, river, or fishery. A breakdown of results for the different “H”s within the different scenarios is also presented in tabular form.

2.2.1 Model Intent

The AHA model is primarily intended be used as a “gene flow calculator” to assess the fitness impacts on the natural population based on the scale of the hatchery program. It does this by keeping track of origins of the individuals in the population. The proportion of



natural origin broodstock (pNOB) represents how much of the hatchery's source of eggs comes from wild fish. Inversely, the proportion of hatchery origin spawners (pHOS) signifies how many of the fish found on the natural spawning ground came from the hatchery. The ratio of these two statistics, expressed as

$pNOB/(pHOS+pNOB)$,

is known as the proportion of natural influence (PNI). Integrated hatchery programs try to achieve a PNI of at least 0.5 to ensure that natural genetic traits are not lost through dependence on hatcheries.

Large hatchery programs may increase the number of total returning salmon, but result in negative effects on the wild fish as genetic fitness is reduced through interbreeding. Unfortunately, studying these interactions requires methods for distinguishing hatchery from natural origin fish, which are not readily available for Willapa chum salmon. The values used in AHA to represent this reduction in fitness, are therefore hypothetical.

2.2.2 Methods

The All "H" Analyzer model was developed by the WDFW as a simple way to test different management scenarios that involve hatcheries, habitat impacts, and harvest levels (and hydropower – not applicable to Willapa). The first step in running AHA is to set the initial conditions. Two main parameters are used to describe population dynamics in the AHA model, so the user starts by entering a best guess for these values and then making small adjustments to each one such that the calculated output from the model (in terms of the number of fish that return to spawn in the wild or the hatchery, or are caught in the fishery) matches the current situation that is observed. Other user-defined parameters include eggs per spawner, smolt to adult survival rates, and the relative fitness of hatchery fish compared to natural fish. No data were available to determine these values for the Willapa chum population so we applied the same parameters that were used to represent the Grays River chum stock in a prior analysis (Appleby, WDFW, personal communication).

The two parameters that define the shape of the Beverton-Holt equation are often difficult to determine, even if spawner-recruit information is available. We compared two alternative strategies for determining the initial conditions. Because we chose to use the Beverton-Holt function as the basis for the viability analysis, one option was to apply the values for productivity and capacity calculated in the previous SPAZ analysis. The other option was to use values that led to results that were reflective of observed catch and escapement numbers within the Willapa Basin. A discrepancy between these two methods became apparent when the expected catches and escapements using the SPAZ parameters were substantially lower than those observed. We reasoned that the objective of the AHA modeling exercise was to represent the outcomes of potential management decisions in a way that was comparable, intuitive and tangible. Therefore, we placed priority on keeping catch and escapement numbers in the same range as those observed, even though it meant productivity and capacity values different from those calculated by SPAZ.

Productivity, or growth rate, is defined as the number of recruits per spawner that would occur in the absence of competition. This occurs theoretically at very low population sizes, but on a bay-wide level. Willapa chum have rarely been at numbers low enough to define



this region of the curve. Carrying capacity is more straightforward. An historical record of chum escapement and catch in Willapa Bay (Suzumoto 1992) and more recent data from 1968-2006 (WDFW) provides the basis for our initial estimate of carrying capacity at 150,000 chum.

Although recently the harvest management goal has been to ensure a minimum escapement of 35,400 fish, AHA requires harvest levels expressed as a fraction of the returning fish. The harvested fraction has been highly variable over the past 4 decades, but on average 40% of the Willapa chum recruits have been harvested; therefore we used 40% as the initial harvest condition.

Hatcheries in the Willapa Basin have had small chum production programs in the past that overall have been relatively minor in comparison to the size of the natural population, with recent small scale plantings occurring throughout the region. For the AHA model initial conditions we considered the hatchery influence to be negligible.

To establish the initial conditions, we set the harvest rate at 40%, the carrying capacity at 150,000, and the size of the hatchery program at 0, and tested a range of production values from 1.00 to 30.00. The numbers of spawners and fish harvested in each case were compared with data from 1968-2003. The production rate used in further analyses was that which generated outputs closest to what had been observed in the Willapa Bay chum population.

The effect of potential changes in management strategies on the population were explored by defining multiple scenarios within each “H” component, and systematically computing results for all possible combinations.

- Productivity was regarded as an intrinsic characteristic of the population and thus kept at the value established in the initial conditions.
- Two possible carrying capacity values were tested: 100,000 was considered a cautious estimate of the current maximum; and 200,000 reflected the potential of the system based on historic catch levels.
- Two harvest strategies were examined: a continuation of the current trend, which on average takes 40% of returning spawners; and a reduction in harvest that over time would represent an average of 20% of the returning fish every year.
- Three hatchery scenarios were designed to represent a spectrum of what would be possible if artificial propagation were used to bolster chum stocks. The first case consisted of no hatchery program. The second case was a minimal hatchery program that involved taking 500 natural origin spawners and breeding them in hatchery, from which 640,000 smolts would be released each year. In the third case, a large scale hatchery program would rely on 10,000 natural origin fish and release 12.8 million smolts every year. In these examples the hatchery-released fish were given a higher productivity value (5.0 as opposed to 3.0 for natural fish) because they are assumed to avoid much of the mortality encountered in the very early life-stages by their wild counterparts.

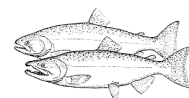


2.2.3 Results

Based on the testing of initial conditions, a productivity value of 3.0 provided the best fit to the existing data (Table 3). With no hatchery program, a 40% harvest rate, production of 3.0 and carrying capacity of 150,000, AHA predicted annual escapement of approximately 40,000 chum and a terminal harvest of approximately 26,000 (Figure 7). WDFW data show that chum escapement in Willapa Bay has ranged from 7,000 to 76,000 over the last 39 years but has averaged between 35,000 to 40,000. The same data show that harvest levels have fluctuated in accordance with regulations based on expected escapement, from a minimum of 192 to a maximum of 175,000 with an average of about 30,000 chum salmon. As such, we felt confident that our values for initial conditions were representative of the average present day population dynamics. However, it is critical to understand that the existing data being used to model potential management scenarios is from *recent* history and certainly may not accurately depict historical chum population dynamics. One potential theory is that the Willapa chum population is already chronically underperforming, meaning that targets for population recovery are off target as well as various management tools (e.g., escapement goals).

Table 3. Results of testing initial conditions with a range of production, hatchery, harvest, and habitat scenarios.

Production	Scenarios			Results		
	Hatchery	Harvest	Habitat	PNI	Spawners	Catch
1.00	NA	40%	150,000	1.00	1	0
2.00	NA	40%	150,000	1.00	14103	9402
3.00	NA	40%	150,000	1.00	39546	26364
4.00	NA	40%	150,000	1.00	52113	34742
6.00	NA	40%	150,000	1.00	64664	43109
8.00	NA	40%	150,000	1.00	70936	47291
10.00	NA	40%	150,000	1.00	74699	49799
15.00	NA	40%	150,000	1.00	79716	53144
30.00	NA	40%	150,000	1.00	84732	56488



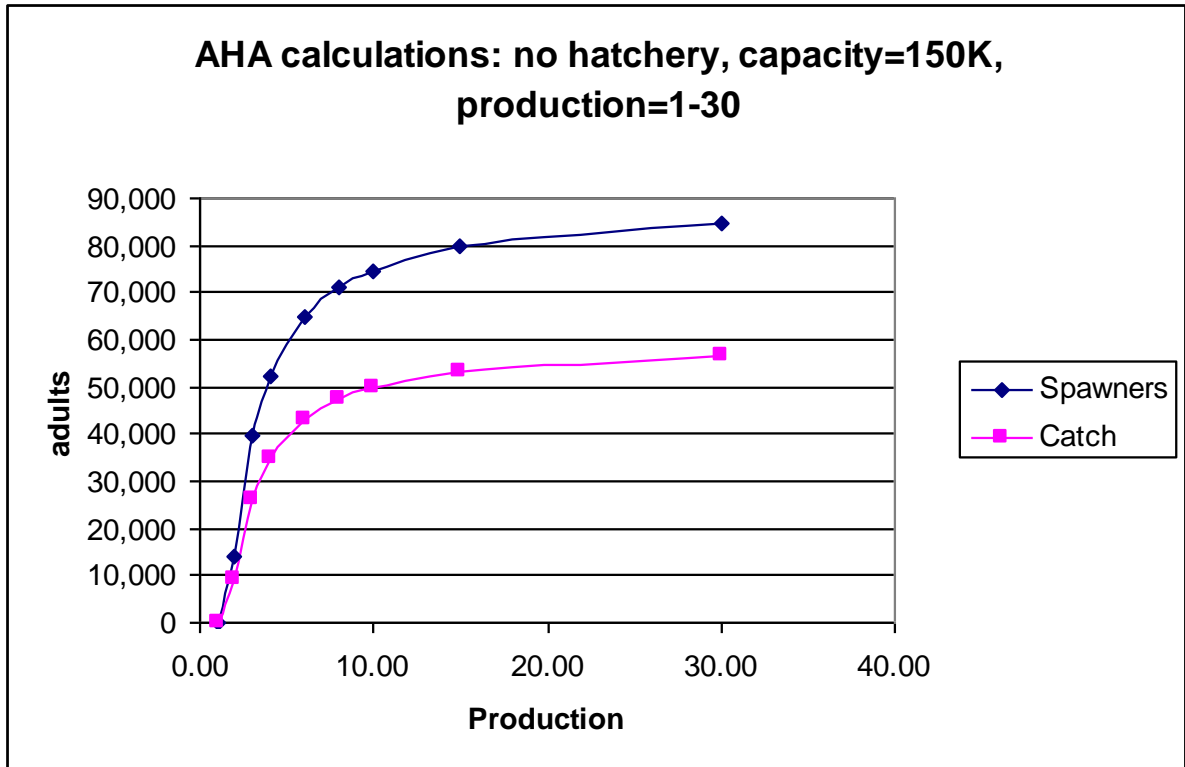


Figure 7. Selected AHA scenario that best fits the existing chum salmon population in Willapa Bay.

Using the selected productivity value of 3.0, all 12 chosen management scenario combinations were tested (Table 4). As expected, the lowest PNI value (0.7) was generated when the large scale hatchery program was in combination with the higher harvest rate and smaller carrying capacity. In general, PNI values were relatively high due to the large influence of the natural population.

Table 4. Selected results from the AHA model under different potential management scenarios. Hatchery 1=no hatchery program; 2=minimal program with 500 natural origin chum used for broodstock and 640,000 smolts released annually; 3=major program with 10,000 natural origin chum used for broodstock and 12.8 million smolts released annually. Harvest 1=catch 20% of returns; 2=catch 40% of returns. Habitat 1=100,000 carrying capacity; 2=200,000 carrying capacity. Productivity was held constant at 3.0. The symbol “+” signifies that returns at the hatchery were in surplus of what was necessary for broodstock and therefore these fish were added into the catch number in addition to the percentage allowed under the harvest percentage goal.

Scenarios	Results					
	Hatchery	Harvest	Habitat	PNI	Spawners	Catch
1	1	1	1	1.00	46323	11581
1	1	1	2	1.00	92645	23161
1	2	1	1	1.00	26364	17576
1	2	1	2	1.00	52728	35152
2	1	1	1	0.98	47149	12156
2	1	1	2	0.99	93475	23738
2	2	1	1	0.97	26895	18747
2	2	1	2	0.99	53262	36325



3	1	1	0.75	61437	42236	+
3	1	2	0.84	108360	53966	+
3	2	1	0.70	35704	54638	+
3	2	2	0.80	62568	72547	+

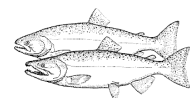
2.2.4 Discussion

In this section we attempt to describe one potential hatchery management scenario based on results of the AHA modeling exercise. Please note that the following scenario has not undergone any significant review by hatchery managers but is simply describing a what-if scenario based on model outputs. All such scenarios would need to receive a full and careful evaluation by resource professionals before considered practical from a management perspective.

The AHA model results reveal that Willapa Bay could potentially support a large hatchery program without the threat of a long-term loss of genetic structure or fitness. A maximum hatchery system within the Willapa Basin, identified in the first column of Table 4 by a value of three, would use the combination of the following AHA management parameters:

- Natural Productivity: 3.0
- Hatchery Productivity: 5.0
- Harvest: 40%
- Broodstock origin: 95% natural
- Carrying Capacity: 100,000

This maximum hatchery program modeling exercise identified that the PNI did not drop to 0.5 until the hatchery program spawned 35,000 chum and released 44.9 million smolts. Under the larger carrying capacity (200,000), the hatchery program could be twice as large, spawning 70,000 adults and releasing 89.6 million smolts before hatchery induced fitness losses to the natural population occurred. An important consideration in this hypothetical situation is that determining the origin of the broodstock is not currently possible. If in fact the hatchery smolts outnumber the wild smolts 24 to 1, then selecting a broodstock that consists of 95% natural origin fish is unlikely. Adjusting the proportion of natural origin spawners used in the hatchery down to 50%, and setting the proportion of hatchery origin fish spawning naturally to 50%, results in the PNI dropping to 0.42. Continuing a large scale hatchery program while further reducing the pNOB will result in a lower PNI. For example if the pNOB reflects the hatchery to wild smolt ratio (24:1 translates to pNOB of 4%) then PNI drops considerably to 0.07. Given a 50:50 chance of selecting natural versus hatchery origin spawners for broodstock, maintaining a PNI of 0.5 would require a reduction in the hatchery program to 18,000 spawners and a release of 23.1 million smolts. For these reasons, if a larger hatchery program is considered in Willapa Bay, it would be most beneficial to Willapa chum management if all hatchery-derived chum salmon were identified with an external mark.



3 FACTORS POTENTIALLY LIMITING CHUM POPULATIONS

3.1 Habitat Access

Except for a few rare cases in northern latitude chum populations, chum salmon spawn in the lower gradient reaches of watersheds, which typically occur in the lower reaches of larger river systems and in smaller tributaries. Suzumoto (1992) summarized chum salmon distribution throughout the Willapa Basin. Known chum producing streams include:

- North River – the lower ten miles of the mainstem, plus the Smith, Salmon and Bitter Creek tributaries;
- Willapa River – South Fork, Rue Creek, and Trap Creek;
- Palix River – most significantly in the Canon River tributary;
- Nemah River – North Fork (especially Williams Creek) and Middle Fork;
- Naselle River – extending to the North Fork and Salmon Creek, plus Ellsworth Creek and other tributaries to the South Fork; and
- Bear River.

Between 1968 and 1991, the majority (58.3%) of natural chum production came from three streams: the Palix River, Williams Creek, and Bitter Creek (Suzumoto 1992). Changes to the landscape, primarily due to logging, road construction, and clearing for agriculture and urbanization (The Willapa Alliance 1998; Smith 2004), have increased substantially in the Willapa Basin during this same time period. Chum salmon rely on the lower and middle mainstem stream reaches of large streams and rivers where channel instability, low habitat diversity, and sedimentation consistently limit habitat suitability.

Smith (2004) reviewed the Salmonid Screening, Habitat Enhancement and Restoration Division’s (WDFW) database, as well as other information to summarize known anthropogenic blockages to habitat in Willapa Basin streams (Table 5). Most of the culverts were far enough upstream that they were not believed to be blocking chum from spawning habitat, although they did pose an impediment to the migration of other salmonid species (e.g., coho salmon). This listing was admittedly not complete because not all areas had been surveyed for blockages and also some removal projects have occurred recently.

Table 5. Number of blockages in each of the six salmon producing watersheds, summarized from Smith (2004). Impact levels defined as: Low=blocking <0.5mi; Medium=blocking >0.5mi but <0.99; High=blocking >1.0mi.

