Click here to return to Report

Klickitat Subbasin Anadromous Fishery

Appendix A

Klickitat River Spring Chinook Stock Assessment and Investigation of Integrated Hatchery Strategies

Chris Frederiksen
Yakama Nation Fisheries – YKFP

Appendix A in Yakima/Klickitat Monitoring and Evaluation Project (199506325) 2005-2006 Annual Report to Bonneville Power Administration DOE/BP 00022449-1

TABLE OF CONTENTS

List of Figures

List of Tables

1. Klickitat River Spring Chinook Stock Assessment

Section 1 of this document covers several aspects related to the current performance of wild Klickitat River Spring Chinook. Beverton-Holt production functions were used in conjunction with brood year specific spawner recruitment data from 1984-1999 to estimate the carrying capacity and intrinsic productivity for Klickitat River Spring Chinook. These estimates did not partition freshwater life stages from marine survival. As a result, stock performance estimates encompass the complete life cycle including potential density independent factors affecting intrinsic productivity. To account for this, brood years were partitioned into 3 distinct clusters hypothesized as a function of density-independent factors such as marine survival.

Current viability of Klickitat River Spring Chinook is assessed by analyzing stock recruitment rates and effective population size estimates observed from 1984 – 2003. A preliminary biological significance assessment is included in this section that was conducted using generic questionnaires provided by the HSRG and a genetic study conducted by WDFW in the early 1990's.

1.1 Current Capacity and Intrinsic Productivity Estimates of the Klickitat Indigenous Stock

This section provides an initial assessment of the Klickitat's current carrying capacity and intrinsic productivity for Spring Chinook natural production as it relates to the quantity and quality of available habitat. In a biological sense, carrying capacity can be defined in many ways and is often unclearly stated in its referenced sense. For this analysis, carrying capacity is expressed as adults with respect to environmental conditions affecting survival throughout the entire lifecycle. Carrying capacity and intrinsic productivity calculations are based on two parameters for the assessment: 1.) Spawner-recruitment relationships for brood era 1984-1999 where intrinsic productivity and carrying capacity for Spring Chinook were estimated using the Beverton-Holt production model. 2.) Productivity and capacity estimates from this analysis are limited to habitat below Castile Falls due to a non-functioning fish ladder blocking passage during this brood era. Recruitment curves were constructed using annual spawner escapement and estimated wild returns by brood year (Table 1). The number of annual natural spawners were estimated from weekly redd surveys in index reaches and modified with expansion factors. Total recruitment for each brood year was calculated by summing wild returns across all age classes including fish harvested in both tribal and sport fisheries. Annual age structures were calculated by expanding age class proportions from scale samples taken during spawning and carcass recovery surveys.

Table 1. Estimated number of Natural spawners and total returns for brood years 1984-1999.

Brood Year	Natural Spawners	Estimated Wild Returns Age-3	Age-4	Age-5	Age-6	Total	R:S
1984	110	29	782	65	6	882	8.02
1985	95	117	381	504	1	1003	10.56
1986	175	43	216	155	4	418	2.39
1987	367	112	303	176	12	603	1.64
1988	1158	76	334	387	3	800	0.69
1989	393	44	318	105	5	472	1.20
1990	231	9	19	25	2	55	0.24
1991	245	10	61	38	4	113	0.46
1992	322	35	334	294	23	686	2.13
1993	432	37	479	145	0	661	1.53
1994	102	22	137	42	0	201	1.97
1995	105	64	108	105	4	281	2.68
1996	290	115	1002	276	0	1393	4.80
1997	599	157	250	118	0	525	0.88
1998	288	198	1069	603	0	1870	6.49
1999	213	355	1394	294	0[1]	2043	9.59

The Beverton-Holt stock recruitment function used to estimate the intrinsic productivity and capacity for Klickitat Spring Chinook can be defined by the following equation:

(Equation 1) $$R = (\alpha S/ (1+\alpha S/\beta))$$

Where:
R = number of recruits (adults + jacks)
S = number of spawners (adults + jacks)
α = intrinsic productivity of the stock
β = carrying capacity of the stock

Total recruitment of age 3, 4, 5 and 6 year old Spring Chinook were plotted against the number of wild spawners for the relevant brood year (Figure 1). The data points suggest no evident relationship between the number of recruits to spawners when considering all brood years together. Recognizing the dynamic and stochastic nature of ecosystems (particularly marine survival variation), the results of this modeling exercise are not surprising. However, when taking a closer look, brood years can be partitioned into three separate clusters, potentially owing differences in recruitment rates to density independent factors such as marine survival. D. Rawding (2004) suggests density dependence occurring in the freshwater lifestage, with marine survival considered a density independent factor driven by the environment. Following this logic, overall carrying capacity and intrinsic productivity for Klickitat Spring Chinook could vary

[1] Age 6 spawner escapement numbers pending 2005 survey

substantially as a function of marine survival. Assuming static conditions in the freshwater environment, recruitment relationships for Klickitat Spring Chinook arguably support this hypothesis (illustrated in Figure 1).

Ocean productivity for salmon populations have been shown to experience periods of high and low productivity correlated to the Pacific Decadal Oscillations. Hare and Francis (1994) used intervention analysis to show large scale shifts in ocean productivity for several Alaska salmon stocks. These large scale interventions occurred roughly 25-30 years apart, a much larger time scale than the time series used for this analysis. Hare and Francis (1994) also hypothesized smaller scale variability about some mean during the 25-30 year climatic regime. Applying this hypothesis, partitioned brood years illustrated in Figure 1 exhibit three distinct recruitment relationships during the 16 year time period. 1.) Favorable ocean conditions or highly productive years are represented by brood years 84-85, 96 and 98-99. This is a reasonable assumption when considering the overall returns of Columbia River stocks between 2000 and 2004. 2.) A short period of poor ocean conditions or low productivity occurring for brood years 90-91. For these two particular brood years, Yakima basin Spring Chinook also experienced the lowest recruitment rates recorded since 1982 (0.4 recruits/spawner and 0.18 recruits/spawner). 3.) Brood years 86-89, 92-95 and 1997, which represent the majority, (9 out 16 years), adhere to a density dependent Beverton-Holt function intermediate of the highly productive and poorly productive brood years (Figure 1) and possibly represent periods

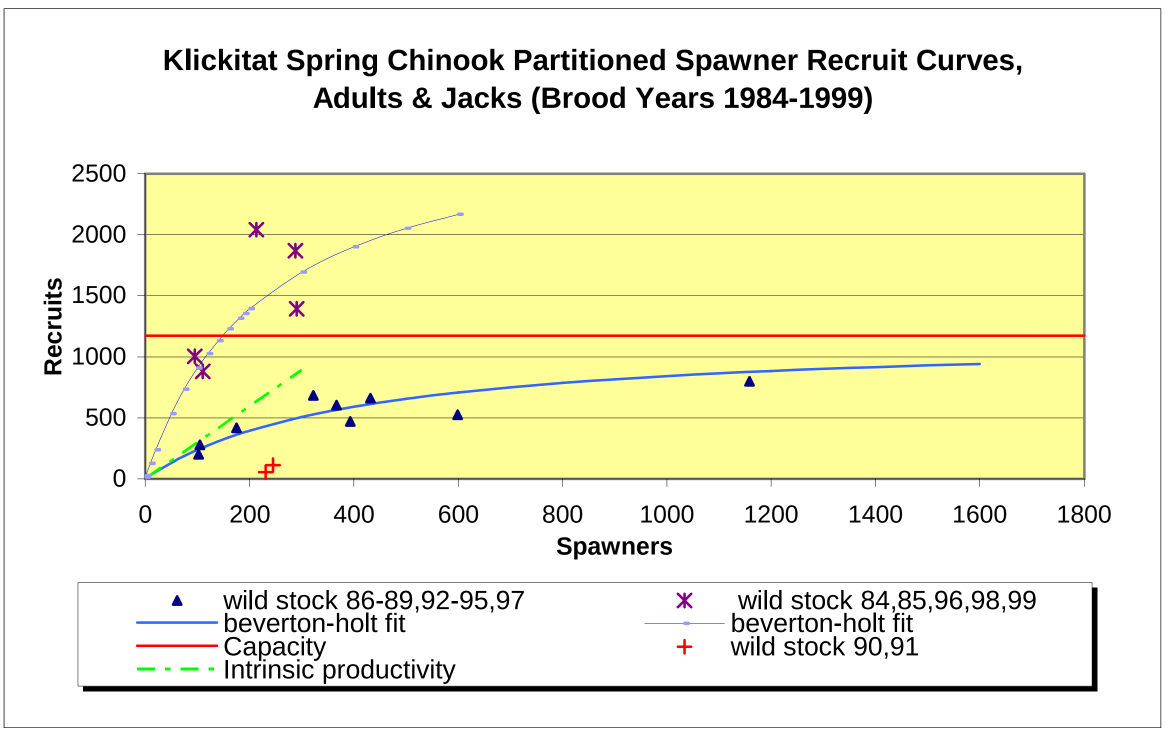

Figure 1. Beverton-Holt recruitment relationship fit to Klickitat Spring Chinook data points: brood years 1984-1999.

where average marine survival were experienced during the brood era from 1984-1999. Another observation worth noting in this analysis is the transition between high, medium and low productive brood years. Ocean productivity has been documented to have consecutive periods transitioning from higher to lower productivity (Mantua et al. 1997). Not only do partitioned consecutive brood years fit the same production function representing high, medium or low ocean productivity, there also exists a transition throughout the entire brood era 1984-1999. In a qualitative sense, this transition begins with high ocean productivity for brood years 1984 and 1985 followed by a period of moderate ocean productivity for brood years 86-89. Minimum productivity occurred for brood years 1990 and 1991 followed by another moderate period of productivity for brood 92-95. The last consecutive brood years (96-99) experienced highly productive ocean conditions, with the exception of brood year 1997[2].