Watershed	Low Impact	Medium Impact	High Impact
North River	31	2	0
Willapa River	17	2	4



Palix River	4	0	0
Nemah River	9	2	1
Naselle River	17	1	3
Bear River	4	0	0

Loss of habitat access to spawning grounds has been a concern for several decades; but perhaps equally important has been the effect of tidegates, dikes and levees that limit juvenile chum access to rearing habitat in marsh and estuarine areas (Smith 2004). This habitat is especially important for chum (see estuary section). Unfortunately, limited information is available to quantify the loss of this habitat in Willapa Bay and its impact on the local chum populations.

Other factors related to habitat access that likely affect chum salmon populations in the Willapa Basin include logging road density and floodplain connectivity. An increase in road density is often one of the primary factors leading to an increase in sediment delivery to a watershed (see Section 3.2). These factors could be addressed in more detail in future research and monitoring efforts to determine the extent to which chum salmon productivity has changed, or could change in the future, due to increases or decreases in road density and connectivity to the floodplain.

3.2 Sedimentation

Throughout the Willapa Basin, anthropogenic alterations to natural sedimentation processes are thought to limit salmon production by reducing the amount and quality of spawning habitat. Significant changes to the landscape have occurred as a result of logging activities since before the turn of the 20th century. Landslides due to road construction, loss of riparian forest, and use of splash dams have all affected the input and transport of streambed sediment. A detailed review of sedimentation concerns within each of the Willapa Basin watersheds is available in the Limiting Factors Report for WRIA 24 (Smith 2004).

Chum salmon are particularly susceptible to sedimentation because they spawn in the lower gradient reaches of streams where fines are more likely to deposit. Even though returning adult chum have access to certain streams, the success of chum spawning efforts may be reduced without the availability of high quality spawning gravels. While streambed condition and quality of spawning habitat are essential to consider as a potential factor limiting chum production, it is difficult to quantitatively assess the direct impact to the population over time due to the nature of the available data. Assessments of streambed sediment occur too infrequently to capture the continuous human caused changes to the hydrology and response of biological communities. Comprehensive assessments in recent years, made possible with new technologies such as satellite imagery and Geographic Information Systems (GIS), provide a snapshot of current conditions. These can be compared to conditions inferred from old maps and charts, but the differences may overlook



shorter time scale trends. Indicators of human impact on streambed sediment are disturbing. Road density in every watershed exceeds the threshold considered by NMFS to be “not properly functioning” (Table 6) (Smith 2004, NMFS 1995). Surveys of Large Woody Debris show that many Willapa rivers and tributaries contain far less LWD than they did historically, which creates conditions where the increase in sediment delivered to streams is not processed naturally.

Table 6. Road Densities in Willapa Basin watersheds. Statistics summarized from WRIA 24 Limiting Factors Report (Smith 2004). Road density in miles of road per square mile of watershed; stream crossings in number of places a road crosses a type 1-4 stream per square mile of watershed; riparian road density in miles of road per square mile within riparian area.

Watershed	Road Density	Stream Crossings	Riparian Road Density
North	4.10	7.8	1.0
Willapa	4.73	18	3.0
Palix	5.68	10	2.0
Nemah	5.50	20	3.0
Naselle	5.20	20	3.0
Bear	4.9	NA	3.2

The compounding impact of small changes to the landscape is important to consider when determining the carrying capacity of the Willapa Basin. Sedimentation resulting from human alterations can degrade the quantity and quality of spawning habitat, which in turn will affect the accuracy of quantitative models (particularly when testing scenarios with the AHA model). Also, restoring natural sedimentation processes may help to increase the carrying capacity of the system. In both cases, knowledge of these processes and the current status within Willapa watersheds will help focus enhancement efforts.

3.3 Freshwater Flow

3.3.1 Background

It has long been understood that stream flows (both low and high) play a critical role in defining the productivity of salmon populations throughout the Pacific Northwest. For Willapa Bay chum salmon, the critical flow periods occur during spawning (October-November) and intragravel incubation of eggs and alevins (December-February). The upstream spawning migration of adult chum salmon in Willapa Bay begins in late September, which is often a very low flow period of the year. As such, Willapa chum are particularly vulnerable to reductions in stream flow that may limit access to spawning habitat. Willapa Bay chum could also be affected during the intragravel incubation period when egg to fry



survival may be reduced either by extremely high stream flows that scour redds, or by low flows that result in low intragravel-oxygen levels.

A USGS stream flow data station on the Willapa River near Willapa, Washington (Gaging Station 12013500) has been collecting daily stream discharge data since 1947. We downloaded stream flow data from this station from the time period 1968-2006, which coincides with the Willapa River chum run-size dataset we acquired from WDFW. The objective of this data collection exercise was to identify possible relationships between Willapa chum salmon abundance and the effects of stream flow.

3.3.2 Mechanism

Because chum salmon do not typically rear in freshwater, stream flow impacts to chum populations are often focused on the spawning and incubation period. In general, severely low flows during the fall can limit access to the better spawning sites within the stream channel, thereby causing spawning salmon to utilize less-than-optimum areas. Poor redd site selection can lead to inadequate intragravel flow and increased exposure to the effects of winter floods, which ultimately leads to a reduction in egg to fry survival. This very same pattern was identified as one of three critical factors that contributed to the decline of summer chum salmon in Washington's Hood Canal (WDFW and PNPTT 2000).

Winter stream flows can have substantial adverse effects on salmon survival due to streambed scouring and siltation during egg incubation (Montgomery et al. 1996). Similar trends have been observed in Oregon coast coho salmon populations (Lawson et al. 2004) and Lake Washington Cedar River sockeye salmon populations (Seiler et al. 2001). Cedar River sockeye salmon studies showed a negative correlation between egg-to-migrant survival and the highest daily average winter streamflow occurring during egg incubation. Studies by Montgomery et al. (1996) in Kennedy Creek of south Puget Sound indicate that even minor increases in the depth of scour, often due to increased winter stream flows, could significantly reduce chum embryo survival. Flow-related impacts on incubating chum salmon eggs and alevins has been defined for chum salmon in the Big Qualicum River, British Columbia by Lister and Walker (1966). This research identified an inverse relationship between chum salmon incubation survival and the peak flow that occurs during incubation. Documented egg-to-fry survivals in the Big Qualicum River varied fivefold – from 25% with no flooding to 5% with flood conditions. The study documents instream flow and resultant streambed scour as the primary factor influencing the freshwater survival rate of chum salmon.

Research from the Campbell and Amazon Rivers of Vancouver Island, British Columbia (Wickett 1958) documents a strong relationship between chum salmon runsize and November mean discharge from 4 years previous (i.e., brood year). Flood-level flows in November can scour incubating chum eggs and alevins resulting in reduced survival; low flows in November reduces the supply of dissolved oxygen to chum eggs, which also results in reduced egg to fry survival. Either way, extreme highs and lows in the hydrograph can often determine the strength of the recruiting chum run three, four, or five years later.



3.3.3 Evidence

3.3.3.1 Spawning Flows

We sought to identify whether lows in the hydrograph during chum salmon spawning, which may have limited chum spawning habitat access, resulted in a reduced number of recruits per spawner (R:S). We conducted exploratory data analysis to determine the extent of the relationship between Willapa Bay chum salmon production and associated stream discharge during the brood year. Mean monthly stream discharge data for the October-November Willapa chum salmon spawning period were examined from 1968 through 2000 and plotted against Willapa Bay chum salmon recruits per spawner (R:S) as reported by WDFW for the same time period. These years were selected for the analysis because they encompass the period of the chum salmon data available. We chose to use mean stream discharge data from the Willapa River (USGS 12013500) alone because it contains the longest flow record available within Willapa Bay and was determined to be very representative of the trend in flow from other streams in Willapa Bay with a shorter period of record (Figure 8).

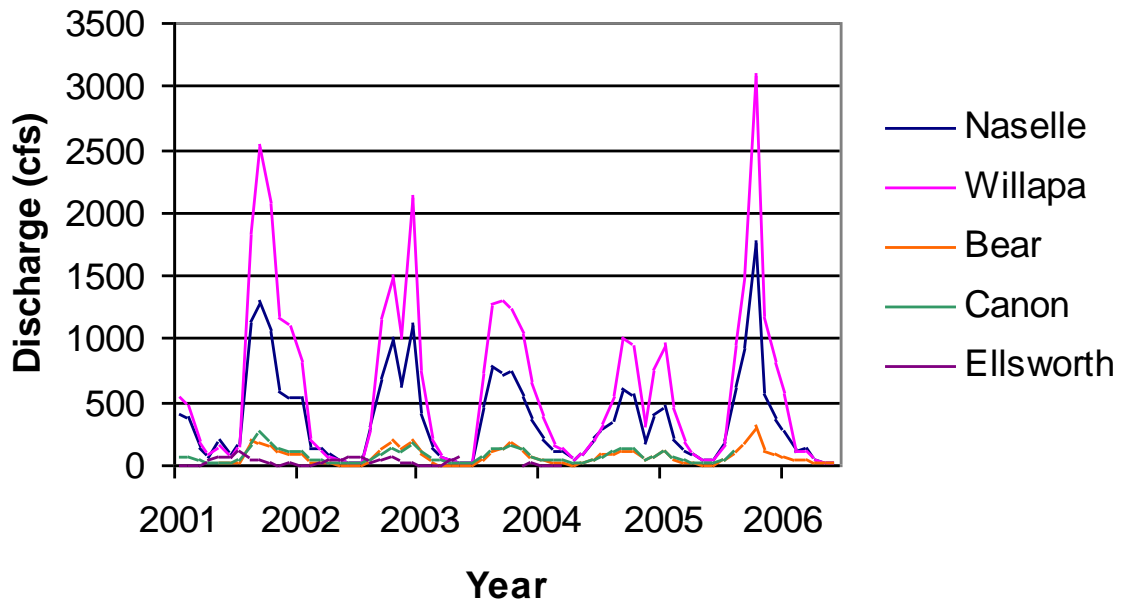


Figure 8. Mean monthly stream discharge data for the Naselle, Willapa, Bear, and Canon rivers, as well as Ellsworth Creek from April 2001-September 2006.

To justify the use of Willapa River stream discharge data as a proxy for flow trends throughout the Basin, we plotted stream discharge data from the Willapa River with discharge data from the Naselle (USGS 12010000), Bear, and Canon rivers as well as from Ellsworth Creek (Bear, Canon, and Ellsworth data available at the Washington State Department of Ecology River and Stream Flow Monitoring Network website <https://fortress.wa.gov/ecy/wrx/wrx/flows/regions/state.asp>). We examined the strength of the stream flow trend between the Willapa River and each of the other streams using mean monthly stream discharge data from 2001-2006 and determined that in each case a very strong linear relationship exists (Figure 9; R^2 values near 1.0). This indicates that Willapa



River stream flow provides an adequate representation of stream flow trends throughout the Willapa Bay Basin.

When plotting Willapa River October-November (i.e., spawning period) mean stream discharge data from 1968 to 2000 with brood-year R:S during that same time period, no apparent pattern is evident (Figure 10). With this in mind, we attempted to identify threshold stream flows below which a noticeable decrease in R:S occurred. To do this, R:S values for the five years associated with the lowest mean October-November stream flows between 1968 and 2000 were compared to the R:S values for the five years associated with the highest mean October-November stream flows. Evidence for flow limited spawning success is not apparent as the average R:S value associated with the five lowest flow years (1.99 average for 1972, 1976, 1987, 1993, and 2000) is actually greater than the R:S value associated with the five highest flow years (1.24 average for 1975, 1983, 1990, 1995, and 1997).



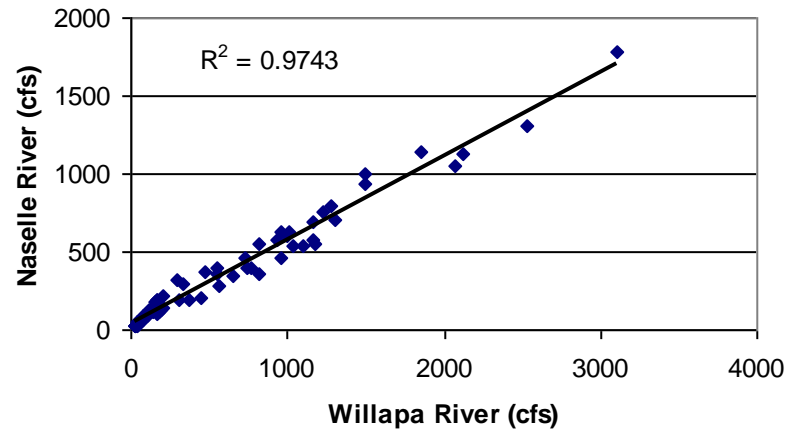
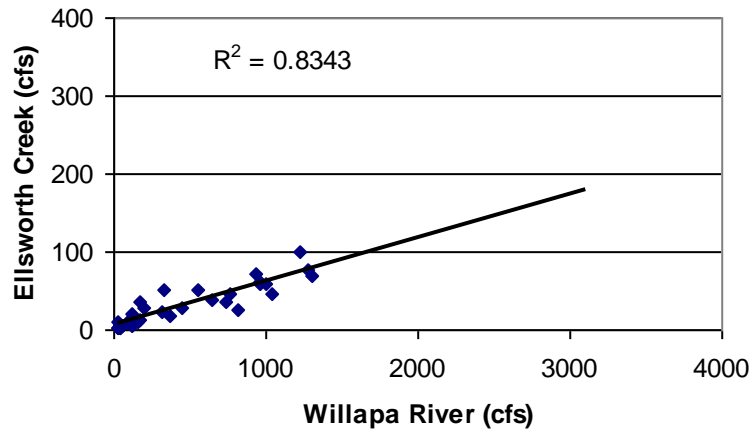
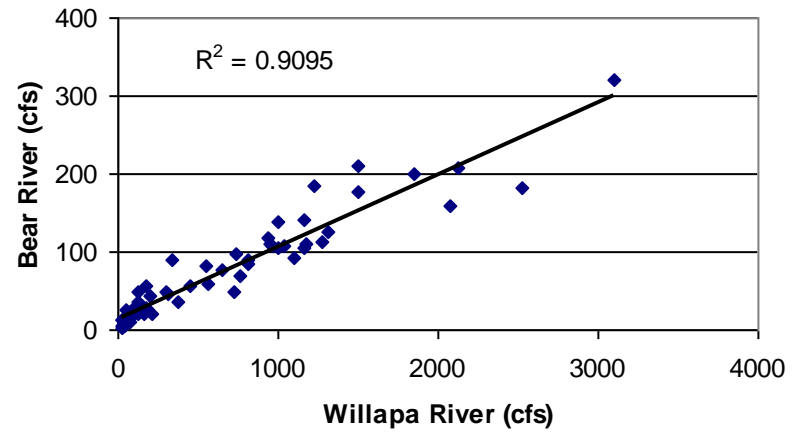
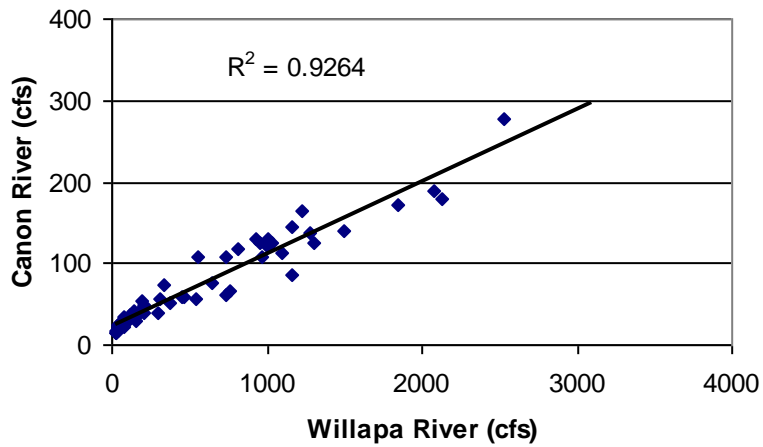


Figure 9. Willapa River mean monthly stream discharge (cfs) plotted against mean monthly stream discharge (cfs) from the Canon, Bear, and Naselle rivers and Ellsworth Creek from April 2001-September 2006.



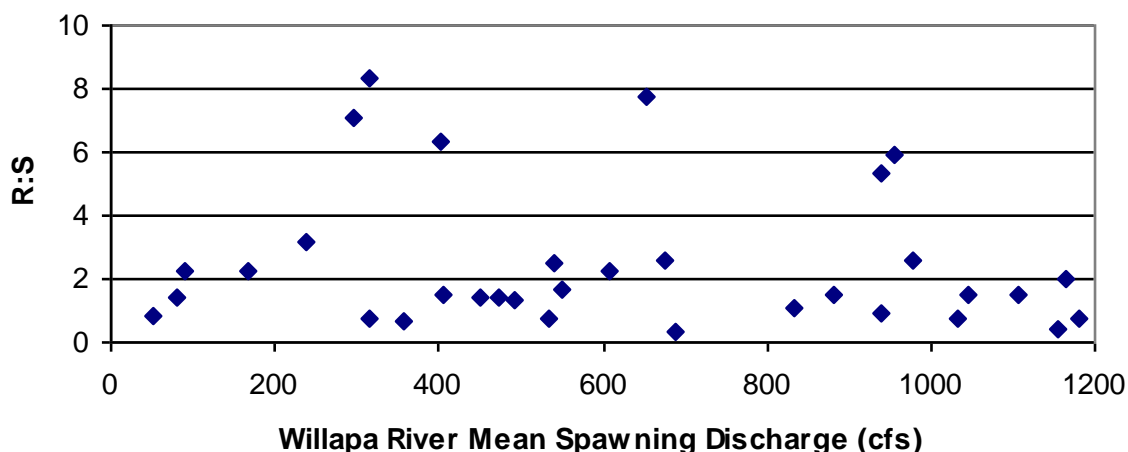


Figure 10. Relationship between Willapa River chum salmon spawning period discharge (October – November) and brood year recruits per spawner.

3.3.3.2 Incubation Flows

We conducted a similar exploratory analysis comparing Willapa chum production and stream discharge during the brood year incubation to determine whether high flows may have scoured incubating chum salmon eggs and alevins. Again we used the number of recruits per spawner (R:S) from 1968 through 2000, as reported by WDFW, and plotted against the Willapa River (USGS 12013500) mean monthly stream discharge data for December-February (i.e., incubation period). The Willapa River station provides the longest flow record available within Willapa Bay and is representative of the trend in flow from other streams in Willapa Bay with a shorter period of record (Figures 8 and 9).

When plotting Willapa River December-February (i.e., incubation period) mean stream discharge data from 1968 to 2000 with brood-year R:S during that same time period, no apparent pattern is evident (Figure 11). Next, we attempted to identify threshold scouring stream flows above which a noticeable decrease in R:S occurred. To do this, R:S values for the five years associated with the lowest mean December – February stream flows (1968-2000) were compared to the R:S values for the five years associated with the highest mean December – February stream flows for the same period. These data show about one full R:S decrease in average R:S when comparing the five lowest mean incubation discharge years (2.69 for 1976, 1984, 1988, 1992, 2000) to the five highest mean incubation discharge years (1.66 for 1970, 1973, 1981, 1994, 1998). Although this comparison is relatively rudimentary in nature, the results do suggest that high discharges during the Willapa Bay chum salmon incubation period could potentially scour eggs and alevins from the spawning gravels to a point where a reduction in the average recruits per spawner is realized.



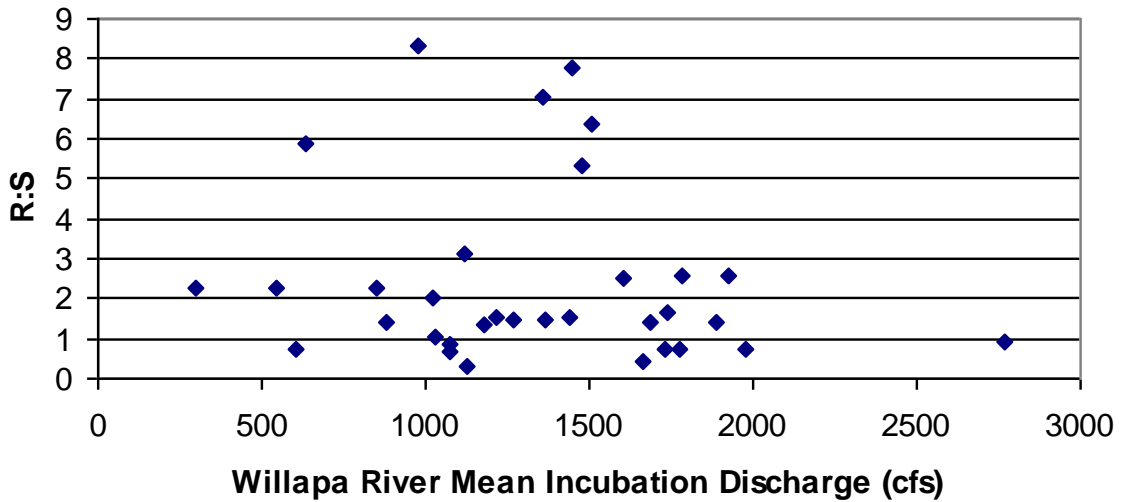


Figure 11. Relationship between Willapa River chum salmon incubation period discharge (December – February) and brood year recruits per spawner.

Similar to sockeye salmon research on the Cedar River (Seiler et al. 2001), we plotted peak daily mean discharge data for the incubation period with brood year recruits per spawner (R:S) to identify the extent to which extreme peak flows reduce brood year chum salmon production (Figure 12). Results suggest that on average, chum salmon recruits per spawner are less when extreme peak flow events occur during egg incubation.

Figures 11 and 12 show inconclusive evidence regarding a trend in R:S compared to mean or peak flows. In fact, aside from six years when chum salmon were highly productive (R:S greater than 5), the R:S value is consistent over the entire range of flows. However, it is interesting to note that these six years all occurred when mean incubation discharge was less than 1600 cfs but greater than 600 cfs. Similarly, during these brood years the peak flows were less than 8000 cfs but greater than 3000 cfs.

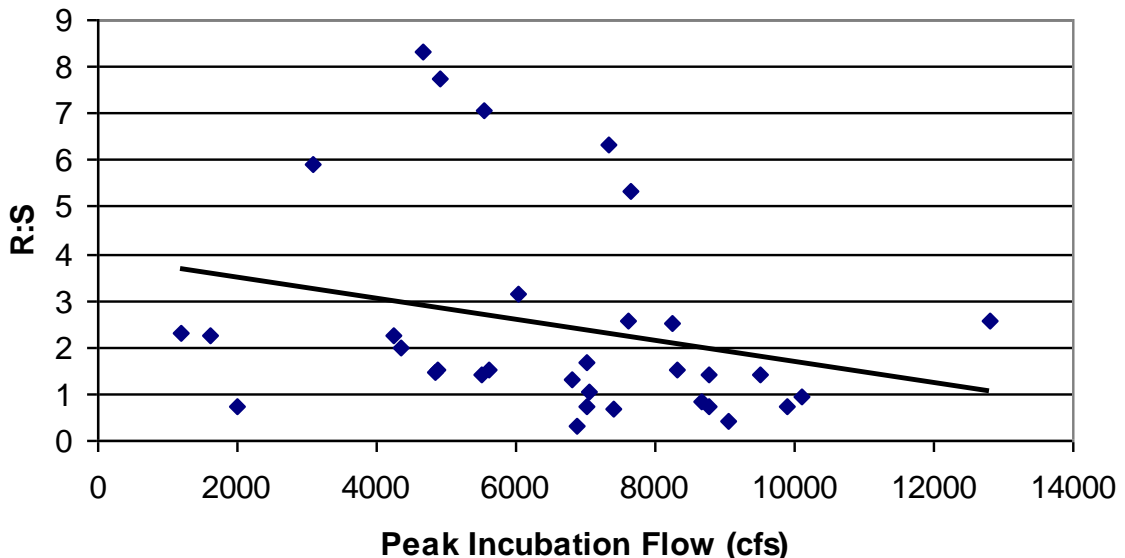


Figure 12. Linear regression of Willapa Bay chum salmon recruits per spawner (R:S) from brood years 1968-2000 as a function of peak flow during the winter egg incubation period (Dec-Feb) in the Willapa River.

3.3.4 Implications

Research conducted on other chum salmon systems provides strong evidence of a relationship between flow and chum production. Our initial analysis of the Willapa Basin reveals some indication that a trend may exist between incubation period stream discharge and chum salmon production, and therefore it remains important to fine tune our monitoring efforts to help understand these effects. In the meantime, limiting urbanization within Willapa Bay watersheds will allow impervious surface area to be kept to a minimum, which will effectively help prevent flashy, scouring flows associated with reduced chum salmon production in urbanizing watersheds within the Puget Sound region.

3.4 Estuary Effects

The physical shape and processes of the Willapa Bay estuary have been impacted by humans for well over a century (Borde et al. 2003). An assessment in 1998 estimated that at least 2,770 acres of estuarine wetland has been lost since historical times (Willapa Alliance 1998), representing almost a third of the total area in several of the chum producing watersheds (Table 7). This loss was primarily due to diking, which converted wetlands to land suitable for agriculture, pasture and homesteading. The limiting factors report for WRIA 24 (Smith 2004) discussed two main threats to juvenile salmon in the estuary: (1) the displacement of eelgrass beds by the invasive *Spartina alterniflora*, and (2) the low amounts of large woody debris in the estuary. In general the Bay and estuary are considered clean, although, oyster aquaculture operations have historically treated parts of the intertidal with carbaryl, a pesticide to reduce burrowing shrimp populations (Feldman et al 2000).

Table 7. Information from the The Willapa Alliance (1998) as provided in WRIA 24 Salmon and Steelhead Limiting Factors Report.

Watershed	Acres Lost	Percentage of Total
North River	865	31%
Willapa River	584	19%
Palix River	810	31%
Nemah River	2	0.2%
Naselle River	9	0.6%
Bear River	500	30%



Smooth cordgrass (*Spartina alterniflora*) was introduced to Willapa Bay over one hundred years ago and has since become an aggressive invasive in the estuary (Simenstad and Thom 1995, Feist and Simenstad 2000). It displaces native eelgrass that provides refuge from predators and the base of the trophic web for juvenile salmon. Furthermore, it establishes in dense clumps that trap sediment and over time raise the elevation of the intertidal flats and change the composition of benthic fauna. Several techniques for removal have been assessed, including mechanical and chemical methods (Patten 2003). A joint agency, Willapa Spartina Management Plan (2001) has been established to contain the spread of and eventually eradicate *Spartina*, but diligence and active management are necessary to prevent further harmful effects.

Large wood plays an important role in forming refuge habitat for juvenile salmonids and stabilizing substrate. This wood supply to the estuary has been dramatically reduced due to extensive logging and immature or non-existent riparian forests. Unfortunately, this process suffers from a self-perpetuating feedback response: generally the establishment of riparian vegetation requires LWD to stabilize soils, but without riparian trees nearby there is no source for the LWD. The lack of riparian vegetation also results in warmer water temperatures and disappearance of the terrestrial based prey items.

Relatively little research has been conducted specifically on the importance of estuary areas in Willapa Bay to the health of its salmon populations (Smith 2004). However, research has identified the period of estuarine residence to be the most critical phase in the life history of chum salmon and may play a major role in determining the size of the subsequent adult run back to fresh water (LCFRB 2004). In a coast-wide study of hatchery releases, Chinook but not coho showed some evidence that survival is positively related to the proportion of the estuary that is in pristine condition (Magnusson and Hilborn 2003). This discrepancy illustrates the life-history differences between these two species: Chinook are known to use estuaries as rearing habitat, whereas coho rear in freshwater, and then migrate rapidly through the estuary to the ocean. If this explanation is accurate, then it would follow that chum are also susceptible to reductions in estuarine habitat quality, since chum fry migrate almost immediately to the estuary after emergence.

Chum salmon behavior, diet and habitat use in estuaries has been well documented (Weitkamp 2001). What has not been quantified is how estuarine conditions affect chum survival during this life-stage. Aside from the catch and escapement numbers described in previous sections, very little monitoring of the Willapa chum population is currently performed. Survival rates at different life stages are not available. Also lacking are clear indicators of change to the estuary. Data regarding land use and habitat types are generally compiled infrequently at discrete intervals in time and do not adequately reflect the rates of this continuous change over time. While this information is useful to characterize the overall trends in the Bay, it is not sufficient for a year to year analysis of its potential impact on chum production.

Given the generally acknowledged importance of estuary habitat for chum, it would be wise to establish a more continuous monitoring program of the estuary. Management of *Spartina* should be continued according to best practices and be administered in the context of maintaining the functions of the ecosystem necessary for salmonid growth and development.



3.5 Ocean/Climate Variability

3.5.1 Background

Assessment of the Willapa chum population relies on framing the current population's health within an historical context. Variability in run-sizes, including the recent years' low returns, is likely due to a complex combination of factors. Amongst the myriad potential anthropogenic impacts, some degree of natural variability also plays a significant role. It may prove impossible to manage large-scale, natural processes, but an understanding of climate/ecosystem dynamics is useful for interpreting whether what we do manage is effective or not.

Broad-scale fluctuations in climate have been shown to affect the northeast Pacific ecosystem, which in turn, affects the size of many salmonid populations (Beamish and Bouillon 1993, Francis and Hare 1994, Francis et al 1998, Hare and Francis 1995, Mantua et al 1997). These fluctuations in general ocean conditions occur at multiple periods; for example the El Niño/Southern Oscillation (ENSO) is an event that persists for 6 to 18 months and recurs every 5-8 years, the Pacific Decadal Oscillation (PDO) is referred to as a "regime" with alternative states that last 20-30 years. The two alternative states are referred to as warm or cool, with ocean ecosystems generally more productive during cool regimes, and less productive during warm regimes. Cool regimes occurred from 1890-1925 and 1945-1977. Warm regimes occurred from 1925-1945 and 1977-1998 (SR1997).

Climate regimes have different biological effects based on the region and the species. Trends in climate and salmon are more closely correlated for coho and Chinook (Hare and Francis 1995, Hare et al 1999) than they are for chum (SR1997), and an opposite effect is seen between Alaskan origin stocks and those from Washington, Oregon, and California (Hare et al 1999). The relationship between Washington coastal chum salmon populations and the PDO is still inconclusive.

3.5.2 Mechanism

The direct pathways in which climate regimes affect salmon are difficult to study and are therefore not well understood, but several hypotheses exist. Seasonal rainfall and subsequent stream flows can be affected by climate, which may be associated with fluctuations in egg to fry survival rates. Availability of prey items, known as "bottom-up" effects, or the abundance and behavior of predators such as birds or other fish species, known as "top-down" effects may play a role. For the most part, scientists believe that climatic variability in wind driven ocean circulation results in broad changes to the ecosystem, especially the primary producers and then on up to higher trophic levels. The availability of zooplankton and other food items in coastal waters to outmigrating smolts likely plays a large role in determining survival during the marine life-stage. Large scale studies to determine the precise mechanism are usually confounded by a combination of factors that change in relation to climate. The chum Status Review (SR 1997 p.48) states, "for example, a biological factor such as intraspecific competition is affected by other biological factors such as prey availability and predation, and these may be affected by climatic factors such as regional cooling and increased freshwater runoff."