Recognizing the correlation between marine survival and productivity for anadromous fish stocks, assessing a stock's carrying capacity and intrinsic productivity should not be limited to the most recent brood years that experienced highly productive marine conditions. This would be rather imprudent for management planning purposes. For this reason only, brood years 86-89, 92-95 and 1997 representing average conditions in terms of productivity for the available time era, were used to estimate the carrying capacity and intrinsic productivity of Klickitat Spring Chinook. A trendline modeled by the density dependent Beverton-Holt production function (equation 1) was fit to the series of brood year recruitment data points. Linear regression analysis was first used for two purposes: 1.) It allows us to correlate a statistical relationship between spawners and recruits with linear equations and trendlines. 2.) It creates a template representing the best possible trendline fit to model capacity and productivity against using Beverton-Holt recruitment functions. Establishing a linear relationship between the spawner and recruitment numbers for designated brood years was done by dividing the number of spawners and recruits into one (Table 2).

Table 2. Spawner and recruitment numbers by brood year divided into 1 for linear regression analysis.

Brood Year	Spawners	Recruits	1/S	1/R
1986	175	418	0.005714	0.002392
1987	367	603	0.002725	0.001659
1988	1158	800	0.000864	0.00125
1989	393	472	0.002545	0.002119
1992	322	686	0.003106	0.001457
1993	432	661	0.002315	0.001513
1994	102	201	0.009804	0.004977
1995	105	281	0.009524	0.003559
1997	599	525	0.001669	0.001904

[2] 1997 was a highly productive brood year for many Columbia River stocks despite the average returns for Klickitat Spring Chinook.

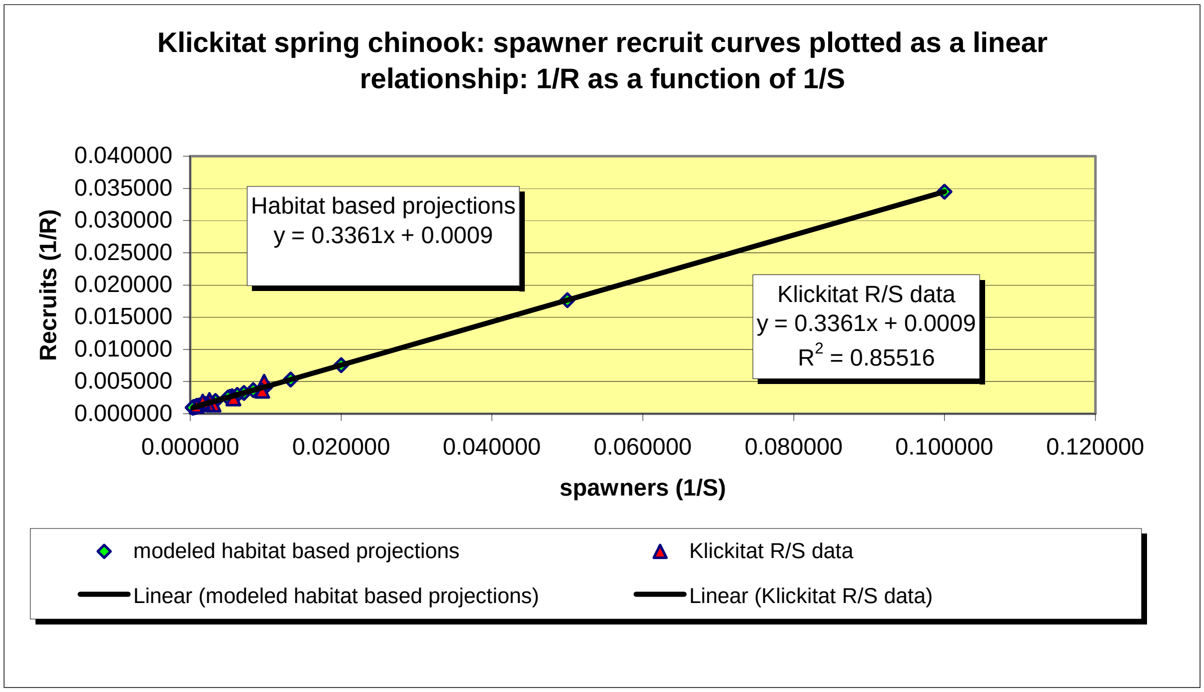

Figure 2. Recruits (adults + jacks) plotted as 1/R to spawners 1/S with linear regression for Klickitat data points and modeled projections fit to a common trendline and regression equation.

By plotting spawners on the X-axis and recruits as a function of spawners on the Y-axis, a linear regressed trendline could be fit to the data points, resulting in an R^2 value of 0.85516 and a regression equation of y = 0.3361x + 0.0009 (Figure 2). This trendline and regression equation represents the most accurate spawner/recruitment relationship fit to the Klickitat Spring Chinook brood years 86-89, 92-95, 97. Modeled results derived from the Beverton holt production function in the form of recruits and spawners can also be converted to a linear relationship (Table 3). Capacity and productivity could then be adjusted until the modeled trendline of 1/R as a function of 1/S traced identically over the trendline fit to the linear regressed brood year data points. A precise tracing could be refined by adjusting the modeled capacity and productivity values until the modeled regression equation corresponded to the regression equation for the brood year data points. Because capacity and productivity values adjust different variables of the regression equation, only one combination of productivity and capacity results in a modeled regression equation identical to the one fit to brood year data (Figure 2). The adjusted values resulting in a identical regression equation are 1,175 for capacity and 2.975 for intrinsic productivity.

Table 3. Modeled results of a density dependent relationship between recruits and spawners using the Beverton-Holt production function with spawners and recruits converted for linear regression.

Spawners	Recruits	Capacity	Productivity	1/S	1/R
1	3	1175	2.975	1.000000	0.336986
2	6	1175	2.975	0.500000	0.168918
10	29	1175	2.975	0.100000	0.034465
20	57	1175	2.975	0.050000	0.017658
50	132	1175	2.975	0.020000	0.007574
75	188	1175	2.975	0.013333	0.005333
100	237	1175	2.975	0.010000	0.004212
120	274	1175	2.975	0.008333	0.003652
140	308	1175	2.975	0.007143	0.003252
160	339	1175	2.975	0.006250	0.002952
180	368	1175	2.975	0.005556	0.002718
190	382	1175	2.975	0.005263	0.002620
200	395	1175	2.975	0.005000	0.002532
300	507	1175	2.975	0.003333	0.001972
400	591	1175	2.975	0.002500	0.001691
500	656	1175	2.975	0.002000	0.001523
600	709	1175	2.975	0.001667	0.001411
700	751	1175	2.975	0.001429	0.001331
800	787	1175	2.975	0.001250	0.001271
900	817	1175	2.975	0.001111	0.001225

Because the trendlines and regression equations are identical for brood year data and modeled data, the R^2 value for the brood year data is also pertinent to the modeled capacity and productivity. Therefore, capacity and productivity estimates of 1175 and 2.975 have a correlation coefficient = 0.92475 and an R^2 value of 0.85516 relative to the actual data points for brood years experiencing average[3] productivity for the time series analyzed.

[3] Average marine survival for analyzed brood era defined on page 6-7

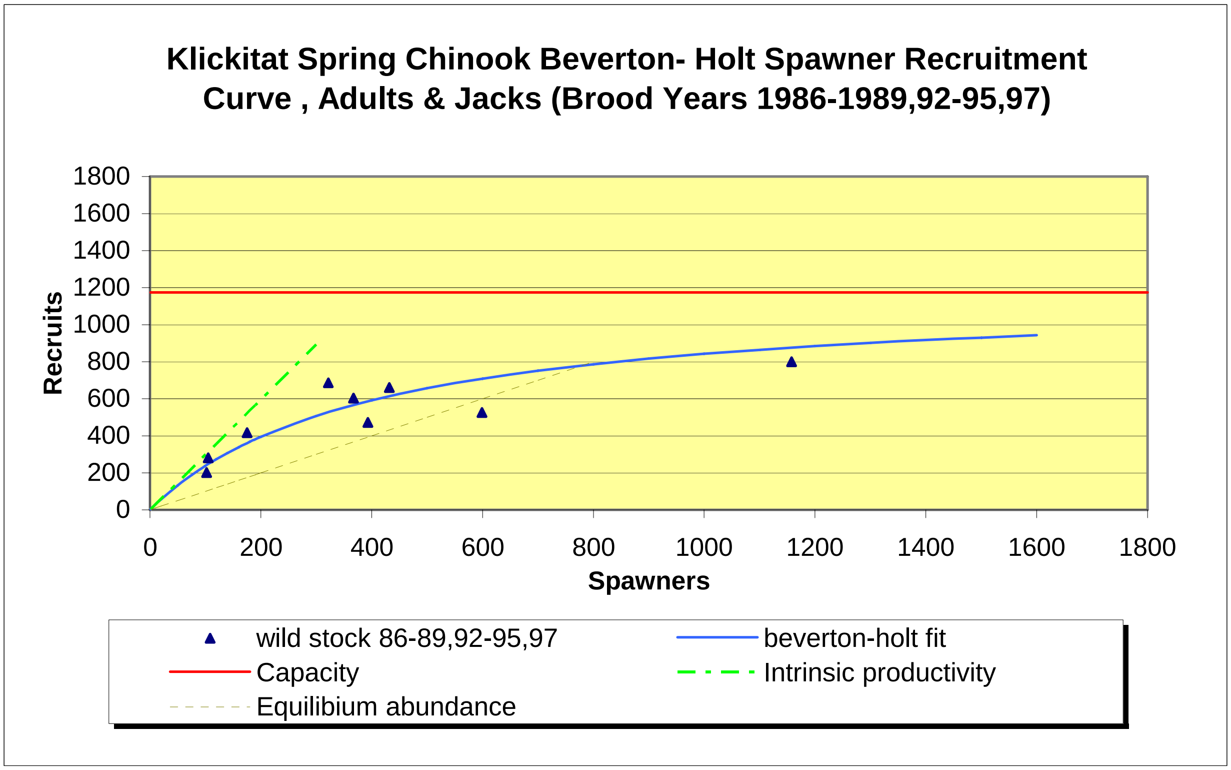

Figure 3. Beverton-Holt Stock recruitment relationship fit to Klickitat Spring Chinook data points: brood years 1986-89, 92-95, 97.