The chum Status Review in 1997 determined that the changes in nearshore marine productivity due to climate, that were linked with declines in Chinook and coho, did not have the same effect of chum because they tended to migrate farther offshore. Hare et al (1999) showed some chum populations in Washington responded positively to the warm phase of the PDO, but Ames et al (2000) presented preliminary evidence that chum (in Puget Sound) responded favorably to the recent change to a cool phase. Gargett et al (2001) proposed an “optimal stability window” hypothesis which explained climate’s affect on salmon populations as a result of the timing of ocean entry with nearshore plankton blooms. If correct, then correlations would be more evident locally and with species/stocks that emigrate directly to marine waters, such as coastal chum. A study of chum populations in the northeast Pacific by Pyper et al (2002) found that survival rates were correlated only at the local/regional level, not basin-wide, which led to the conclusion that chum are less affected by large-scale, climate driven cycles.

3.5.3 Evidence

3.5.3.1 Grays Harbor Parallels

A comparison of Willapa Bay chum populations to Grays Harbor chum stocks provides some evidence that large-scale processes such as climate may have a strong effect on survival (Figure 13). From 1968 to 2000, the interannual variability in run sizes have been closely correlated (correlation coefficient = 0.95). The relationship between escapements is less defined (0.76), likely as a result of differing harvest policies and pressures. This correlation suggests that the primary factors affecting chum stock sizes on the Washington coast act universally across basins/watersheds and may very well be occurring in the ocean stage of the life-cycle.

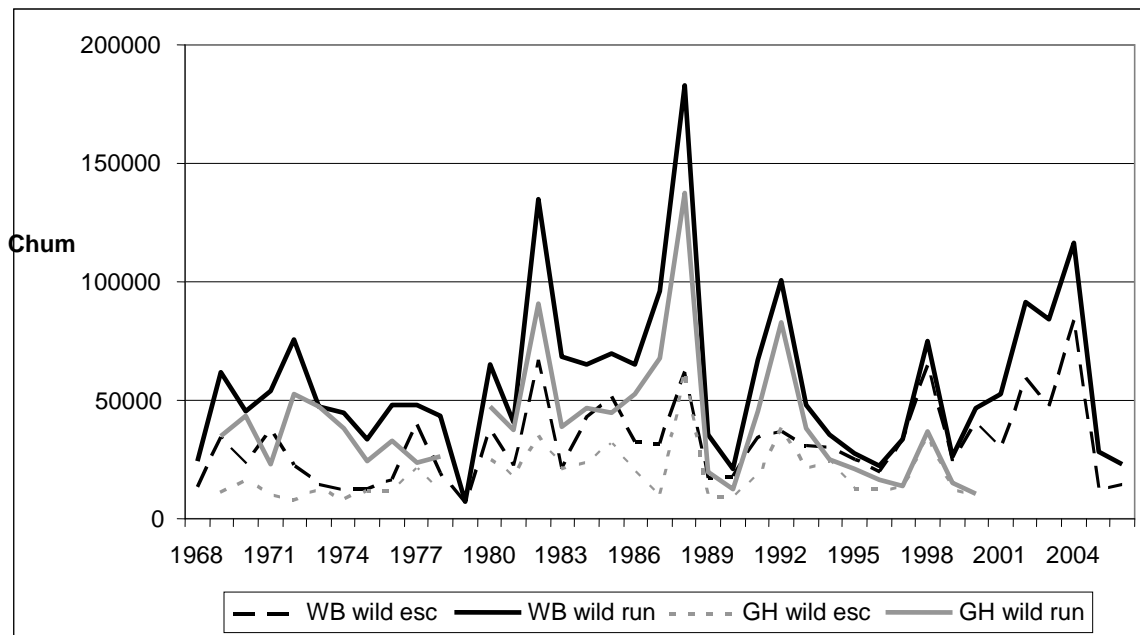
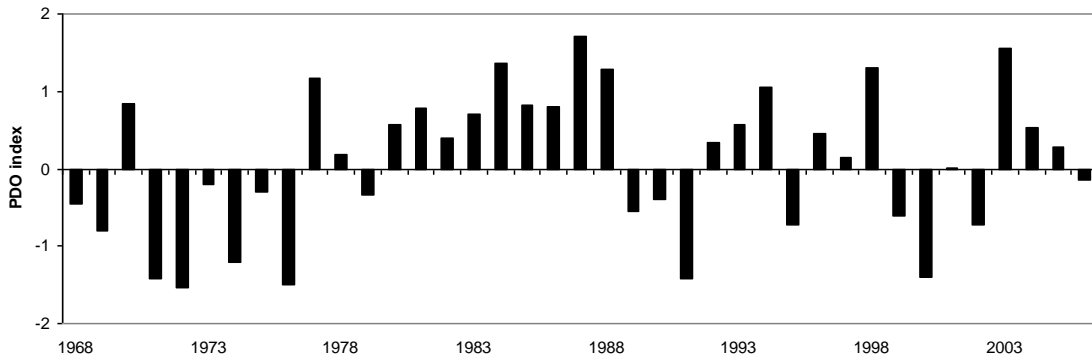


Figure 13. Wild chum run-sizes and escapements from Willapa Bay and Grays Harbor.

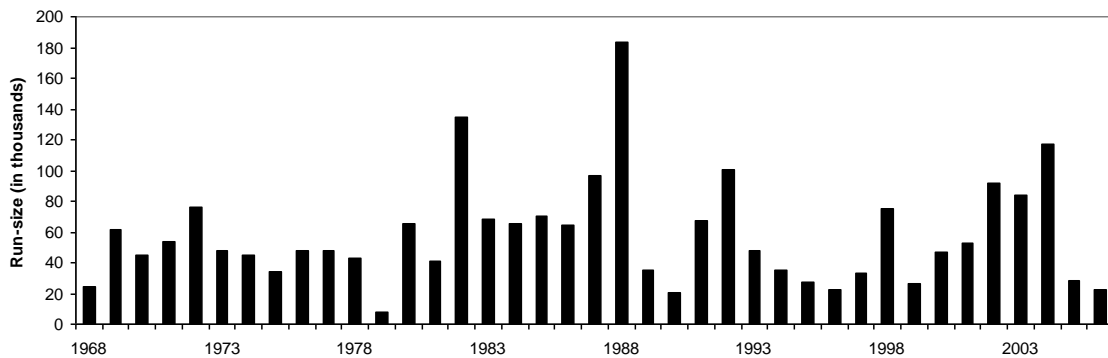


3.5.3.2 Warm vs. Cool Regimes

Wild chum run sizes in Willapa Bay have been highly variable over time. Annual catches historically ranged from 15,000 to over 200,000 chum (Suzumoto 1992) giving some indication of the capacity, although estimating abundance is difficult without information regarding the escapement and effort involved (see Section 4). During the more recent period of record, chum run-sizes have averaged almost 58,000 fish between 1968 and 2006, but with a standard deviation of 34,500 fish. The average run-size appears to have increased after the well documented phase shift from cool to warm that occurred in 1977. Because these ecosystem effects are thought to influence early marine survival, it is likely that returning chum populations do not show a response until 3 to 4 years after a regime shift. Thus, during the cool phase until 1980, run-sizes averaged approximately 46,000 fish (+/- 17,500). Between 1981 and 2000, when the next shift would have been noticed, chum run-sizes averaged approximately 63,000 per year (+/- 41,000), an increase of 37%. However, since 2001 when the 1998 flip (back to a cool phase) would have been seen, chum runs have averaged 66,000 (+/- 28,000). Averages can be deceiving, and often a few isolated, strong runs can dramatically affect the results. Also, since 1989, it has been more difficult to identify regimes because phase shifts occur at a higher frequency (Figure 14).

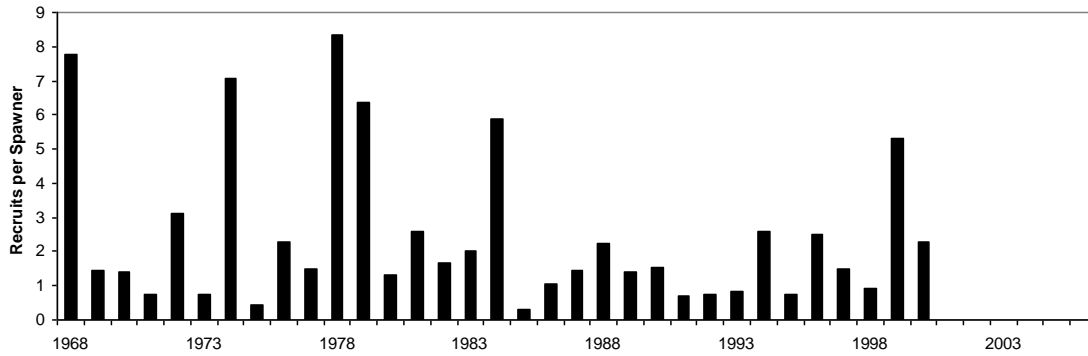


A



B





C

Figure 14. Time series' of the Pacific Decadal Oscillation index (A) Willapa chum run-sizes, (B) Willapa chum recruits per spawner, and (C) PDO data from <http://jisao.washington.edu/pdo/PDO.latest> and calculated as the mean monthly values from the preceding October to March.

3.5.3.3 Pacific Northwest Index

Another common indicator of regional climate trends is the Pacific Northwest Index (PNI) developed by Ebbesmeyer and Strickland (1995). The PNI combines three long term records to generate a composite index of past and current climatic conditions in the region. The three components include: snowpack depth at Paradise, Mount Rainier on March 15; annual average air temperature at Olga in the San Juan Islands; and annual average daily rainfall at Cedar Lake in the Cascades. Positive values indicate warm/dry years and negative values indicate cool/wet years. Therefore, before 1977 the PNI was mostly in the negative range and from 1978 until the present has been in the positive range. The PNI was developed as an indicator of terrestrial climate and representative of freshwater conditions, as opposed to the PDO which is linked more closely to ocean conditions. The PNI does not correlate perfectly with the PDO (Figure 15) and therefore offers an alternative perspective on climate trends.

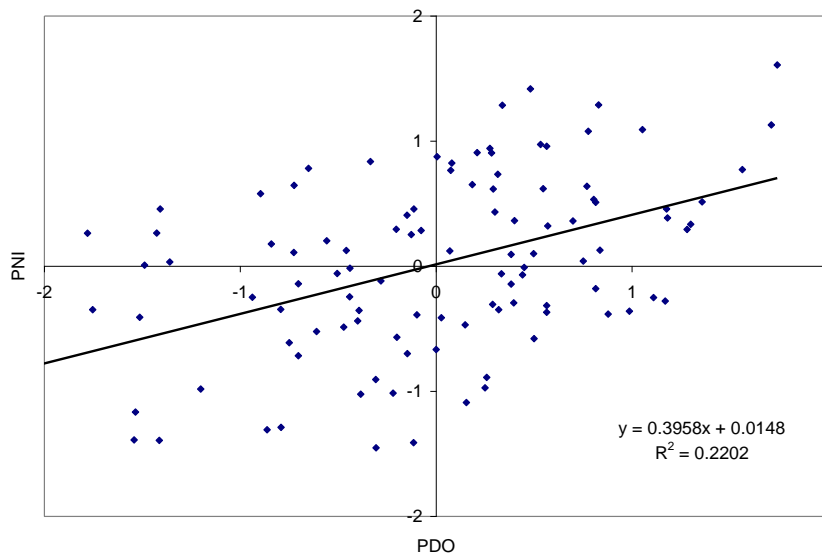


Figure 15. Comparison of climate indices. Annual values for the PDO (x-axis) and PNI (y-axis).



Some evidence of a correlation between Willapa chum run-size and the PNI was apparent (Figure 16) after 1990 (correlation coefficient = 0.49); however this relationship was not consistent over the entire dataset. For example the correlation coefficient between the PNI and total run-size was 0.15 (this coefficient has possible values between 1, indicating perfect correlation, and -1, indicating perfect negative correlation). The correlation between PNI and run sizes 3, 4 and 5 years later was also weak (0.11, 0.21, and 0.12 respectively).

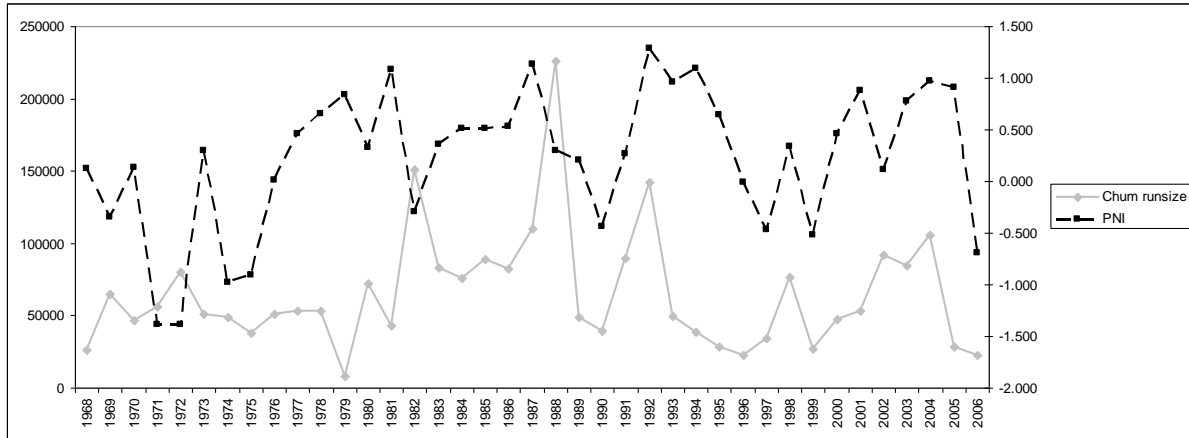
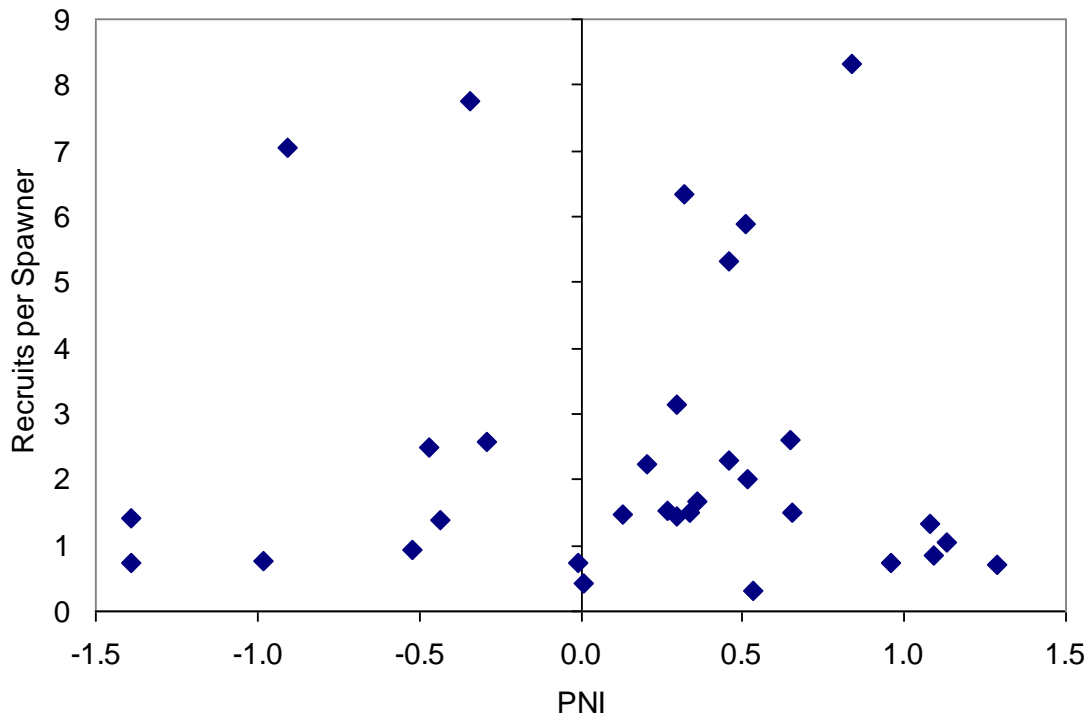


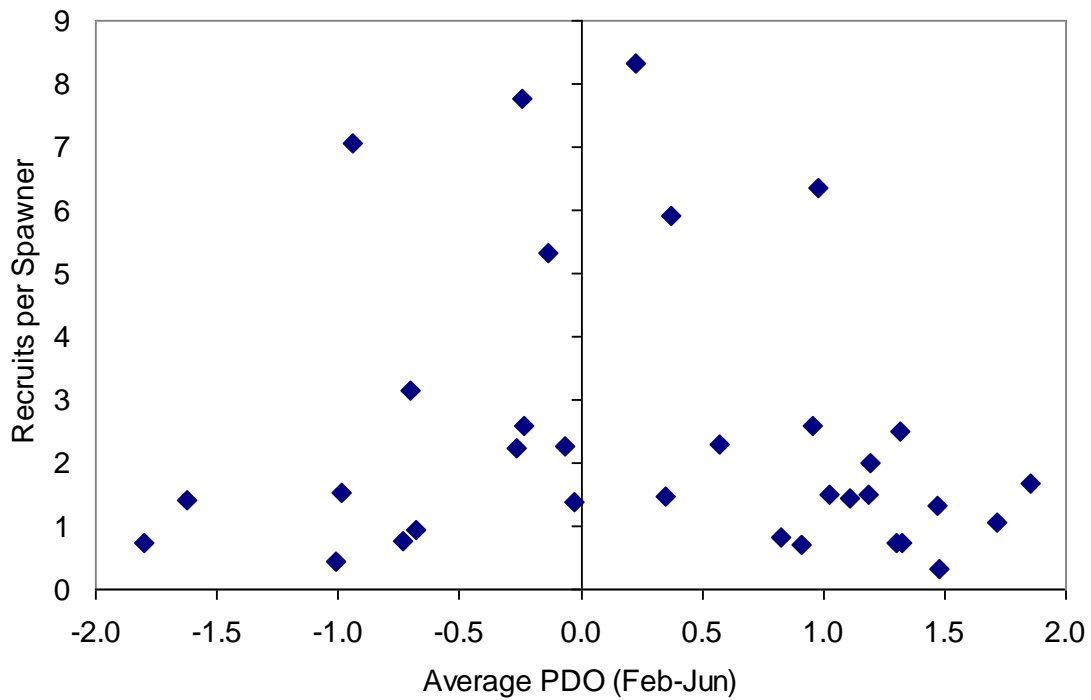
Figure 16. Pacific Northwest Index (PNI, data from http://www.cbr.washington.edu/data/pni_data.html) and Willapa Bay chum run size (1968-2006).

To look more specifically at the relationship between the climate and survival of chum salmon, we compared the PNI and PDO indices during outmigration to the number of recruits per spawner from each brood-year (Figure 17). No conclusive pattern was evident.





A



B

Figure 17. Chum recruits per spawner realized during different climate regimes. (A) The PNI values from the year after spawning were used to indicate conditions during outmigration, and (B) The PDO values represent the average monthly values from February to June following the corresponding brood-year spawning season.



3.5.4 Implications

Fluctuations in basin-wide ocean conditions have been shown to affect trends in Pacific salmon productivity. However, the available data for chum salmon in Willapa Bay do not provide a clear picture of how this particular population is influenced. The apparent increase in average run-sizes following the major regime shift of 1977 is counter to the documented responses of Chinook and coho populations, perhaps indicating a decrease in the influence of interspecific competition. Interpreting the impact of climate regimes on Willapa chum populations will require identifying the specific mechanisms, the life-stages most susceptible to conditions represented in different regimes, and how differences in life history between coho, Chinook, and chum might result in different responses.

The relationship between Willapa chum salmon and climate is difficult to quantify in a way that is meaningful for management. Nonetheless, even simple awareness of this phenomenon can be incorporated into management in a systematic and precautionary way. There is an opportunity to develop strategies that account for the possibility of ocean effects. First, it may be inappropriate to use average values from the time series when determining the likely returns or capacity of the system. Second, the role of an integrated hatchery system might change in response to expected ocean survival rates: during periods of low ocean survival, increased hatchery production might help to avoid disastrously low returns; whereas, during periods of high ocean survival, hatchery activity could be scaled back so that natural origin recruits are not limited by carrying capacity.

3.6 Interspecies Effects

3.6.1 Background

Historic catch records from salmon fisheries in Willapa Bay indicate that the watershed was primarily dominated by chum (Suzumoto 1992). From 1913 to 1959 chum comprised on average 65% of all salmon catch, with coho and Chinook making up about 22% and 13% respectively (Suzumoto 1992). However, from 1960 to 1991 chum made up only 43% of the total catch, whereas coho increased proportionally to 37% and Chinook to 20%. This trend likely reflects the focus on higher value species and the influence of the hatchery programs for coho and Chinook.

Hatchery programs over the past 3 decades have focused on increasing the number of returning Chinook and coho. As a result, these populations have either increased or remained stable. In contrast, chum stocks continue to rely primarily on natural stocks to replenish themselves. It is possible that the artificial increases in the size of other species' populations may be negatively affecting chum stocks either through competition or predation.

3.6.2 Mechanism

Competition may occur at several life-stages. Returning chum may face increasing competition for spawning habitat as the numbers of other species are increased. Generally, this type of competition is minimal since optimal spawning habitat and run timing of the different species do not overlap. However, this may be an issue in areas where salmon are blocked from accessing the historical upstream spawning areas. If coho and Chinook are forced to utilize downstream habitat for spawning, this geographic shift may overlap with



chum spawning grounds. It is important to note that chum generally spawn later in the year, in which case chum redds would disrupt those of other species but not necessarily vice-versa. The mechanism for increased competition for spawning habitat is therefore unclear.

Competition may also occur at the fry and smolt stage depending on the availability of food resources in the streams and estuary. Alevins of most salmonid species emerge in the spring and rely on the same types of prey items. However, chum quickly emigrate downstream and enter the estuary at small sizes, thereby reducing the significance of competition for food in freshwater systems. Chum smolts grow rapidly in the estuary and nearshore ocean environment, which indicates a high demand for food. Diet overlap with juvenile coho has been shown in nearshore marine waters (King and Beamish 2000). The productivity of these areas is thus likely to be a major factor in determining survival and future run sizes.

In contrast to chum, coho spend a full year in freshwater before migrating out to the ocean. As coho salmon grow during their first year, their diets change to include larger prey items, including insects and other fish species. Because chum fry generally emigrate shortly after emergence, predation mortality by yearling coho during downstream emigration can be significant (Beall 1972; Johnson et al. 1997). The estimated mean freshwater mortality as a result of predation ranges from 22% to 58% (LCFRB 2004). In general, predation on smaller chum fry is thought to be high and predation decreases as chum fry size increases (Beall 1972).

3.6.3 Evidence

Escapement data for Chinook and coho are limited. Annual escapement numbers for the three Chinook stocks were estimated starting in 1986 (SaSSI). Annual escapement data for the six coho stocks are only available from 1996 to 2003. With this limited information it was difficult to establish any relationship between these three species.

Bay-wide estimates of terminal run sizes for both chum and coho offer the longest data set for comparison. For coho, only the 5-year averages are reported from 1976 to 1990 in the Review of 2005 Ocean Salmon Fisheries Report (p.221), therefore we utilized data reported in Suzumoto (1992) for annual run-size estimates during this period. Comparing trends in run-size between chum and coho in Willapa Bay reveals a slight positive correlation, especially at a 1-2 year lag (correlation coefficient at lag0=0.19, lag1=0.47, lag2=0.43). This suggests that the two species are responding to similar external factors in the early marine life-stage, rather than competing with one another (Figure 18).



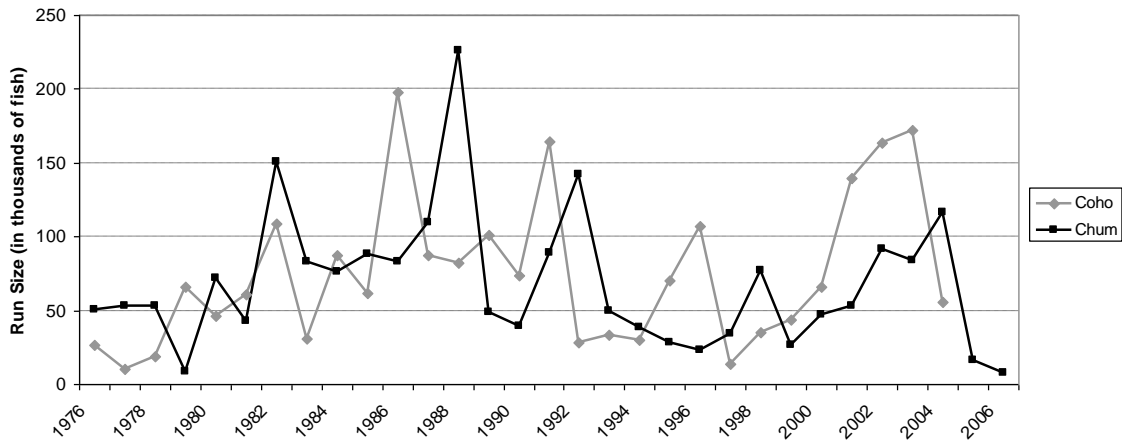
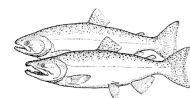


Figure 18. Run size of coho and chum in Willapa Bay from 1976 to 2006. Coho data compiled from Suzumoto (1992), and WDFW.

To further investigate possible competition for spawning habitat between chum and either coho or Chinook, we looked for evidence of a negative correlation between the escapement of other species and the success of chum brood years. In other words, for years when coho escapement was relatively high, chum returns from that same year’s cohort would be relatively low. In Willapa Bay, neither natural coho escapement, nor natural Chinook escapement are correlated with chum recruits per spawner (Figure 19), although only five years of data are available for comparison (1996-2000). Similarly, a weak negative relationship between chum recruits per spawner and Chinook escapement (from 1986-2000) is evident (Figure 19). It is interesting to note that the lowest year of Chinook escapement (3,376 Chinook in 1999) corresponds with the highest chum R:S of the time series (5.34), however the R:S ratio is fairly consistent over the rest of the continuum of Chinook escapement.



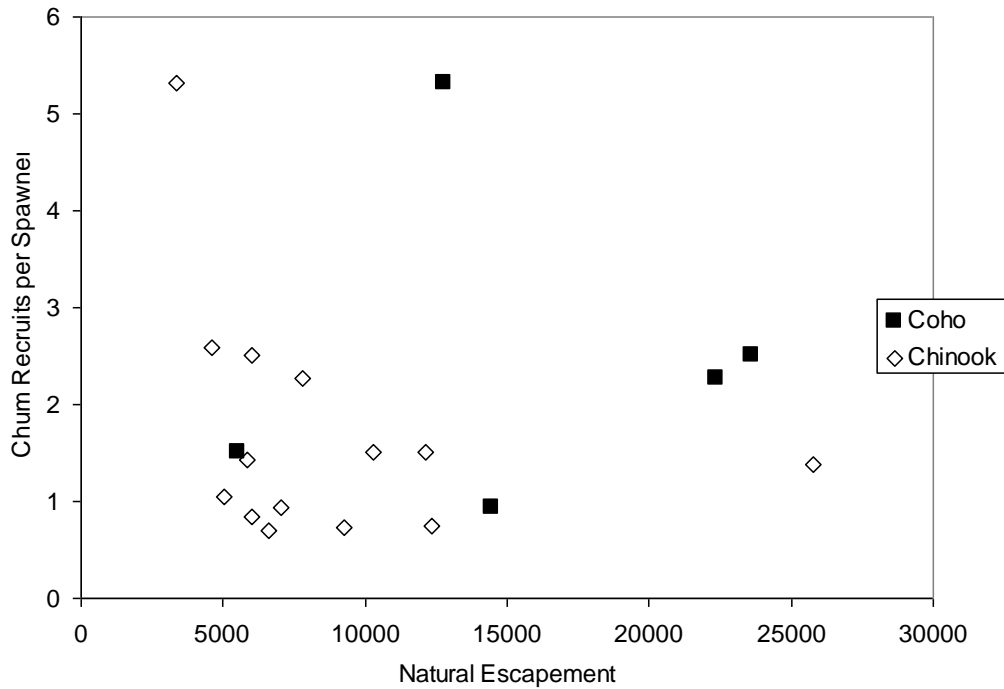


Figure 19. Chum recruits per spawner compared to the natural escapement of coho and Chinook

Competition between chum and either coho or Chinook at the fry stage would also be evident in the previous analysis. Therefore it is difficult to determine the true mechanism, or importance of a combination of mechanisms, that would explain an observed relationship. Unfortunately, data regarding natural origin smolt numbers for these species is not available. The only possible way to assess competition at this life stage is by using indirect/proxy methods for estimating the number and overlap of salmon smolts. This process generally introduces assumptions and unquantifiable error, leading to little confidence in the results.

Predation by yearling coho on juvenile chum would be expected to show a negative correlation between stocks at certain time lags. For example, a strong escapement of coho at year t would likely result in a strong cohort of yearling coho in the streams in year $t+1$. The success of chum spawning effort from year $t+1$ would not be evident until the age 3, 4, and 5 spawners returned in years $t+4$, $t+5$, and $t+6$. Over the years of data that were available to us, we observed an intriguing relationship between chum survival, as indicated by the recruits per spawner, and the number of yearling coho smolts in the streams, assumed to be proportional to coho escapement from the year prior (Figure 20).



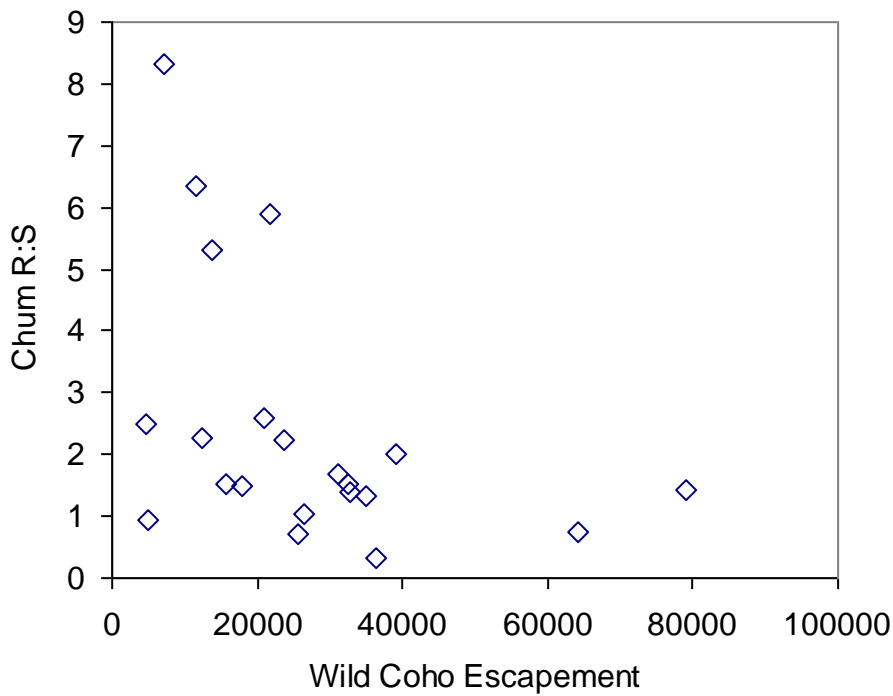
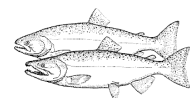


Figure 20. Chum recruits per spawner compared to natural coho escapement from one year prior.

Unfortunately, myriad other factors may influence survival over this time frame, making it impossible to isolate the predation effect. Identifying predation as a potential limiting factor will require research directed at the juvenile stage of these salmonid species.