1.2 Viability of Klickitat River Spring Chinook

Viability of an anadromous salmonid population can be defined as the ability of the population to sustain itself over multiple generations while encountering environmental adversity in either fresh or saltwater portions of a populations life history. HSRG 2004 points to two independent factors affecting the viability of a population: 1) the habitat or environmental conditions encountered by individuals of a population throughout their life cycle and 2) the intrinsic genetic characteristics or fitness of the population. In terms of the former, habitat and environmental conditions dictate the quality and quantity of habitat available to a population. It is these factors that drive a populations intrinsic productivity.

Intrinsic productivity also represents the ability of the population to withstand environmental variation and rebound from poor environmental conditions that caused low spawner escapement numbers. McEelhany 2000 states that, "If a population can be demonstrated to have an intrinsic productivity substantially above one, the actual abundance of the population becomes much less relevant. A resilient population will likely be viable, even if it is very small." When considering the lowest spawner escapement years observed in the Klickitat (brood years 84-85 and 94-95), spawner recruitment relationships (Table 1) point to the populations resiliency and ability to rebound from such low numbers. When modeled, these brood years fit with two different Beverton-Holt models. The 1984-85 brood years fit to a model resulting in an intrinsic productivity roughly equal to 14. All brood years fitting this same trendline experienced favorable marine conditions. Brood years 1994-95 fit a Beverton-Holt model with an intrinsic productivity value of 2.975. This particular model fit a majority of brood year spawner recruitment relationships which seem to represent the average environmental and marine conditions when considering the entire brood era analyzed (84-99).

Along with this interpretation is a cautionary note: low returning numbers of Spring Chinook observed in 1994-95 were a result of either poor freshwater rearing conditions and/or marine survival for fish derived primarily from brood years 90 and 91. These years displayed the poorest recruitment rates (Table 1) for Klickitat Spring Chinook over the brood era 1984-99. When modeled, these brood years did not fit with any other data points and possess a significantly lower intrinsic productivity value that approaches 1. Aside from density dependent factors, environmental conditions experienced by these brood years represent the harsh end of the spectrum resulting in unusually low return numbers. Observations arguably suggest poor ocean conditions may have been responsible for such below normal recruitment rates instead of freshwater rearing conditions. Which ever the culprit is not the point. In the face of environmental adversity, the overall intrinsic productivity, when considering the complete life history of a population, can, and will fluctuate as a function of the environmental conditions. If poor environmental conditions experienced by Klickitat Spring Chinook derived from 90-91 brood years extended over multiple generations, the ability of this population to rebound from low numbers would be drawn into question.

With respect to the viability of a population in terms of its intrinsic genetic characteristics and fitness, the estimated effective population (Ne) size can be used to generically assess the genetic diversity within a population. Effective population size places an upper limit on the amount of genetic diversity that can be maintained in a population in relation to its pedigree history and potential losses due to genetic drift (HSRG April 2004). The guidelines outlined by the HSRG for minimum effective population sizes are:

- $N_e > 50$ to prevent inbreeding depression and a detectable decrease in viability or reproductive fitness of a population (Franklin 1980)

- $N_e > 500$ to maintain constant genetic variance in a population resulting from a balance between loss of variance due to genetic drift and the increase in variance due to spontaneous mutations (Franklin 1980; Soule 1980; Lande 1988)

- $N_e > 5{,}000$ to maintain a constant variance for quasi-neutral, genetic variation that can serve as a reservoir for future adaptations in response to natural selection and changing environmental conditions (Lande 1995)

The effective population size (N_e) of an entire population is approximately the harmonic mean of the effective number of breeders per year (N_b), multiplied by the generation time in years (g) (Waples 1990). The effective number of breeders in a given year has been shown to be substantially less than the observed number of spawners (N_c), ranging from $0.1N_c$ to $0.33N_c$ (Waples 2004). Based on previous work done by Ardren and Kapuscinski 2003, the HSRG recommends using the upper limit value of 0.33 multiplied by N_c for an estimate of the effective numbers of breeders per year. Calculations for the effective number of Klickitat Spring Chinook spawners are presented in Table 4 below.

Table 4. Calculations for estimated number of annual effective spawners for brood years 1984-1999.

Brood Year	Estimated Spawners (N_c)	# Effective Breeders ($N_b = 0.33N_c$)
1984	110	36
1985	95	31
1986	175	58
1987	367	121
1988	1158	382
1989	393	130
1990	231	76
1991	245	81
1992	322	106
1993	432	143
1994	102	34
1995	105	35
1996	290	96
1997	599	198
1998	288	95
1999	213	70
2000	516	170
2001	312	103
2002	898	296
2003	1142	377

Taking the harmonic mean of the effective number of breeders (Table 4) results in a value of 74. Generation time is defined by the average age of the spawners at the time of reproduction. The average age was calculated using the age classes presented in Table 1. When averaged together, the proportion of age classes for three, four, five and six year old Spring Chinook are 12.4%, 56.2%, 30.3% and 1.1%, respectively[4]. Using these proportions of each age class, the weighted average age of spawners was calculated. This number, equivalent to 4.20, represents the generation time (g) in years. Effective population size is the product of this number (4.20) and the harmonic mean (74). The equations used in this analysis indicate the effective population size influencing the

[4] Age 2 mini jacks not included in overall age structure, no estimate of spawning numbers exist

genetic diversity of the Klickitat Spring Chinook population from brood years 1984-2003 is about 326.

When considering the estimated effective size of the Klickitat Spring Chinook spawning population (326), it would appear that this stock is at risk of losing constant genetic variance due to genetic drift. In theory, an effective population size (Ne) of 500 is needed to maintain this genetic variance (Franklin 1980; Soule 1980; Lande 1988). Because of this, the Klickitat Spring Chinook population may not meet one of two criteria for a long term, self sustaining viable population.

1.3 Biological Significance of Klickitat River Spring Chinook

The biological significance of a stock is a function of the origin of the stock and its inherent genetic diversity, its biological attributes, uniqueness, local adaptation, and the genetic structure of this population relative to other con-specific populations. A population can be considered highly significant if it exhibits unique genetic and biological attributes that are not shared with other adjacent stocks. These attributes may include unique life history, physiology, morphology, behavior, and disease resistance characteristics with a genetic basis (HSRG 2004).

Bearing in mind all of the above listed attributes, assessing the biological significance of a stock can be a challenging task from a scientific perspective. We use criteria outlined by the HSRG designed to assess the biological significance of Puget sound and coastal region stocks. The criteria are based on a scoring system derived from a series of questions specific to the demographic and genetic characteristics of the population. Questions for the biological significance assessment are listed below.

Each population or stock was assigned a total score ranging from 5 to 17 according to the following scoring system.

1) What is the genetic origin of the population or stock? (possible scores = 1–5)

- a) Native population. Score = 5.
- b) Genetically admixed population between native and introduced populations.
  - i) > 50% native genes? Score = 4.
  - ii) < 50% native genes? Score = 3.
- c) Reintroduced population: species occurred historically in watershed, was extirpated, but stock transfers re-established species in watershed.Score = 2.
- d) Introduced population: species was historically absent from watershed. Score = 1.

2) How unique are the biological characters (e.g., life history, physiology, morphology, behavior, disease resistance, etc.) of the stock and to what extent are they considered irreplaceable attributes? (possible scores = 1–5)

- a) Population has unique, irreplaceable biological attributes that are not shared with other stocks/populations within the same Genetic Diversity.Unit (GDU)[1] or with other GDUs within western Washington. Score = 5.
- b) Population has no unique biological attributes, but shares some unique attributes with other stocks/populations within the GDU not shared with other GDUs. Score = 3.
- c) Population has no unique biological attributes that are not shared with other stocks/populations in other GDUs. Score = 1.

3) To what extent is the population or stock part of a larger subdivided population structure or metapopulation? (possible scores = 3–7)

- a) Number of distinct spawning aggregations (e.g. tributaries) within the stock or population under consideration
  - i) Number of spawning aggregations < 5. Score =2.
  - ii) Number of spawning aggregations > 5. Score = 1.
- b) Total number of populations or stocks within the GDU.
  - i) Number of populations/stocks within GDU < 3. Score = 2.
  - ii) Number of populations/stocks within GDU > 3. Score =1.

c) What is the viability of other populations or stocks within the same GDU (see Box 2)?
i) Mean viability = "high.".= Score = 1.
ii) Mean viability = "medium." Score = 2.
iii) Mean viability = "low." Score = 3.

Sum of scores and ratings to assess the biological significance of a population or stock:
14-17: Biological significance = High.
9-13: Biological significance = Medium.
5-8: Biological significance = Low.

1 The Washington Department of Fish and Wildlife defines a GDU as follows: A genetic diversity unit (GDU) is a group of genetically similar stocks that is genetically distinct from other groups. The
Stocks typically exhibit similar life histories and occupy ecologically, geographically, and geologically similar habitats. A GDU may consist of a single stock (Busack and Shaklee 1995).

Using the recognized demographic characteristics and previous genetic work of Klickitat Spring Chinook, results from the questionnaire for assessing the Biological significance of Klickitat River Spring Chinook are summarized below.

1) What is the genetic origin of the population or stock?
(possible scores = 1–5)

a) Native population. Score = 5.

Klickitat River Spring Chinook are the native, indigenous stock

2) How unique are the biological characteristics (e.g., life history, physiology, morphology, behavior, disease resistance, etc.) of the stock and to what extent are they considered irreplaceable attributes?
(possible scores = 1–5)

a) Population has unique, irreplaceable biological attributes that are not shared with other stocks/populations within the same Genetic Diversity Unit (GDU)1 or with other GDUs within western Washington. Score = 5.

*Several biological characteristics of the Klickitat Spring Chinook support this index score of 5; 1.) Klickitat Spring Chinook display a complex age structure with 3,4,5 and 6 year old fish contributing to the spawning aggregate. More importantly though, genetic work done with Klickitat Spring Chinook also point to unique, biological attributes possessed by the stock as indicated by this quote, "We observed the sAH*69, sIDHP-2*83, LDH-B2*112, LDH-C*84, and sMDH-B1,2*126 alleles in one or more Klickitat Spring Chinook samples, which are rare or uncommon alleles, relative to known allelic diversity in Washington Chinook populations" (WDFW Genetic Analysis draft report, May 2000).*

3) To what extent is the population or stock part of a larger subdivided population structure or metapopulation? (possible scores = 3–7)

a) Number of distinct spawning aggregations (e.g. tributaries) within the stock or population under consideration

i) Number of spawning aggregations < 5. Score =2.

Klickitat River Spring Chinook spawn exclusively in the mainstem (no tributary spawners) below Castile Falls with limited spawning below the Big Muddy confluence. There is most certainly less than 5 spawning aggregations.

Part b and c of question 3 are difficult to answer because the number of populations/ stocks and their viability status within the same GDU are not known at this time. However, even with this uncertainty, the biological significance assessment indicate a high level of biological significance associated with Klickitat Spring Chinook which require a score between 14-17. When summing the total score with minimal values for questions 3b and 3c (values of 1 and 1 respectively), the total score has a minimum equivalency of 14 (question 1 = 5, question 2 = 5, question 3a = 2, 3b = 1, 3c = 1). This assessment suggest Klickitat River Spring Chinook are of high biological significance regardless of a final score of 14 or 16.

2. Klickitat Spring Chinook Artificial Production

Overview of proposed actions

The Master Plan proposes a long term transition of the current program using hatchery origin stock to an integrated program releasing 800,000 smolts derived from at least one natural origin parent (MP 2.2.1). In addition to this integration strategy, another proposal for an integrated hatchery strategy using a 200,000 smolt release while maintaining a segregated program with 600,000 on station releases is outlined below.

An integrated hatchery program consisting of roughly 125 adults for 100% wild broodstock. Smolts from this brood source will be released from acclimation sites above Castile Falls. Adults retained for this broodstock will consist entirely of natural origin fish, trapped near the mouth of the Klickitat at Lyle Falls. One of the primary purposes of acclimating smolts above Castile Falls is to reseed habitat and increase overall natural production. Returning adults from these acclimated smolt releases will also be expected to spawn with Spring Chinook below Castile Falls due to the close proximity of one acclimation site to the existing spawning distribution. A segregated hatchery program continuing on station releases of 600,000 smolts from the Klickitat Hatchery would continue. Hatchery fish from this stock will be used for broodstock, interactions with the wild population will be kept to a minimum. One of the objectives of the segregated hatchery program is to provide harvest opportunities for treaty and sport fishermen.

2.1 Integrated Spring Chinook hatchery program

The overall goal for Klickitat River Spring Chinook is to increase annual returns as indicated in section 2.2.1 of the Master Plan. Objectives under this goal differ among two proposed artificial production programs with the intended purpose of increasing natural production for the integrated hatchery program. The current status of wild Klickitat Spring Chinook in conjunction with habitat conditions were fundamental components in the development of the proposed integrated program. Biological objectives of the integrated program adhere to the scientific principles and adaptive management policy under the Yakima Klickitat Fishery Project which are to:

- Enhance existing stocks of anadromous fish in the Yakima and Klickitat river basins, while maintaining genetic and ecological resources.
- Reintroduce stocks formerly present in the basins.
- Apply the knowledge gained from supplementation throughout the Columbia River Basin.

With the exception of Objective SC2, Spring Chinook objectives outlined in the Master Plan apply to the integrated hatchery program (section 2.2.1 MP). Rigorous monitoring of the population performance and freshwater habitat capacity under these objectives and strategies will guide adaptive management decisions through time. Other important biological objectives for the Spring Chinook integrated program include:

1.) Reseed habitat above Castile Falls using acclimated smolt releases derived from a wild brood source with the purpose of increasing natural production, spatial distribution and diversity of spawning aggregate.

2.) Increase the effective population size of the wild stock from roughly 326 (1984-2003 brood years, section 1.2) to a minimum of 500 to maintain constant genetic variance.

3.) Minimize genetic divergence between wild and hatchery spawning aggregates.

2.1.1 Rationale of Integrated Spring Chinook Hatchery Program

If not already clearly stated, recent passage improvements at Castile Falls will open some of the best available habitat in the Klickitat for spawning and rearing Spring Chinook in spite of intermittent areas of habitat degradation. Before passage improvements, natural production in the upper Klickitat basin was virtually non existent. In 1998, 3% of all wild Spring Chinook redds were counted in areas above the falls. Other than 1998, natural production and migrating fish attempting to negotiate the falls have not been documented in the upper basin since the initial passage improvements failed some time ago. Adults returning from acclimated smolt releases derived from wild brood will serve to reseed the available habitat above Castile Falls and increase the spawning number of fish below the falls as well.

One of the most important parameters affecting genetic diversity is effective population size (HSRG 2005). Franklin et al 1980 suggest a minimum effective population size of 500 is needed to maintain constant genetic variance in a population. An average effective population size of 326 for Klickitat Spring Chinook was estimated (section 1.2, p. 13) using spawner escapement numbers from 1984-2003 (Table 4). By reseeding habitat above Castile Falls and allowing returning adults to spawn with the existing population, the integrated hatchery program intends to increase and maintain above the minimum effective population size of 500.

Using the guidelines outlined by the HSRG, a preliminary analysis suggests Klickitat river Spring Chinook are of high biological significance. The inherent genetic diversity is one of several components influencing the biological significance of a stock. Selective responses of a population to a changing or dynamic environment are a function of the inherited genetic predisposition. Conserving a natural populations genetic resources can be accomplished via an integrated hatchery program where natural origin fish are infused into the broodstock. For the Klickitat Spring Chinook integrated program, 100% of the brood would consist of natural origin fish not only to conserve genetic resources but to prevent genetic divergence between the hatchery and natural environment. This is of special importance since the integrated hatchery origin returns will be designated for the spawning grounds. The suggested guidelines by the HSRG for initiating an integrated hatchery program are based on a declining or imperiled stock of high biological significance. Klickitat Spring Chinook recent trends in abundance don't necessary support a status quo of declining abundance or an imperiled stock. Nevertheless, in times of poor ocean productivity, Klickitat Spring Chinook spawner recruitment relationships drop well below a value of 1 resulting in spawner escapement numbers of 105 or less (Table 1). When considering the population size and the habitat capacity of the Klickitat, extended periods of poor ocean productivity have the potential to decrease the effective population size below threshold values of 50 that may result in a decrease in viability or reproductive fitness (Franklin 1980).

2.1.2 Utilization of HSRG Recommended Operating Guidelines for the Klickitat Spring Chinook Integrated Program

In development of the integration program, operating guidelines recommended by the HSRG were used in conjunction with the current state of habitat conditions and stock performance to size the initial program. A detailed review of the guidelines can be found at the following website http://www.lltk.org/HRP.html within the literature provided. When adhering to these guidelines, limitations to the program are directly influenced by productivity and capacity of the natural environment along with harvest rates on the natural population. From an agencies management perspective, one must also have the ability to control the hatchery environment's influence on the genetic makeup and adaptation of the composite population (HSRG 2005). The following guidelines assisted in the development of the Spring Chinook integrated hatchery program:

1. The targeted value of pNOB/(pHOS+pNOB) should be based upon the current status of the stock, the goals for the stock, and involves a benefit versus risk judgment. For any fixed pNOB, the smaller the pHOS, the stronger the selective forces for the natural environment.

2. The proportion of natural-origin fish in the broodstock must exceed the proportion of hatchery-origin fish on the spawning grounds (pNOB > pHOS) for the natural environment to drive adaptation, which is equivalent to pNOB/(pHOS+pNOB) > 0.50.

3. pNOB/(pHOS+pNOB) for integrated programs with stocks of moderate or high biological significance and viability (or goals to maintain or improve the biological significance and viability of the stock) should be greater than 0.7 to ensure high levels of natural dominance.