3.6.4 Implications

If further research indicates that significant competition and/or predation is limiting chum populations, then managers will need to explicitly prioritize restoration and enhancement actions on a basin wide scale while considering multiple species. The effectiveness of chum restoration efforts might be undermined by coho enhancement efforts elsewhere in the watershed.



4 WILLAPA CHUM MANAGEMENT

Willapa Bay chum salmon are harvested mostly in commercial fisheries, as described in Section 4.1 below. The harvest management process is based on three major components: 1) a set spawner escapement goal which is 2) compared annually to the predicted run size, to determine whether there is a harvestable surplus, and then 3) implementation of a fishery via regulations developed by WDFW. Annual estimation of spawner escapements to the spawning areas and the production of hatchery-reared chum salmon are other integral aspects of this process.

4.1 Harvest

4.1.1 History

Salmon fisheries are an important cultural and economic component of the Willapa Bay region. Chinook and coho are targeted by both commercial and sport fishers inside and outside the bay, while chum are primarily caught by commercial gill-nets inside the bay. A limited sport fishery for chum exists in the rivers, but these catches are usually less than 5% of the total.

Commercial salmon catch in Willapa Bay was predominately chum for many decades. From 1913 to 1959 chum landings averaged 83,400 fish and represented 65.3% of the total salmon harvested in Willapa Bay (Suzumoto 1992). More recently, these numbers have declined as a result of the generally lower number of chum returning to the Bay. Since 1968 the total chum landings have averaged fewer than 30,000 fish annually.

4.1.2 Current Harvest Management

Salmon fisheries in Willapa Bay are managed by the Willapa Bay Fishery Management Framework, which lays out region-specific objectives that are consistent with state-wide goals. First developed in 2000 and last updated in 2003, this plan guides pre-season harvest management decisions that are made during the North of Falcon process. The primary goal of the framework is to “maintain important fishery values while incrementally improving protection of existing natural spawning populations” (W.B. Fishery Management Framework 2003).

4.2 Escapement Goal

Willapa Bay chum salmon are managed such that a minimum number of adults return to spawn each year. This number is known as the escapement goal. Annual harvest quotas are set based on the expected surplus, calculated as the predicted run size minus the escapement goal.

4.2.1 History and Current Status

The current Willapa Bay chum salmon spawner escapement goal is 35,400 fish for the entire basin (including all six stocks delineated in SaSSI) and has apparently been unchanged for several decades. The history of how the goal was established is vague at this point (unless additional information can be uncovered). There are some printed and hand-written notes



from the 1980s and early 1990s that allude to estimating the number of miles or square yards of spawning habitat, and then multiplying times the expected number of fish per mile or area, but the documents are insufficiently clear to truly determine the actual calculations. It has been anecdotally reported that the habitat-based relationships of fish per mile or area were taken from the Chehalis River. To quote from one 1980s-era hand-written page “Willapa Bay escapement goals were based on an average escapement (peak count mean / 0.9 -- omitting over escapement and under escapement years) and stream catalogue data to develop standard yd^2/sp pair statistic.”

4.2.2 Critique

The escapement goal is the heart of successful salmon management. It is also notoriously challenging to estimate because of changing habitat and changes in the habitat-production relationship. If the escapement goal is too low, then habitat is unused and potential production is lost. If the goal is too high, then harvest opportunities are lost. With this in mind, it appears that the Willapa Bay chum salmon escapement goal should be thoroughly revisited, preferably on a stock-by-stock basis, for more accurate management.

4.3 Escapement Estimation

Quantifying the annual escapement is an essential component to salmon management. Since 1968, WDFW has estimated wild chum escapement in Willapa Bay using spawner surveys and extrapolation techniques. These data were provided graciously to us for this report and form the basis of many of our analyses. In this section, we describe the methods used to generate these estimates.

For many years, surveys of spawning chum salmon were conducted at index reaches on 9 to 10 streams distributed within the six main Willapa watersheds (Figure 1 and Figure 21). These included:

- Bear River
- Ellsworth Creek (Naselle River)
- Ellsworth Creek tributary (Naselle River)
- Davis Creek (Naselle River)
- Williams Creek (Nemah River)
- Canon River (Palix River)
- South Fork Willapa River
- Trap Creek (Willapa River)
- Bitter Creek (North River)
- Lower Salmon Creek (North River)



Survey data were used to estimate escapement in each stream using the “Area Under the Curve” (AUC) method¹ and multiplying by a certain percentage (adding between 0-15%) to account for sampling limitations. The bay-wide total was found by summing the streams and adding another 15% for non-surveyed areas. Occasionally certain streams could not be surveyed. In these cases, biologists interpolated the data based on observed correlations with other streams. For example in 1983, only five streams (Ellsworth Creek, Williams Creek, Bear River, S. Fork Willapa River, and Davis Creek) were surveyed sufficiently for an AUC approach. The survey of the Canon River was incomplete, and therefore Canon River escapement was calculated with a regression equation based on its past relationship with the Williams Creek estimate. Another regression was developed using 12 years of data to correlate the escapement subtotal for the remaining three streams (Trap Creek, Bitter Creek, and Lower Salmon Creek) to the subtotal of the former six.

In 1991, the WDFW explored the correlation between bay-wide escapement and the 10 different streams by testing a series of linear regression models. The goal was to determine whether chum escapement could be reliably estimated using less survey effort. Individually, the Canon River correlated the closest ($r^2 = 0.918$) with total escapement; but the fit was even better by including Ellsworth Creek and Lower Salmon Creek to the equation ($r^2 = 0.975$). Because of this close relationship WDFW decided to scale back chum survey effort and sample only these three streams. As a precaution, the original 10-stream method was performed in 1996 and 2004 in addition to the 3-stream method for comparative purposes. In 1996, the 3-stream method estimate was less than the 10-stream method by only 3% (697 fish), but in 2004 it was greater by 15% (11,098 fish).

The linear regression equation used for annual bay-wide escapement estimates appears to have changed slightly over time. More recent documentation (‘WBCMHis.WB3’) shows the model as:

$$\text{TOTAL BASIN} = 2346 + 4.33 * \text{Canon} + 1.83 * \text{LowerSalmon} - 1.2 * \text{Ellsworth},$$

However, these coefficients differ from those in the original step model (R. Brix, WDFW internal memorandum July 30, 1991). Two general issues should be addressed more explicitly regarding this model. First, it is not clear how often interpolative techniques were used to “fill gaps” in the escapement records. A high degree of correlation between bay-wide escapement and individual stream escapement is not surprising if some proportion of the individual stream escapement values are simply predictions calculated based on the same assumption of correlation. Second, it would be wise to justify the negative value of the coefficient for Ellsworth Creek. Statistically, it has been shown to improve the fit and therefore makes sense to include for forecasting. It is illogical however, that chum spawning in Ellsworth Creek count against the bay-wide total.

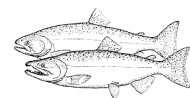
According to statewide definitions used by the Salmon and Steelhead Stock Index (SaSSI), six stocks of chum are found within Willapa Bay, but the current 3-Stream method only

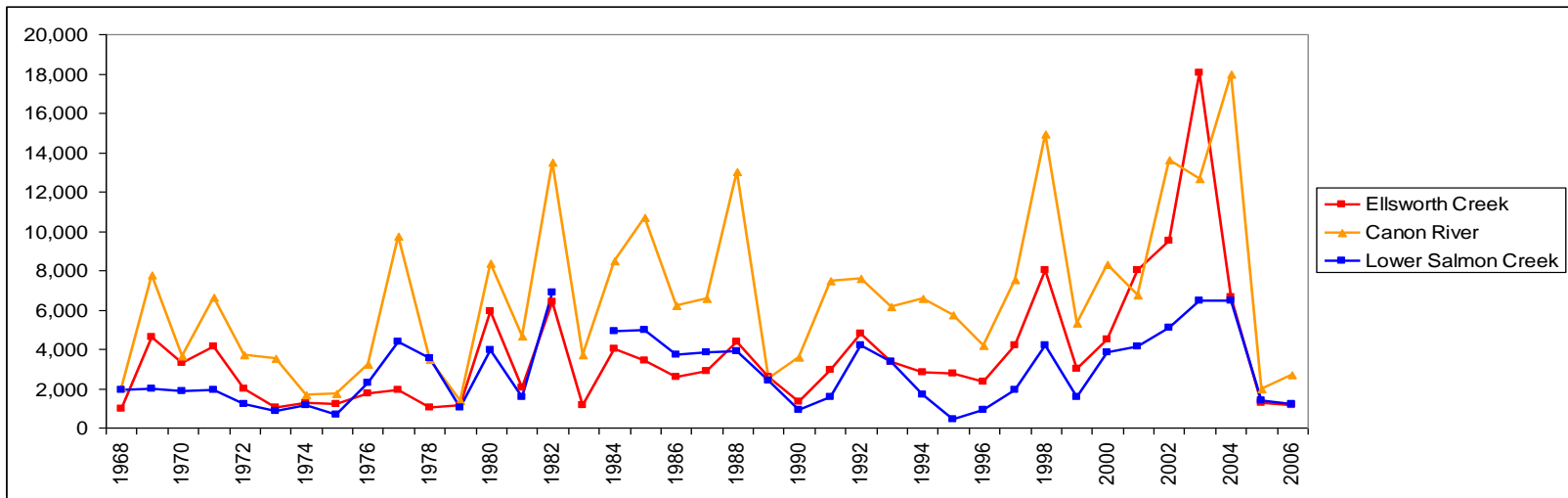
¹ The AUC method: Live chum observations collected through the season in each index reach are plotted on a graph and a line is fit by eye through the counts. The area described under the curve is calculated (fish x days), and this value is divided by the assumed average residence time of the fish on the spawning grounds (usually 10 days) to derive an estimate of total spawner abundance in the surveyed reach.



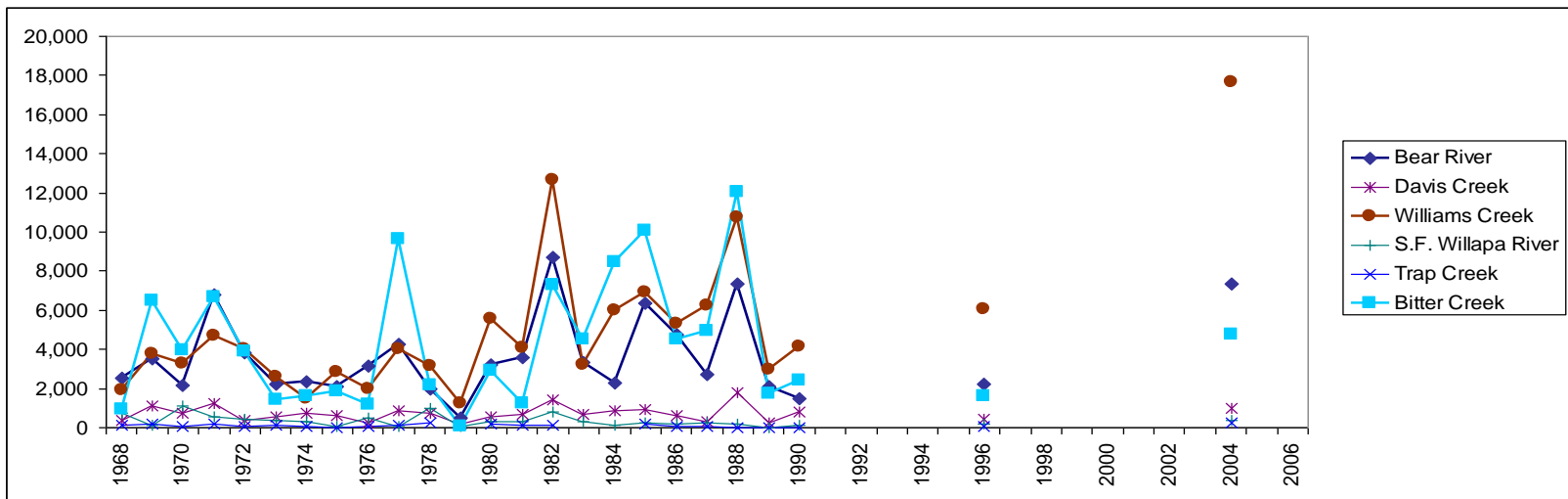
makes direct observations on three stocks. As a result, the Willapa chum SaSSI reports define each of the six stocks as healthy in 1992, but in 2002, only three were considered healthy because three were un-assessed. The Commercial catch areas in the bay are delineated loosely around the different watersheds, but it would still be impossible to determine the natal river of harvested fish, especially in area 2-G where most chum are caught. This inconsistency regarding the “management unit” makes prioritizing and planning monitoring efforts difficult.

Due to the limitations of currently available information on chum, quantitative analyses of limiting factors are not possible at a finer geographic scale. Any local declines of chum due to area-specific habitat issues would not be evident in the annual escapement estimates. While clearly more accurate estimates of bay-wide escapement are possible by surveying more streams, fishery managers must always consider trade-offs between accuracy and available resources. Considering the close fit of the regression equation, it may have made sense at the time to conserve limited resources. However, the current ability to assess the changing conditions of the individual watersheds and the status of different chum stocks within Willapa are now limited as a result. The remaining concern with estimating escapement using the three-stream, or even the 10-stream method, is that many of the chum habitats are not included in the calculation, whether they presently contain chum or not.



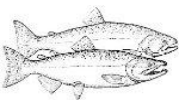


A.



B.

Figure 21. (A) Estimated chum escapement to the three index reaches used for the 3-Stream method and (B) the six other streams that were surveyed consistently until 1991, and then only in 1996 and 2004.



4.4 Pre-Season Run Size Prediction

Managers need a way to compare the expected return each year to the escapement requirement, so they can determine the amount of the harvestable surplus. This is generally done by using parental spawning stock sizes and recent survival rates to generate an expectation of the returning run size. In multi-aged chum populations, this requires development of a brood table, often referred to as a run reconstruction model. The success of run reconstruction depends heavily on accurate escapement and harvest numbers in the brood years (See sections 4.1 and 4.3).

4.4.1 History and Current Status of the Run Reconstruction Model

The WDFW uses a run reconstruction model each year to estimate the predicted return of chum salmon to Willapa Bay. The predicted run size is used to regulate the Willapa Bay chum salmon fishery.

The model we examined is an Excel Workbook that includes all the computations (File name: 2006 WB2 Chum forecast model Final2 02.16.06.xls). The model is essentially based on the average of the previous 3-4 years even or odd-year return per spawner values, as a proportion of the brood year escapement, for each returning age. (The even-year return rates are greater on average than the odd-year return rates.) These estimated returns per brood year spawner are then summed over the three returning ages to estimate the total numbers predicted to return. The results are then adjusted in three general ways.

First, the expected returns of the predominant ages (4- and 5-yr-olds) are adjusted by a correction factor that accounts for the performance of the same year-class in the previous year. This process assumes there is a relationship between the returns at age 3 and 4 predicting the returns at age 4 and 5 respectively. A quick and simple analysis of the existing return data indicates there is a positive relationship, although it is quite variable annually.

Second, in many years, only a portion of the data record in the brood table is used, apparently to account for variations in years when a) the expectations for return (survival) rate are different from the survival for all years, and/or b) there was little or no hatchery returns. For example, in the spreadsheet we examined, which estimated the numbers predicted to return in 2006, only the data since 1994 were used (a note in spreadsheet explains this is because it includes the years where there was little hatchery influence on the return rate). Since the model is based on brood-years returns, and because odd and even-year data is separated in the model, this resulted in the use of only four observations to determine the predicted return. This also affects the denominator of the correction factor: the relationship between 3 and 4-yr-olds appears to be non-significant when based on only four observations.

Third, return rates are calculated separately for odd and even years because of a suspected interaction with pink salmon. Although more prevalent in Puget Sound, there has been some indication of coastal chum-pink interaction in the ocean during odd or even years. Figure 1 exhibits a pattern that chum returns are often greater in even years than in adjacent odd years.