4. pNOB should be a minimum of 10% to avoid divergence of the hatchery population from the natural component, even when pHOS is zero.

5. A general rule of thumb is that the total number of adults (hatchery- and natural-origin) used for broodstock cannot exceed the total number of natural-origin escapement.

6. The size of the program should take into account the quantity and quality of habitat available for juveniles and adult spawners, and the effect of the hatchery program on natural stocks.

2.1.3 Use of the AHA Model For Planning Stages of the Klickitat Spring Chinook Integrated Hatchery Program

The success or failure of an integrated hatchery program hinges upon the complex synergistic relationships of the freshwater habitat conditions, marine survival, status and viability of the stock, size of the hatchery program and exploitation rate. Attempting to jointly evaluate these parameters in a scientific context is a most challenging task without the support of a quantifying tool. Because of this, the AHA model was used to *assist* the development of the integrated hatchery program while adhering to the HSRG principles and guidelines. The AHA model is the only available tool that attempts to evaluate the 4H's synergistically, and over multiple generations with fluctuating marine survival. Use of this model allows an individual to explore the simplistic relationships between various strategies of hatchery programs with regards to the other "H" parameters. In our particular case, the most appealing feature of the AHA model is its ability to model the limitations and consequences of an integrated program with respect to natural production and habitat capacity, while considering the expected harvest rates on both hatchery and wild fish. Recognizing the crude nature of point estimate input parameters such as intrinsic productivity, capacity and exploitation rate, quantitative analysis from the model should be used with caution. Interpretations derived from the model should serve as a working hypothesis of the integrated relationships of the 4 H's. The model is not designed to produce outputs that would dictate strict quantitative goals and objectives for management practices.

3. AHA Modeling: Hatchery Strategies and Scenarios

Application of the AHA model version 3.22 for Klickitat River Spring Chinook consisted of exploring the consequences and benefits associated with a variety of scaled integration programs. The Master Plan proposes a long term transition of the current segregated program to an integrated program for an 800,000 smolt release. The plan also proposes an immediate 200,000 smolt release program using 100% natural broodstock serving multiple purposes (refer to section 2.1). Different integration strategies were modeled ranging in magnitude from 2, 4, 6, and 800,000 smolt releases. Two integration hatchery strategies will be presented in this document including the proposed long-term 800,000 smolt program and the proposed immediate 200,000 smolt release program. These strategies also include several modeling scenarios with the purpose of investigating altered proportions of natural broodstock and their effect on threshold values outlined in the HSRG guidelines (section 2.1.4). A brief overview of the two modeled strategies are summarized below :

1.) Transition current segregated hatchery practices to an integrated program as outlined in the master plan. This entailed modeling an integrated program with 800,000 smolt releases using different proportions of natural broodstock, and with both current and selective fishery harvest regimes. Multiple hatchery recruitment rates were modeled for each scenario

2.) A scaled back integration program with a release number of 200,000 smolts. Current harvest rates and selective harvest rates were also included in this analysis. Multiple hatchery recruitment rates were modeled for each scenario

Modeling different values of hatchery recruitment rates for both strategies was an essential component in this analysis. This parameter has a high level of uncertainty for nonexistent programs and most certainly influences the likelihood of success or failure of the program. The parameter is simplistic by nature but yet it captures so many complex, unknown variables. In the AHA model, this parameter is a point estimate that represents the expected or observed mean recruitment rate over time. While the annual hatchery recruitment rate varies in the model by following the same oscillation of marine survival experienced by wild fish, the input value represents the mean. As a result, point estimates limit the upper and lower bound possibilities of randomly generated SARs relative to hatchery recruitment rates throughout generational computations. Results from the modeled scenarios considered the long term impacts to the productivity and abundance of natural production and the consistency of remaining within the HSRG operational guidelines.

3.1 AHA Data Input Parameters

The AHA model incorporates a broad range of data parameters with regards to the 4 “H’s” including habitat, hydro survival, harvest and hatcheries. Some parameters are straight forward with ease of estimation while others can be quite cumbersome with some level of uncertainty, regardless of data sources. Integration of the 4 H’s and the parameters associated with them give the AHA model versatility. Because of its versatility, one must determine their intended use of the model and parameters most affecting their diagnosis. Listed below is some background of the data sources and their use in the model. All other AHA input parameters not listed here can be viewed in appendix A.

3.1.1 Habitat Parameters

The Beverton-Holt production model is the underpinning function used for all natural production algorithms in the AHA model. Any AHA analysis involving habitat interactions requires an estimate of the populations capacity and intrinsic productivity as it relates to the environment for the complete life history/cycle. Estimates are not explicit for freshwater habitat but also include out of basin factors affecting survival. The problem with this, when considering the entire life cycle, is the amount of variation in a population's intrinsic productivity and capacity that is a function of outmigration and marine survival. A future improvement in the model would be segregation of freshwater capacity and productivity from the hydro and marine survival parameters. Estimates of the parameter would be much easier with subbasin smolt productions estimates and would have a much higher level of certainty. This modeling exercise required several estimates of capacity and intrinsic productivity for multiple scenarios. 1.) Estimates for current habitat conditions. 2.) Estimates for unseeded habitat above Castile Falls. 3.) The combined estimate of both 1 and 2 representing the capacity and productivity of Klickitat Spring Chinook when distributed above and below the falls.

Estimates of Current Capacity and Intrinsic Productivity

Estimating the parameters for the current conditions (or habitat below Castile) was extremely important because of its useful insight of the models behavior and accuracy. Capacity and intrinsic productivity estimates for current conditions used Beverton-Holt production calculations derived from Klickitat Spring Chinook observed spawner/ recruitment relationships (see section 1, Figure 1). Recruitment estimates used in the Beverton-Holt functions represent total recruitment, including all estimated harvested fish. Several different recruitment rates and capacity estimates emerged from this analysis, from differences in environmental conditions experienced by the fish, particularly ocean survival. As indicated in section 1, there seems to be three distinct spawner/ recruitment curves with high, medium and low rates of intrinsic productivity and capacity. A majority of the brood years fit to the one curve representing the middle of the range when considering the three distinct relationships. To some degree, this curve represents the average environmental conditions experienced by the combined brood years of 1984-1999. The recruitment curve produced a capacity estimate of 1175 adults and jacks, an intrinsic productivity estimate of 2.975, and a correlation coefficient of roughly 0.925. These are the capacity and intrinsic productivity estimates used for the current conditions and one of two components for estimating the overall Spring Chinook capacity and productivity for the entire life cycle.

Estimates of Capacity and Intrinsic Productivity Above Castile Falls

Due to the fact that natural production is virtually nonexistent above Castile Falls, estimating these parameters could not rely upon actual spawner/recruitment data. The EDT model was used to estimate the capacity and productivity above the Falls. An estimate for the habitat above Castile Falls was important since a major objective of the integrated program is to reseed this area after recent passage improvements. Results from the EDT analysis are presented below in Table 5.

Table 5. EDT estimates of capactiy and intrinsic productivity above Castile Falls.

Population	Scenario	Diversity index	Productivity	Capacity	Abundance
Upper Klickitat Spring Chinook	Current without harvest	84%	5.9	672	559
	Current with harvest	79%	3.3	378	264
	Historic potential	93%	10.7	964	874

Results from this analysis reflect the current potential of the upper Klickitat watershed for Spring Chinook production. Areas directly above Castile Falls represent some of the best spawning and rearing habitat for Spring Chinook in the Klickitat watershed. Channel complexity in the form of low gradient, anastomosing stream segments with high wood densities are typical. In contrast, there exist intermittent areas with habitat degradation from historic and current land uses, as indicated by the historical potential of the EDT analysis. Current, ongoing habitat projects through Yakama Nation Fisheries (Klickitat Watershed Enhancement Project, BPA # 1997-056-00) are addressing these concerns in the upper Klickitat.

Combining Capacity and Intrinsic Productivity Estimates for the Entire Basin

Integration of the two individual estimates of capacity and productivity (above and below Castile Falls) for an overall basin estimate was used for the modeled strategies and scenarios presented in this document. These habitat parameters are major drivers in the AHA model, and are most important when exploring model responses and relationships between the habitat and an integrated hatchery program. Combining the intrinsic productivity of the two estimates can be problematic. An uncomplicated approach would be a simple average of the two. But realistically, there exists the possibility of density dependent relationships not easily accounted for. A conservative estimate of 3.5 for intrinsic productivity was used in this analysis versus the average of the two which would result in a much higher value of 4.44. Taking a conservative approach using an underestimated intrinsic productivity value is much less consequential as opposed to using an overestimated value. Using an overestimated value could result in a false sense of confidence when considering the feasibility of an integrated program. For capacity, a simple, straight forward summation of the two areas was used for the overall Spring Chinook capacity estimate. This combined capacity estimate is 1,847 (1175 + 672), including adults and jacks. Habitat parameters are summarized below:

Table 6. Summary of Klickitat Spring Chinook capacity and intrinsic productivity estimates.

Geographic Area	Capacity	Intrinsic Productivity
Below Castile Falls	1,175	2.975
Above Castile Falls	672	5.9
Sum of Capacity	1,847	
Estimated Productivity		3.5
Klickitat Total estimated Habitat	1,847	3.5

3.1.2 Harvest Parameters

Harvest parameters in the AHA model used to calculate total exploitation rate are broken into ocean, mainstem and terminal harvest rates. The parameters require simple, mean averages representing the users desired time frame estimate for past and current conditions or projected averages for future scenarios. The models stochasticity is captured with a random generation of SARs but regardless of predicted returns, harvest rates are static. Two different harvest patterns were used in the Klickitat AHA model runs defined below.