4.4.2 Critique of the Run Reconstruction Model



A positive highlight of the model workbook is that it is an apparently complete bookkeeping record of all the relevant data for managing the Willapa chum salmon run. Much of the annual data, such as escapements, harvests, and age compositions have been “permanently” recorded in the spreadsheet.

The actual run forecasting model performance from 1993 to 2005, as shown in the model Workbook, has averaged 0.96 of the actual run size, but it has ranged from underestimating the run size by 66%, to overestimating the run by 2.2-times the actual run size. Such large discrepancies between the prediction and the actual run size can potentially result in substantial under- or over-harvest and/or under- or over-escapement. The sources of the discrepancies generally fall into two categories: unaccounted natural variation or methodological inaccuracies. The former cannot be managed but could eventually be measured and accounted for. The latter is somewhat manageable via improved data quality and methodological technique.

Several current techniques may be having a negative effect on the model performance. One is the choice of years to average, in this case the most recent years. Since chum salmon survival is likely mediated by ocean conditions, we expect that survival rates are autocorrelated and reflective of the bimodal ocean “regimes” (see Section 3.5). It is difficult to predict when the regime will shift, so there is low confidence in the estimated return rate. Underestimating the survival rate (returns per spawner) will tend to over-predict the return numbers, and vice versa. It may therefore be advisable to use the long-term average return rate. In the longer run, it will be important to determine the factors that affect survival and build that into the predictive model.

Another potential negative effect on the run reconstruction model performance is the assumption of survival variability due to interactions with pink salmon, as commonly observed with Puget Sound chum populations. While there is some indication of an odd-even year effect, it may not be sufficiently significant to warrant reducing the available data by 50%.

A third issue is the lack of extensive, accurate age composition data. The current model is apparently built upon age data that is of unknown origin through 1997. The values are “inherited” from previous managers and preserved as such; there is no way to back-track to aging data. Beginning in 1998, the age data is more accurate and better-known. The proportions of the age samples are indicated in the “Age” worksheet. Although apparently nothing can be done to improve the historic age data, we emphasize the importance of continuing to collect thorough age data from the harvest and escapement.

Last, the Willapa Bay chum salmon run reconstruction model has generally been used to estimate the predictions by “hand”. That is, it is more of a bookkeeping tool than a relational or statistical model. One positive feature of this approach is that it incorporates considerations for variation in productivity that a long-term statistical model does not. It may be useful to conduct a full model evaluation using a Ricker or Beverton-Holt spawner-recruit model. While these models have their own drawbacks (generally because they lump all sources of variation into one composite model), the results may provide corroboration of whether short-term survival patterns and/or the pink salmon effect are important.



A final, overarching flaw with the current run reconstruction approach, which is common to many salmon stocks, is that the total production capacity of the habitat for chum salmon may actually be greater than is currently be utilized. This arises from chronic under-escapement as the result of setting the escapement goal too low based on a period of data collected while the stock was already depressed or not fully utilizing all potential habitat (Knudsen 2000). There is evidence that this may be true in Willapa Bay, based on a comparison of historic run size indices to more recent data: the average harvest during 1913-1959 was more than twice the average for 1960-1991 (Suzumoto 1992). There are a number of management and/or biological reasons why a stock may be under-producing, but the current model is not based on any information that can detect this phenomenon. These should be fully investigated in support of Willapa Bay chum salmon rebuilding.

4.5 Pre-Season Management Process

4.5.1 Current Status of Pre-Season Management

WDFW holds several pre-season meetings with the local public (within the Grays Harbor and Willapa Bay areas) to gather input and suggestions for both the commercial and sport seasons for the upcoming fall fisheries (suggestions are also taken by phone and email). This year, WDFW also held a separate meeting in Olympia for an entire day to go through any other possible suggestions and scenarios. There are two North of Falcon (NOF) meetings, usually in mid- and late March. These are the first official meetings where WDFW and tribes get together to go over coastal fishery issues and limitations. Generally, the public meetings take place either just prior to NOF or one before and one after the first NOF meeting. At both NOF meetings there is time for additional public discussions and suggestions. There are also two Pacific Fishery Management Council (PFMC) meetings usually during the first week of March and first week of April. Both of these meetings include continual meetings between WDFW and the tribes to try and settle co-management issues.

Pre-season (and in-season) management is generally described (for 2003) on the web (at <http://wdfw.wa.gov/fish/regs/commregs/2003framework.htm>). A process begun in 2000 and continued in 2003, attempted to establish a Willapa Bay Salmon Management framework, as described on the web. The framework lays out general, long-term goals and more specific short-term goals. The long-term goals include: abundant natural spawners, improvements in hatchery programs, accurate assessments of the resource, and the ability to adapt to new information and new ideas. As expressed on the web site, the need continues to refine the short-term fishery management framework while necessary steps are identified to develop a more comprehensive watershed plan for Willapa Bay. As a result, the primary short-term goal continues to be maintaining important fishery values while incrementally improving protection of existing natural spawning populations.

4.5.2 Critique of Pre-Season Management Process

Although the general framework process of pre-season management is adequately described (as above), detailed information on the process (such as how the run reconstruction model is used and/or whether any harvest allocations are modified during the process) is not readily available. The web site should be updated annually (e.g., 2003 is the latest). Progress should



also be made on identification and implementation of short-term goals. An integrated planning process that involves fishery managers, stakeholders, and the public, and includes consideration of improved pre-season management and chum stock rebuilding, should be implemented.

4.6 In-season Harvest Management

4.6.1 Current Status of In-Season Management

According to the WDFW web site, “The natural chum spawning escapement objective is 35,400; target chum fisheries can occur if harvestable numbers are available based on the pre-season or in-season forecast and consistent with maximum allowable impacts on natural coho; chum fisheries will be targeted in times and areas where chum predominate rather than natural coho” (<http://wdfw.wa.gov/fish/regs/commregs/2003framework.htm>). Specific locations for the chum fishery are also identified on the web site.

In-season management of the chum fishery is minimal, as described on the web site: “The intent will be to fish the scheduled commercial fisheries as established pre-season. In-season changes to scheduled chum fisheries could occur if observed catch rates are well below expectations and if it is determined that further fishing could jeopardize meeting the escapement goal.... No in-season run size updates are anticipated for 2003 fisheries in Willapa Bay..... Chum fisheries may be altered in the unusual circumstance that catch rates indicate a very weak run in-season.”

WDFW sets mainly fixed fishery schedules and they do not usually have in-season management other than commercial sampling and the statewide Quick Reporting to maintain their sampling percentages of the fishery (for CWT's and scales), and to keep track of fishing daily for any anomalies in the season, as described above.

4.6.2 Critique of In-Season Management

There is a reference in the web site to “in-season forecasts” but we have not seen any indication that the pre-season forecast is adjusted as the run progresses, except when “catch rates indicate a very weak run”. In many fisheries, the progress of the run is monitored carefully and the harvest managed accordingly so that the target escapement is more likely to be met and/or any unpredicted surpluses can be harvested.

4.7 Hatchery Management

4.7.1 History

Hatchery supplementation has been used in Willapa Bay as a tool for meeting the escapement goals of chinook, coho and chum while providing opportunity for recreational and commercial harvest. Most hatchery effort to date has focused on producing coho and chinook which form the basis for more valuable fisheries, but a limited and inconsistent chum supplementation program has been in place since the 1960s. Chum supplementation increased during the 1980s, and in 1990 represented almost half of the total escapement of chum in Willapa Bay. Since the mid-1990s however, these programs have been minimized (Figure 22).



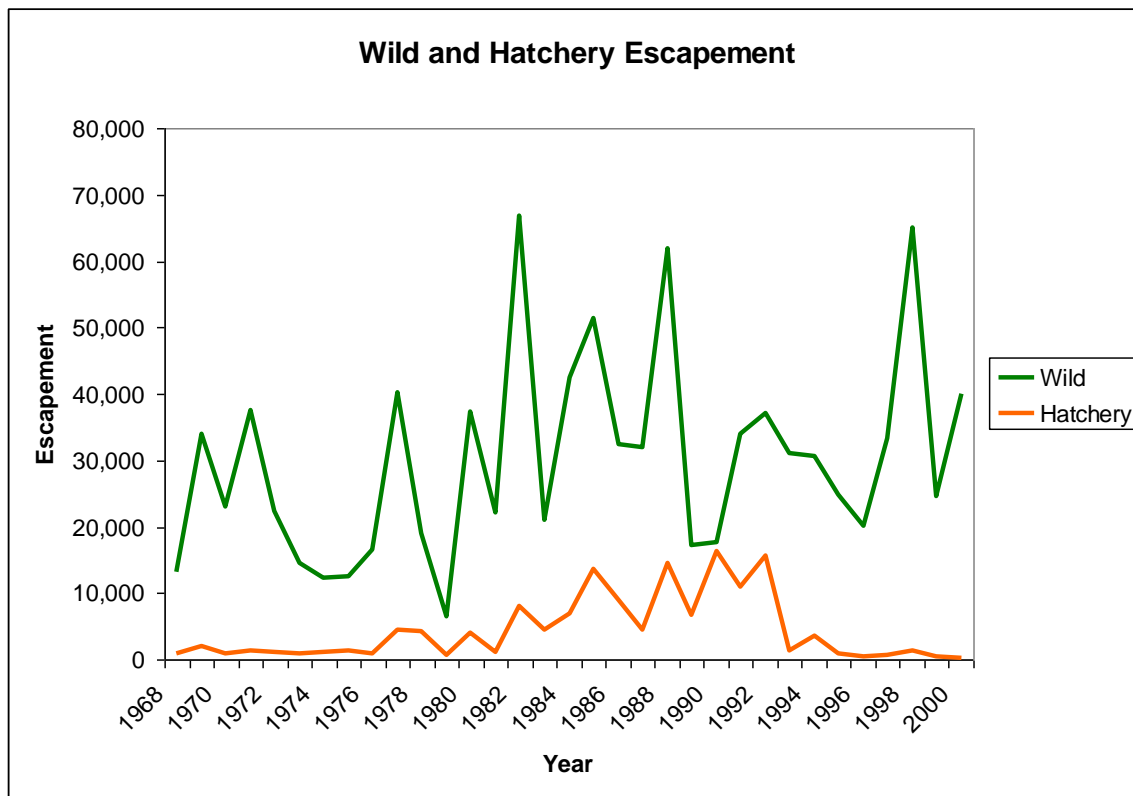


Figure 22. Escapement of chum at the hatchery and in the streams.

One important caveat to consider when analyzing these data is that hatchery-origin chum are not distinguishable from natural-origin chum. Therefore, it is not possible to calculate relative rates of survival or other comparative statistics. The location to which a fish returns (either to the hatchery or the stream) is the only indication of its origin. The proportion of hatchery chum harvested in the fishery is calculated based simply on the proportion of hatchery to wild escapement estimates and the assumption that hatchery and wild chum are caught with equal likelihood. This approach unfortunately precludes any detailed analysis of hatchery effects or discrepancies in survival.

4.7.2 Status

All chum hatchery programs in Willapa Bay are considered integrated (with wild populations) and intended for conservation and educational opportunities (HSRG 2004). The three main facilities operated by WDFW are located on Forks Creek (a tributary of the Willapa River), the Nemah River, and the Naselle River, and are used to provide eggs or fry for WDFW and RFEG projects in other basins.

In the North River system, chum are considered native with natural production although long-term effect of using fry from Nemah River broodstock in the early 1990s has not been evaluated. According to the most recent Future Brood Document (WDFW 2007), the goal of the hatchery program is to take 220,000 eggs derived from Bitter Creek (a tributary of the North River) spawners, incubate and hatch them at the Forks Creek hatchery, and release 200,000 fry at the Fred March site (also on the North River).



The Forks Creek hatchery also takes 305,000 locally derived eggs to produce 50,000 juveniles for release into Forks Creek, and to supply the RFEG with 250,000 eyed eggs for release at sites on Oxbow Creek, Mill Creek, Elk Creek, and other Willapa River tributaries. Willapa River chum stocks are considered native with natural production but have in the past used broodstock from the Naselle and Nemah Rivers.

The Naselle Hatchery program was most active in the 1980s using broodstock from the Nemah River and, in one year (1980), from Hood Canal. It currently uses broodstock exclusively from the Naselle with an egg take goal of 300,000. Eyed eggs from the Naselle Hatchery are intended to be planted in remote site incubators in Johnson Creek (50,000) and transferred to the RFEG for projects in the Willapa River and Salmon Creek (250,000).

The Nemah Hatchery had a large chum program that ended in the mid-1990s. Since then, natural returns have dropped significantly. The Nemah Hatchery is still used sporadically to provide chum for projects in the Willapa Bay Refuge (HSRG 2004) but it appears that these activities are not recorded in the FBDs (WDFW 2004, 2005, 2006). In 2007, WDFW intends to re-start a large chum program that would release 2,000,000 fry, and provide another 450,000 eyed eggs to the RFEG (WDFW 2007).

4.7.3 Discussion

Several recommendations for improving Willapa Bay hatchery methods were addressed by the Hatchery Scientific Review Group during the recent statewide reform process (HSRG 2004). These included: updating spawning protocols according to the best practices described by the HSRG; improving monitoring efforts to determine if hatchery programs provide a net benefit to natural stocks; and ensuring good habitat is available to the integrated population so that sustainable populations are assisted but not dependent on hatcheries. In general, WDFW agreed with these recommendations but noted that many of the changes, such as improved monitoring, will require additional funding.



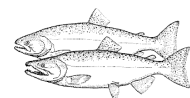
5 RECOMMENDATIONS

5.1 Process Issues

1. An integrated planning process should be implemented that involves fishery managers, stakeholders, and the public, and includes consideration of improved pre-season management and chum stock rebuilding.
2. That process should include engaging in a more systematically organized use of the AHA model, using input from other experts and stakeholders to lay out the goals first, then use the model to explore how to get to the preferred goals (Nisqually Chinook process is a good example).
3. Assess viability of each of the six chum runs within Willapa Bay specifically. This will require more in-depth conversation with WDFW and other local groups to determine what data are available and how they might be used to interpolate watershed-specific information.
4. Explicitly determine whether Willapa Bay chum should be managed as one bay-wide stock, or as six unique stocks from the different watersheds. Biological information (i.e. genetics, life-history, stray rates) should be used to make this determination.
5. The Willapa Bay salmon management web site should be updated annually (e.g., 2003 is the latest).

5.2 Harvest Management Issues

1. The escapement goal-setting process should be improved by 1) thoroughly reviewing and documenting the history of the current goal, and 2) reviewing and evaluating possible alternative escapement goal-setting methods, and 3) beginning implementation of the best method identified.
2. Short-term chum salmon management goals should be identified and implemented.
3. Evaluate and compare the pros and cons of estimating the predicted survival rate (returns per spawner) from short vs. long-term data.
4. Conduct Ricker and/or Beverton-Holt spawner-recruit modeling on Willapa Bay chum salmon data and compare the results to the current model that includes short-term survival patterns and/or the apparent pink salmon effect and to the SPAZ model results.
5. Determine the factors that affect survival and build those into the spawner-recruit model including such variables as stream flow patterns, pink salmon abundance, and marine survival variability.
6. Increase in-season monitoring that will support improved responsiveness of harvest management to ensure escapement, rebuild stocks, and/or harvest apparent surpluses.



7. Re-examine the 3-Stream method for estimating escapement. The “healthy” status of Willapa chum determined by the state is at odds with the general feeling of the resource users. This may be due to inadequate sampling by managers. At a minimum, the original 10-Stream survey should be conducted more frequently for comparison.