Current harvest pattern

Current harvest patterns were used for calibrating and examining the AHA predicted numbers representing current conditions against the actual observed return numbers. This harvest regime was also used as one alternative for modeling future proposed integrated hatchery strategies and scenarios. Wild Spring Chinook ocean and Columbia mainstem harvest rates were estimated using a status report developed by WDFW & ODFW July 2002 analyzing Columbia River stocks from 1938-2000. Estimated harvest rates used for ocean and mainstem current conditions are 1.34% and 5.6% respectively. Klickitat terminal harvest estimates were derived from the YN database. Estimated averages are for the time period 1977-2000 with an average value of 36%. Because hatchery Spring Chinook in the Klickitat have not been 100% marked until recently, it was assumed they were exposed to similar harvest rates as wild fish.

Future selective fishery harvest pattern

Modeling future integrated hatchery programs used a selective fishery harvest regime as one alternative. Terminal harvest rates were reduced by 10% for wild Spring Chinook which represents the past sport fishery average on the wild stock. Currently, approximately 75% of Klickitat Spring Chinook returns are composed of hatchery fish which means a high percentage of fish harvested are of hatchery origin. Because of this, estimating increases of harvest rates for a selective fishery is difficult to quantify. An additional 2% were added to the terminal hatchery harvest rate as a conservative increase in harvest of hatchery Spring Chinook. Average ocean and mainstem harvest rates for wild Chinook under the current condition harvest regime were used under this scenario as well. These harvest rates were maintained so harvest effects of wild fish could be evaluated across current conditions and future proposed integration strategies using different terminal harvest techniques. By switching to a selective fishery, mainstem harvest rates of hatchery fish were expected to change. A 7% mainstem hatchery Spring Chinook harvest was used for the selective fishery regime. All harvest rates used in the analysis are summarized below.

Table 7. Harvest rates used for modeling current conditions and integration hatchery strategies under different harvest regimes.

Klickitat AHA model harvest rates				
Locality	Current conditions		Selective fishery	
	Wild	Hatchery	Wild	Hatchery
Ocean	0.013	0.013	0.013	0.013
Mainstem	0.056	0.056	0.056	0.070
Terminal	0.360	0.360	0.260	0.380

3.1.3 Hatchery Parameters

For an integrated program, hatchery parameters in the AHA model are important components influencing the interactions among natural origin broodstock requirements and fish available for natural escapement. Fecundity, sex ratios, and hatchery survival all influence the prerequisite number of adults that are needed to meet smolt release quotas. For the Klickitat's current program, empirical data was used to estimate the average for adults taken for brood, pre spawn survival, sex ratios, fecundity and final release numbers. The one parameter difficult to estimate in the hatchery is the fry to smolt survival. For modeling purposes, this number was adjusted to fit the calculated final release numbers in the model to the average observed release number[5] from 1990 -2004. Recruits per spawner for the current hatchery program were calculated using brood years 1989-1999. A value of 2.35 represents the hatchery recruitment rate for the current Klickitat Hatchery program. The current hatchery parameters were also used for the integrated hatchery scenarios. Empirically derived hatchery parameters used for modeling can be viewed in appendix A, Table A1.

[5] Estimates include on station smolt releases and fry thinning releases

3.1.4 Hydro Survival Parameters (SARs)

Stochasticity within the AHA model (version 3.22) is a function of the random generation of SAR values modifying habitat productivity and capacity. The pattern of randomly generated SAR values attempts to replicate PDO cycles that ultimately drive ocean survival. The targeted SAR value the user provides is calculated by adjusting the juvenile outmigrant survival, ocean survival and adult migrant survival back to the mouth of the subbasin. In one sense, this could be one of the most important input parameters in the model. On the other hand, it only acts as an intermediate calculation affecting the models randomness, and can virtually have no affect on the models predictions. There are two different locations the user inputs a SAR value in the model. One is located on the population worksheet and the other is on the natural component worksheet. These two different input sources for the SAR work together to adjust the habitat capacity and productivity values. If the SAR values are different in the two locations, the user will see a divergence between the input habitat parameters and the adjusted habitat parameters I the cells directly below. *It is the adjusted habitat capacity and productivity that influence the models predictions for the upper and lower bounds of the model results (e.g. min and max predictions), not the input SAR directly.* If the user inputs the identical SAR values in the two different worksheets, there is no adjustment in the habitat parameters. Therefore, a conservative, estimated value of 4.28% was input into *both* source locations for the SAR values. However, as stated before, it is the habitat parameters driving the results of this analysis, not the SAR value.

3.1.5 Genetics and Fitness Parameters

For our intended use of the model, these parameters were generally left alone in the fitness worksheet. The initial fitness of both the wild and hatchery populations were set at 100 and all other genetic parameters were left alone with recommended default values. (personal communication C. Busack, WDFW)

3.2 Model Behavior and Current Condition Predictions

AHA model predictions in the form of min, max and average numbers for total returns, harvest and escapement were compared to the Klickitat observed numbers for Spring Chinook (Figure 4). Numbers presented for Klickitat observations correspond to 1977-2003[6] recorded data. Modeling current conditions allows us to examine the models behavior and provides useful insight regarding precision and accuracy. The model consistently predicted higher or lower numbers for min, max and average values across total returns, total harvest and escapement.

The largest divergence between observations and model predictions occurred for minimum values of total returns and harvest. AHA predictions for maximum return

[6] All harvest rates used in the AHA model and observed Klickitat numbers presented correspond to the time frame of 1977- 2000.

numbers were 21% higher than the observed maximum return number of Spring Chinook. As a function of predicted maximum return numbers, maximum harvest predictions of the model were 30% greater than the observed harvest numbers as well. Maximum escapement predictions displayed a higher level of accuracy with a value 9% below the observed maximum escapement. Because this prediction was actually lower than the observed number, it deviated from the models pattern of over estimating maximum values for total returns and harvest.

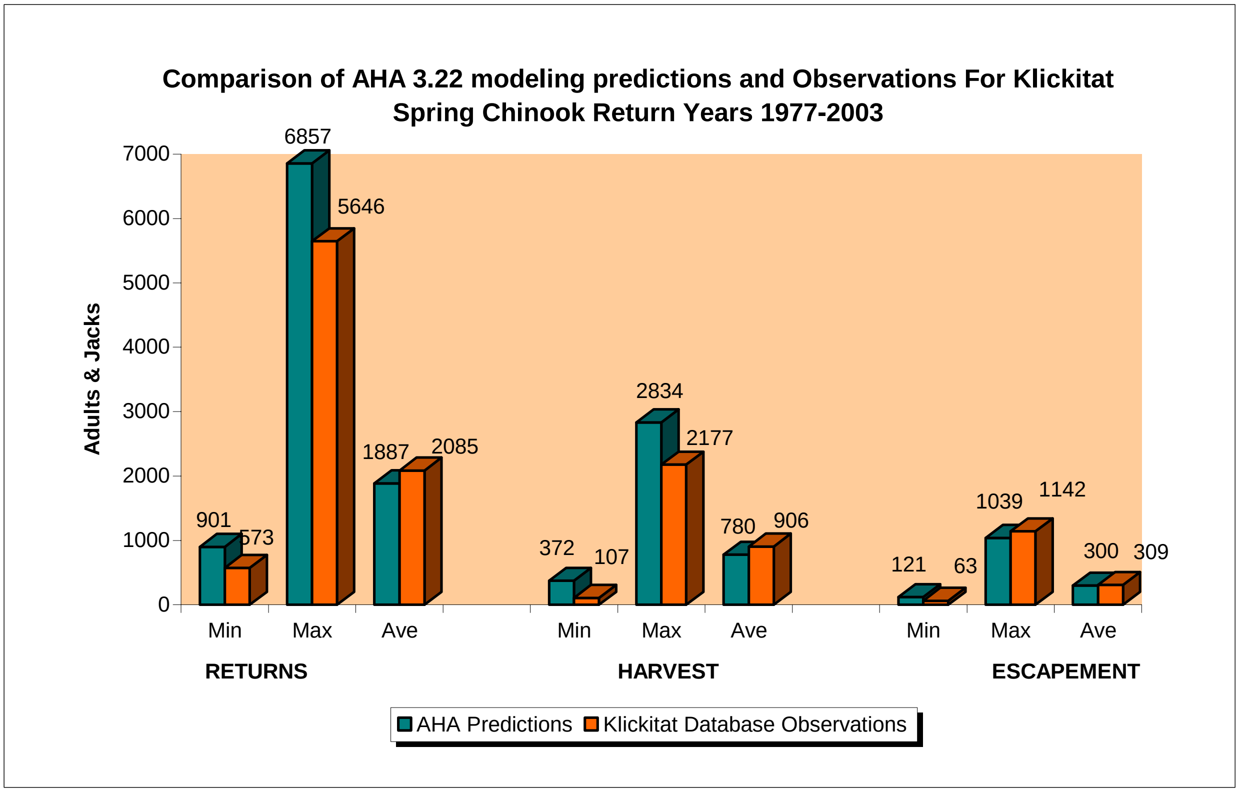

Figure 4. 1977-2003 observed Klickitat Spring Chinook returns, harvest and escapement plotted with AHA version 3.22 model predictions.

The model consistently over estimated minimum values across all three categories of returns, harvest and escapement. The over estimated values for minimum predictions were 57%, 247%, and 92% greater than the observed numbers for total returns, harvest and escapement respectively. The model prediction for average values displayed the highest level of accuracy across the min, max and average values generated by the model. Every predicted average value was slightly less than the observed numbers. Total average return predictions were 10% below observations, average harvest predictions were 14% below observations and average escapement predictions were only 3% below observed escapement numbers.

Interpretation of the models behavior can be framed in a simplistic or complex manner depending on how much detail one is willing to provide. In general, the largest deviations in the model predictions occurred for maximum and minimum predicted values for total returns and harvest. There are a couple simple explanations for this; 1.) Random SAR values used to modify the habitats capacity and productivity values during periods of low and high ocean survival are less than and greater than those experienced by Klickitat Spring Chinook. 2.) Real, observed values of Klickitat Spring Chinook are not 100% accurate. For the Klickitat Spring Chinook AHA model, its strength is its ability to closely predict average numbers across total returns, harvest and escapement. The escapement predictions were impressively accurate with little deviation from observed numbers. Considering this, the model should be capable of providing insight into our intentional purpose of modeling interactions of integrated hatchery programs with natural production. However, it is just a model. Acknowledgment of its deficiencies and simplistic nature should weigh into interpretations and assumptions.

3.3 Quantifying Model outputs in a qualitative sense: What useful insight can we gain from modeling the integration strategies?

The purpose of modeling the integrated hatchery strategies and numerous scenarios is to explore the response of natural production to the proposed actions with the consideration of congruency between model predictions and objectives for the integrated program. HSRG guidelines and program objectives provide the context for questions in need of further information and hypothesis generation. Specific questions pertaining to natural production responses include the following:

1.) **Is there sufficient natural escapement to support broodstock needs while maintaining equal or larger numbers of natural origin spawners?**
    -This question relates directly to HSRG guideline #5, which states in a general sense the number of natural spawners should be larger than the hatchery program brood requirements.

2.) **Does the integration program increase natural production in the form of spawner escapement and total natural recruitment?**

3.) **Does the model suggest a threshold point of diminishing returns with respect to spawner escapement and estimated habitat capacity?**

4.) **What is the suggested proportion of natural influence (PNI index value[7]) on the composite population hypothesized by the model and how does this value align with program objectives?**

5.) **What is the suggested effective population size hypothesized by the model when considering total natural escapement and does it meet our objectives?**

6.) **What caveats must be considered with the model outputs when considering uncertainties and parameters beyond the models capabilities?**

[7] The PNI index value is calculated as the ratio of pNOB/(pHOS+pNOB).

Modeling different harvest regimes

Two different harvest regimes were modeled for both strategies and their scenarios. One intended to capture the harvest affects of the current terminal harvest rates for both hatchery and wild Chinook. The second harvest regime intended to capture harvest effects for a selective fishery. For more information about harvest rates used for modeling, refer to section 3.1.2.

Use of different Hatchery recruitment rates

Each scenario also included systematic changes to the hatchery recruitment levels and harvest regimes. Modeled hatchery recruitment levels ranged from 2.35 recruits per spawner (R/S) up to 6.5. A value of 2.35 was chosen for the low end because it represents the observed hatchery recruitment level for the current segregation program[8]. Although current integration programs are capable of producing recruitment rates greater than 6.5, a range of values up to and including 6.5 were modeled to capture potential trends and interactions between the 4-H's with an increased return number of hatchery origin fish. Differing hatchery recruitment levels can significantly impact the proportions of hatchery fish on the spawning grounds along with the long term levels of natural recruitment and sustainable natural production. Low levels of hatchery recruitment can dismiss the purpose of an integration program if recruitment levels drop below those of natural production. Under these circumstances, a large scale integrated hatchery program would tax natural production with little contribution from returning hatchery fish designated for the spawning grounds. Higher than expected recruitment levels of hatchery fish can result in an increase of hatchery fish on the spawning grounds. This would lead to a greater than desired hatchery influence on the selective forces affecting the genetic makeup of the integrated population.

Context and presentation of modeling results: graphical outputs

The AHA model comes with several built in graphical outputs to display modeling results. For our purposes, customized outputs were created in order to synthesize model runs and create visuals for observing similarities and differences within scenarios. Values generated by the AHA model used in these custom outputs can be viewed near the end of this attachment in appendix A. Results for these scenarios are presented in Figures 5 through 12 below. All returning numbers presented in these model runs are the mean return rate over 100 generations. Two different model runs were included for each scenario. One consists of maintaining current terminal harvest rates and is represented by the solid lines. The second model run used estimated harvest rates for a terminal selective sport fishery of consideration in the Klickitat represented by the dotted lines. For both harvest model runs, recruitment rates were systematically changed while maintaining all other input parameter values. Model runs for different recruitment rates were plotted consecutively for trend observations in total recruitment and escapement

[8] Average hatchery recruitment for brood years 1989-1999

levels as a function of the mean hatchery recruitment rate. Also included in the figures are modeling results for Spring Chinook under current conditions. Unlike specific hatchery recruitment rate model runs, the current condition does not include habitat above Castile Falls and characterizes current natural production estimates of the AHA model with current terminal harvest rates and habitat performance estimates[9]. This was included for the purpose of comparing the current state of natural production to proposed hatchery programs utilizing additional habitat above Castile Falls. There is also a minimum NOR escapement threshold in the graphs representing the suggested minimum NOR escapement to spawning grounds. The threshold value is based off of HSRG guideline #5 indicating minimum NOR escapement should be equal to or greater than the number of adults used for the integrated hatchery program.

3.4 Strategy 1: Integrated 800,000 Smolt Release Program

Multiple scenarios were run for the proposed integrated 800,000 smolt release program using different proportions of natural broodstock. These included the following:

Scenario 1: 100% natural broodstock, 2 different harvest regimes, multiple hatchery recruitment rates
Scenario 2: 75% natural broodstock, 2 different harvest regimes, multiple hatchery recruitment rates
Scenario 3: 50% natural broodstock, 2 different harvest regimes, multiple hatchery recruitment rates
Scenario 4: 25% natural broodstock, 2 different harvest regimes, multiple hatchery recruitment rates

3.4.1 Scenario 1: 100% natural broodstock for integrated program (Figure 5.)

Synthesis and interpretation of the outputs will be framed in the context of questions outlined in section 3.3. In general, model results for the two different harvest regimes seem to consistently track together with the selective harvest regime providing a greater amount of total and natural escapement for all hatchery recruitment rates. One would expect this based on the assumed 10% decrease in terminal harvest for NOR Spring Chinook. With a hatchery recruitment rate of 2.35, the population experiences a decrease in natural production from current conditions even with the additional habitat. Natural broodstock requirements and hatchery recruitment rates below intrinsic productivity of natural origin fish are causal factors leading to this decreased natural production. The trend in natural escapement levels approach an asymptotic limit as recruitment rates for hatchery origin fish increase (hatchery fish destined for the spawning grounds). Several factors are potentially affecting these observed responses of natural production to increasing hatchery recruitment: 1) As hatchery escapement to spawning grounds increase, total escapement levels approach or even exceed the estimated capacity[10] of the

[9] Current habitat capacity and productivity estimates defined in section 3.1.1
[10] Capacity estimates used in the AHA model encompass all factors affecting freshwater and marine survival throughout the entire life history.

environment 2.) In relation to #1, the model uses density dependent Beverton-Holt functions which would limit average natural adult recruitment based on the habitat parameters used in the AHA model. Bearing these factors in mind, the model suggests escapement numbers approach capacity estimates when hatchery recruitment rates are greater than roughly 5 recruits per spawner. As a result, increases in natural production seem to diminish when hatchery recruitment exceed this value.

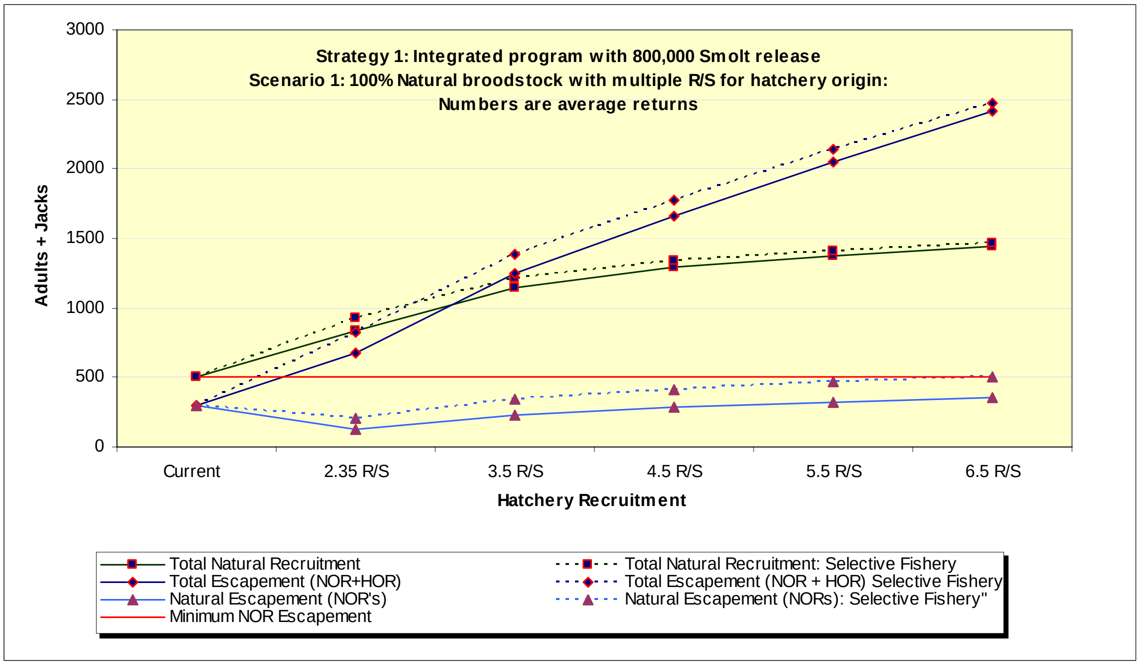

Figure 5. Predicted average Spring Chinook return numbers for integrated 800,000 smolt release program using 100% natural broodstock: version 3.22 AHA model.