5.3 Habitat Management Issues

1. Evaluate whether Willapa Bay chum salmon habitat is being fully utilized, and compare to current production estimates predicted by the run reconstruction model.
2. Emphasize filling the vacant habitat, rather than habitat restoration, per se, as well as hatchery, to be sure the capacity is maximized.
3. In the long-term, chum populations will only be healthy and self-sustaining if spawning habitat is available in sufficient quantity and quality. Supplementation efforts, while useful for the short term, should not de-value the need for habitat preservation/ conservation/ restoration. In the case of chum, the greatest habitat concerns are: sedimentation in the lower watersheds, and access to natural estuarine and nearshore food webs.

5.4 Ecological Issues

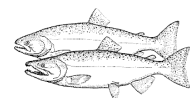
1. Predation by hatchery and wild coho salmon on chum salmon should be quantified. Our initial investigation suggests that the Willapa Bay populations of these two species may be correlated. If further evidence of a limiting effect on chum becomes available, then the scale of coho supplementation may need to be reconsidered.
2. Be aware that long-term climate related trends may affect chum production. While the specific relationship between Willapa chum and climate remains unclear and unquantified, managers must consider possible effects, especially when determining long-term averages of run-size, escapement, etc.
3. The analyses performed as a part of this investigation to define a link between potential chum salmon limiting factors (e.g., marine survival, stream flow, estuarine conditions, etc.) and R:S were primarily observational in nature. We recommend running multivariate statistical analyses to determine which limiting factors, or combination of limiting factors, most accurately predicts chum productivity based on observed data. Principal component analyses could also prove useful in the exploratory phase of such statistical evaluations.

5.5 Hatchery Management Issues

1. Mark hatchery chum salmon in such a way that they can be distinguished from wild fish. With this capability, the following new research strategies would be possible: relative proportion/health/status of wild chum; effectiveness of supplementation; more accurate AHA simulations; annual variation in ocean survival rates; etc.



2. Include other potential chum habitats in sporadic annual surveys to determine whether additional chum are utilizing these.
3. An integrated hatchery program should be given careful consideration to accomplish the immediate goal of “more chum in the streams.” Hatchery protocol should follow the most recent HSRG guidelines. The average wild run-size and estimated capacity of Willapa Bay chum indicate that a substantially larger scale hatchery program could be developed, with minimal risk to wild genetic diversity. However, this depends on using a high proportion of natural origin spawners for broodstock, which can only be guaranteed if hatchery fish are distinguishable from wild (see recommendation #1 in this Section).

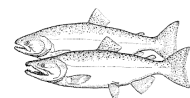


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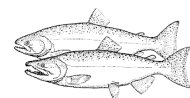
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APPENDIX A – RESPONSE TO WDFW COMMENTS

Appendix A includes comments from Bruce Sanford (WDFW) and Steward and Associates' response to the comments. Italic text represents Steward and Associates' response to WDFW comments.

September 20, 2007

To: Cleve Steward and Dustin Hinson (Steward and Associates)

From: Bruce Sanford, WDFW 360 249-1203

Here are a few changes you might consider in your Willapa Bay chum report. Hopefully this is all understandable.

The opening purpose is a bit unclear. It is stated: "...to increase the number of naturally spawning chum salmon in Willapa Bay." However, the focus seems to be on increasing hatchery production. Table 3 illustrates different production levels, each with 40% harvest rates, implying that hatchery production is primarily dedicated towards increasing either indirect or directed harvest opportunities. The goal should perhaps be: "assure natural sustainability of Willapa chum salmon populations," as the first priority and "sustainable fisheries" as the second priority.

We agree that the goals of this report could/should be stated more clearly. The opening purpose statement reflects the directive from the Willapa Bay RFEF when we began this investigation. Over the course of this project, more specific objectives and questions became clear and helped steer the focus toward certain details and scenarios.

Page 3, 1st Paragraph: It is stated that chum spawn from mid-to-late October through November. Chum will spawn through the end of the year and into January, but they are not necessarily the last to spawn as indicated at the top of page 39. Late coho spawning will go into February.

Thank you for clarifying.

Page 6: It would be good to explain more about the model SPAZ. Not many people are really familiar with it. However, with the model the estimate carrying capacity for Willapa Bay was 40,000 chum (page14), which is fairly close to our current escapement goal of 35,400. Using a habitat model, I would think that the estimated capacity would be significantly higher...maybe not. Then on page 17, you mention that we (WDFW) estimated carrying capacity at 150,000. Was that using EDT?

In general, we decided to exclude technical descriptions of the models in order to keep the report accessible to a broader audience. Instead we referred to documentation written by the creator of the model so that interested readers could follow-up in more detail. We also thought that 40,000 chum was surprisingly low and that a habitat-based capacity estimate would be much higher. However, the value of 150,000 was estimated by us (Steward and



Associates), not WDFW, by using a crude estimation from past run size and escapement numbers. An official EDT assessment has not been conducted in this region.

Table 1: The numbers in the model don't quiet agree with our numbers. It looks like some were rounded while others were not. Even with the rounded numbers, some were not rounded correctly. Does this include both hatchery and natural spawners? If so, how were hatchery fish estimated? What does the regime column mean? Regarding sources, could references be more specific rather than "various sources." Where did the age information come from? Not sure if 2006 scales have been read.

We also noticed some discrepancies between these values from different sources, but in general, they were not grossly different. The "spawners" column represents both wild and hatchery escapement, with data obtained from <http://wdfw.wa.gov/fish/chum/data/14willapa.xls> for the period between 1968-2000. Until around the late 1980s escapements appear to have been estimated to the nearest 100. The values for 2001-2006 were the sum of wild escapement (using the 3-stream estimation technique, received as a paper copy from WDFW) and hatchery escapement (from online WDFW hatchery reports). Unfortunately, a more authoritative/documented source was not available to us. Catch for this more recent time period was provided by Barbara McClellan. Proportion at Age data were found embedded in the run reconstruction model we received from WDFW, with the exception of 1968, for which we applied the average age distribution reported by Suzumoto (1992). It appears that the Table 1 caption was not updated to reflect incorporation of the WDFW run-reconstruction age structure. The regime column represents a feature of the model that we did not use due to our limited understanding of the link between climate/ocean regime and chum survival. The value in this column is used as a multiplier within the stock-recruit equation (multiplying by 1.0 results in no effect) to identify years when climate positively or negatively influenced salmon reproductive success and thereby allows for more accurate estimation of the underlying/intrinsic recruit/spawner relationship. See McElhany (2006b). The column of regime values was included in the report only for the purpose of thoroughly documenting our inputs, and ensuring the repeatability of our results.

Page11: It was hard to read Figure 4. I assume that the original is in color, but for those that received a copied version in b/w, we can't quite make out which line is which., but I can guess.

Unfortunately, the graphical output from the SPAZ model is difficult to manipulate, and therefore the default style was used. We apologize for the difficulties with interpreting b&w reproductions. For reference, the maximum extent of the Beverton and Holt line is the third from the top.

Page 14: It would be good to have more detail regarding the estimated chum catch in early years, rather than just the average of 83,400 between 1913 and 1959.

We refer the reader to Figure 11 in Suzumoto (1992). While the figure gives an impression of historic catches, a table with the specific values was not included in the report, therefore, the potential for more quantitative analyses and/or statistical summaries was limited.



Page 15: I agree that there is negligible risk of extinction and that stock breakout would be more useful, especially in terms of potential artificial production.

Page 15: I believe that we are pretty safe in using the AHA model in determining that there would be little genetic risk from hatchery production. It would take an awful lot of hatchery production to even approach a PNI value of 0.5. In fact, I don't believe we have the hatchery capacity to rear that number of chum. Compared to natural returns, chum hatchery production is only a fraction of the total, and the PNI values will always be in the "safe zone". However, that is not the major issue in dealing with artificial chum production. The main question is, given the status of the habitat, would increasing production via hatcheries make any difference in terms of increasing natural origin recruits. Something we need to think about.

The "scenarios" used for the AHA model were not necessarily intended to be entirely realistic. Instead, they were meant to explore certain limits of the system. The tradeoffs and considerations mentioned above illustrate the need for an interactive workshop where the AHA model can be used in relation to specific goals defined by the participants.

Page 17, the third bullet: 40% would be identified as the harvest economic value, while the 20% could be the ecological value. This brings up a point regarding the goal of increasing natural spawning. An example is Hood Canal summer chum. Although there was a successful supplementation component, which was initiated in the Quilcene River, the primary concern was harvest interception, both direct and indirect. Without additional controls over harvest, the spectacular increase in abundance would not likely have happened. This is something that should not be lost in determining the appropriate direction for Willapa chum.

Good point. Again, this is an example of an issue that should be raised during further discussion, perhaps in a workshop setting and in conjunction with the AHA model.

Section 3, page 21: There is a good discussion regarding the habitat component as a factor in limiting chum population, for freshwater and marine. However, nothing is said about harvest. It would be good to at least include some historic background about the level of commercial catch, especially within the last 20 years or so. Figure 2 provides a graphic of the harvest levels, but some discussion should be made about its effect on fulfilling escapement goals.

Harvest is obviously an important consideration when determining how many fish return to the streams. However, because Willapa chum salmon are managed to achieve an escapement goal, with harvest of any surplus chum, the mechanism for scaling back harvest would be to set a higher escapement goal, perhaps in accordance with habitat-based capacity estimates. This is why our report focused on how the escapement goal was set, and how annual escapement is monitored, rather than on the potential effect of different harvest levels.

Page 24: Regarding low flows, apparently this has not been much of a problem in Willapa Bay. The paper points this out at the bottom of page 26. In the first paragraph of 3.3.2, you might mention high flow effects in the Skagit, especially for Chinook salmon. WDFW has



done some excellent studies, using smolt out-migration monitoring. Chum could be affected in the same way.

Noted. We admit there is certainly room for further study and analysis; however, our time and budgetary constraints did not allow for us to explore this topic further.

Page 30: There is a question in Table 7 pertaining to Nemah and Naselle rivers in that the number of lost acres seems pretty low. Is this all that has been lost?

This table presents the data originally collected by the Willapa Alliance (1998) and made available in the Limiting Factors Report for WRIA 24 (Smith 2004). It refers only to the area of estuary lost/converted in comparison to the historical area, and does not include other land types within the watershed.

Page 33, Figure 13. Where did the Grays Harbor information come from and why does it stop in 2000? In any case, this shows a strong ocean influence regarding the survival rates of chum.

Data for the Grays Harbor chum come from the WDFW website <http://wdfw.wa.gov/fish/chum/data/13ghfallchum.xls>. Similar to the Willapa chum spreadsheet mentioned above, data was only updated through 2000. Unfortunately, because our communication with WDFW staff focused on gathering information on Willapa, we did not prioritize tracking down the most up-to-date data on Grays Harbor populations. This would be a valuable comparison to make to see whether this pattern holds in more recent years.

Page 3.6.1 It is mentioned that there has been a decline in chum harvest in terms of percentage. There could be a number of reasons for this outside of actual abundance levels. In recent years, for example, there have been significant changes in harvest opportunities, perhaps related to chum forecasts, but also likely related to concern with coho and/or Chinook. It's dangerous to use percentages since changes could be attributed to the other species and/or changes in harvest regulations and patterns. Your final sentence in that section alluded to that point in terms of levels of artificial production of coho and Chinook..

We agree that the percentage of total catch is not necessarily indicative of changes in abundance and tried to avoid implying such a conclusion. Our rationale for including this statistic (which was presented in Suzumoto (1992)) was to point out that human attention and priorities in Willapa are shifting toward other species, a trend that may continue in the future and steer general management decisions. Efforts to increase chum abundance may need to consider the management plans for other salmonids in the watershed.

Page39: There is a discussion about coho risks to chum salmon and the potential of predation. The statement: "...predation mortality by yearling coho during downstream emigration can be significant," is a somewhat blanket statement. There are a lot of variables that need to be considered in terms of the timing, spatial placement, flows, turbidity, etc. If there is a large coho release from a hatchery that occurs during chum out-migration, then it can be significant. However, chum salmon leave the watershed early, generally before coho emigration or their release from hatcheries. In developing the Puget Sound Chinook EIS, we modeled predation risks, using a number of parameters. Actually this was done through



Jones and Stoke (aka. Mobrand and Co.), and depending upon specific circumstances, the risk was quite variable. Some qualifiers need to be inserted in your report.

There are indeed many factors to consider when identifying whether coho predation on chum may be a threat. Our statement that predation “can be significant” means only that it has been shown to be a possibility in other systems. The analysis in section 3.6.3 is intended to offer a first-order look at available data, to identify whether this potential interaction warrants further examination. We decided that investigating the Willapa-specific temporal and spatial distributions of natural and hatchery coho, along with their dietary preferences was beyond the scope of this report, but encourage further research along these lines.

Page 40, figure 18: I’m not sure what I’m looking for in the graph. You are comparing competition for spawning habitat among chum, coho and Chinook. However, I believe that there are significant spatial and timing difference that any comparison would be difficult, as your graphic show.

Figure 18 was intended to provide a side by side comparison of the trends in coho and chum run sizes, allowing the reader to identify any broad scale correlations between these trends. Admittedly, correlations do not imply a cause-effect relationship. More detailed research focusing on quantifying the mechanism of any type of interaction is needed, but given the very general data available to us, this was merely a first step in identifying whether interspecific effects might be evident.

Page 43, 4.2. The use of the word “quota” is incorrect. A quota would be an actual number beyond which the fishery would be closed. In Willapa Bay, fisheries are based on schedules, which are set during the preseason process, and this schedule is usually adhered to regardless of catches.

Noted. Instead of “quota,” “expected annual harvest” would have been more appropriate.

Page 44, Critique: You might think about removing this section since the statements are obvious. It is also mentioned that the goal can be too high and harvest opportunities would be lost. However, this depends on priorities, remembering that management intent is not necessarily devoted to harvesting the last harvestable fish. It is also mentioned that a stock-by-stock management approach may be preferred. Willapa fisheries are basically mixed stock fisheries, and to manage chum, or any other species, on a stock-by-stock basis, it would require either harvesting fish only in extreme in terminal areas, or management based on the weak stock approach. In either case, it would be much more limiting than the present management direction and perhaps require complete closures in most years.

We made efforts to write this report in a way that was accessible to those who are not fisheries professionals, and therefore we included statements that might seem obvious to experts in the field. The most appropriate unit of management for Willapa chum stocks should be debated and consider many logistical issues such as those mentioned above. Once again, we encourage discussion in a follow-up workshop situation, where basin-wide integrated goals can be defined and provide a foundation for improvements in management.



Page 50, Section 4.5: It is questioned as to why there is a discussion of the pre-season management process. There is a lot of history here in terms of both biology and politics, and much of it was driven with the attempt to work on a co-manager basis. We are talking about a complex process involving five species of salmon, each comprised of many different stocks, all of which are migratory through international and national waters, a multitude of co-managers, and a number of user groups including purse seiners, gillnetters, trollers, recreational fishers, both in marine and freshwater. This is an integrated process that does involve fishery managers, stakeholders and the public, and it does include consideration of improved pre-season management and recovery for all stocks and species. Given this setting, it is hard to provide a useful critique that would make this process simpler politically and more accurate biologically.

We appreciate Mr. Sanford's comments on this complex management process and reconsider the wording of the last sentence in section 4.5.2. One of the limitations of this report, due to its focus on chum salmon, is that the broader context of multi-species, multi-sector, multi-area fisheries management is often simplified because it seems outside the initial scope. Obviously chum management directives will need to fit amicably within the larger management context, and this will require careful, deliberate coordination.

Other things:

- There has been no DNA work on chum since 1998 in Willapa Bay. Allozymes were collected in the 1980's but only for Naselle and North rivers.
- We feel that the 3-stream method provides a good representation of indices . When conducting coho and Chinook surveys, which include other systems, chum are also counted. However, if funding is available, periodic surveys for all systems would be appropriate.
- It takes about 2 weeks to 40 days for chum to leave the estuary.
- There may be a relationship between the abundance of ghost shrimp and chum salmon. Juvenile chum will feed on shrimp larvae.

Thank you for these additional insights.