The modeling results also indicate a failure to reach minimum natural escapement levels (line represented in red) under the current harvest regime while barely meeting this objective under a selective sport fishery harvest regime which requires higher levels of hatchery recruitment. When considering the numbers of hatchery and wild fish in the total escapement composite, the model implies an integration program of this magnitude is disproportionate to the total habitat capacity[10] and productivity. Furthermore, the feasibility of the population to sustain annual broodstock needs, harvest and some level of natural escapement requires further investigation. For more information regarding this, see section 3.6 below covering caveats and uncertainties for model predictions.

3.4.2 Scenario 2: 75% natural broodstock for integrated program (Figure 6.)

Synthesis and interpretation of the outputs will be framed in the context of questions outlined in section 3.3. Similar to other scenarios under this strategy, model results for the two different harvest regimes seem to consistently track together with the selective harvest regime providing a greater amount of total and natural escapement for all hatchery recruitment rates. With a hatchery recruitment rate of 2.35, the population experiences a decrease in natural production from current conditions even with the additional habitat. Natural broodstock requirements and hatchery recruitment rates below intrinsic productivity of natural origin fish are causal factors leading to this decreased natural production.

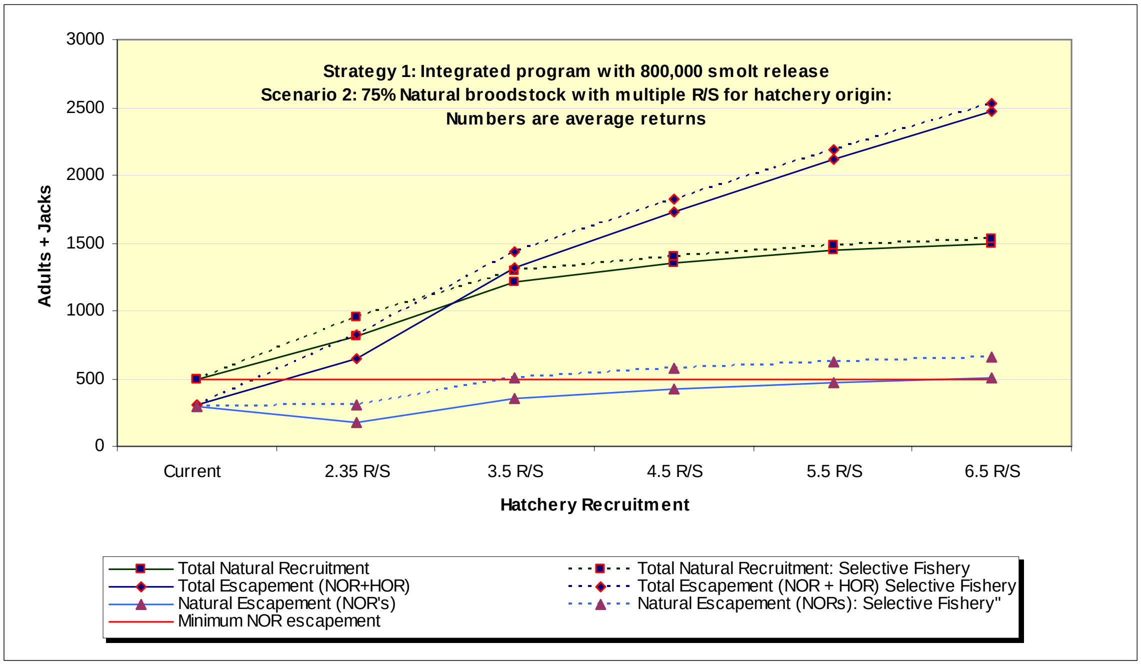

Figure 6. Predicted average Spring Chinook return numbers for integrated 800,000 smolt release program using 75% natural broodstock: version 3.22 AHA model.

Trends in both natural recruitment and total escapement track closely to those in scenario 1 (Figure 5). These similarities can be attributed to the fact that a program of this magnitude quickly fills or exceeds the environment capacity, capable of producing only so many natural recruits when considering the relationship between mean return rates and Beverton-Holt dynamics. Minimum natural escapement levels reach the minimum threshold of 500 (refer to HSRG guideline #5) at fairly low hatchery recruitment rates for the selective fishery harvest regime (~ 3.5) while current harvest regimes suppress natural escapement below 500 until hatchery recruitment rates exceed 5.5 recruits per spawner.

3.4.3 Scenario 3: 50% natural broodstock for integrated program (Figure 7.)

Synthesis and interpretation of the outputs will be framed in the context of questions outlined in section 3.3. Similar to other scenarios under this strategy, model results for the two different harvest regimes seem to consistently track together with the selective harvest regime providing a greater amount of total and natural escapement for all hatchery recruitment rates. In fact, total escapement and total natural recruitment mean values are very close to those for the other scenarios as hatchery recruitment rates increase. Comments listed under scenario's 1 and 2 also apply to this scenario for the trends in total escapement and total natural recruitment.

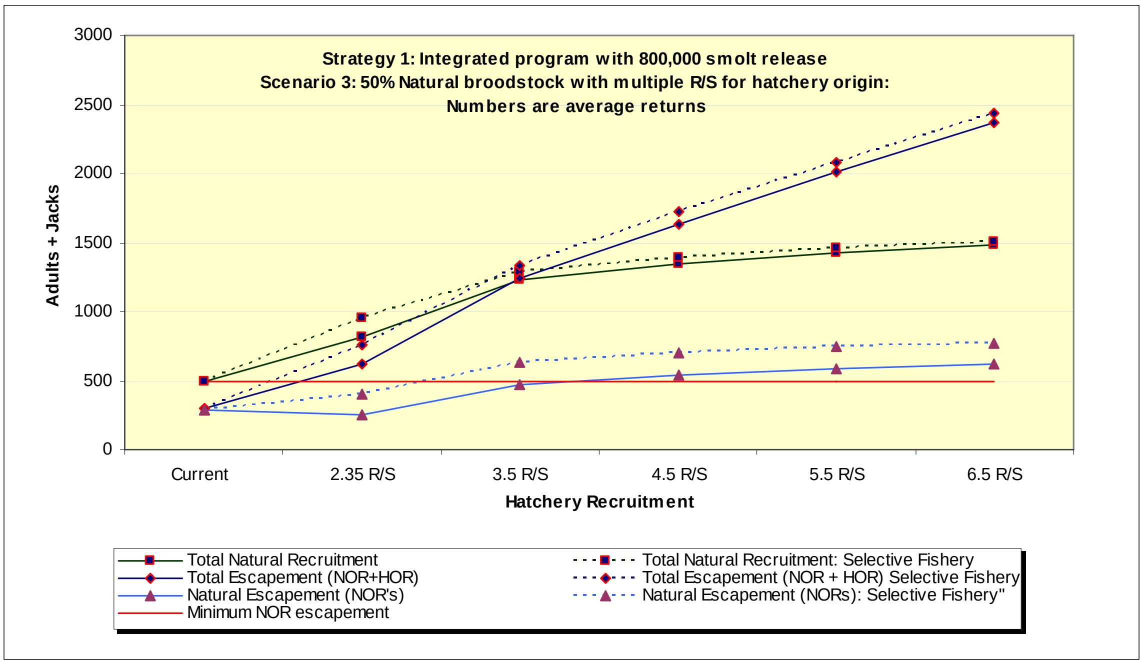

Figure 7. Predicted average Spring Chinook return numbers for integrated 800,000 smolt release program using 50% natural broodstock: version 3.22 AHA model.

Mean values for natural escapement approach the minimum escapement levels rapidly for both selective and current harvest regimes (3 R/S, 4 R/S respectively). Unlike scenarios 1 and 2, natural escapement is not as heavily impacted when hatchery fish recruitment rates are near 2.35 recruits per spawner.

3.4.4 Scenario 4: 25% natural broodstock for integrated program (Figure 8.)

Synthesis and interpretation of the outputs will be framed in the context of questions outlined in section 3.3. Similar to other scenarios under this strategy, model results for the two different harvest regimes seem to consistently track together with the selective harvest regime providing a greater amount of total and natural escapement for all hatchery recruitment rates. Trends in total natural recruitment and total escapement are similar to those in scenarios 1-3 once hatchery recruitment approach values greater than 3.5. Interpretations of these trends in the first 3 scenarios also apply to scenario 4. Compared with other scenarios exists a subtle difference in natural escapement with a hatchery recruitment rate of 2.35. With this low level of hatchery recruitment, total natural escapement levels do not decrease as sharply for this scenario as they do for the others. The logical explanation for this is the smaller proportion of natural origin fish required for broodstock needs under this scenario. Thus, buffering the natural population from mining natural escapement with poor hatchery return rates for fish destined to the spawning grounds. Also, with 25% of broodstock derived from natural origin fish, natural escapement approaches the recommended minimum value much more rapidly than other scenarios requiring higher levels of natural origin broodstock.

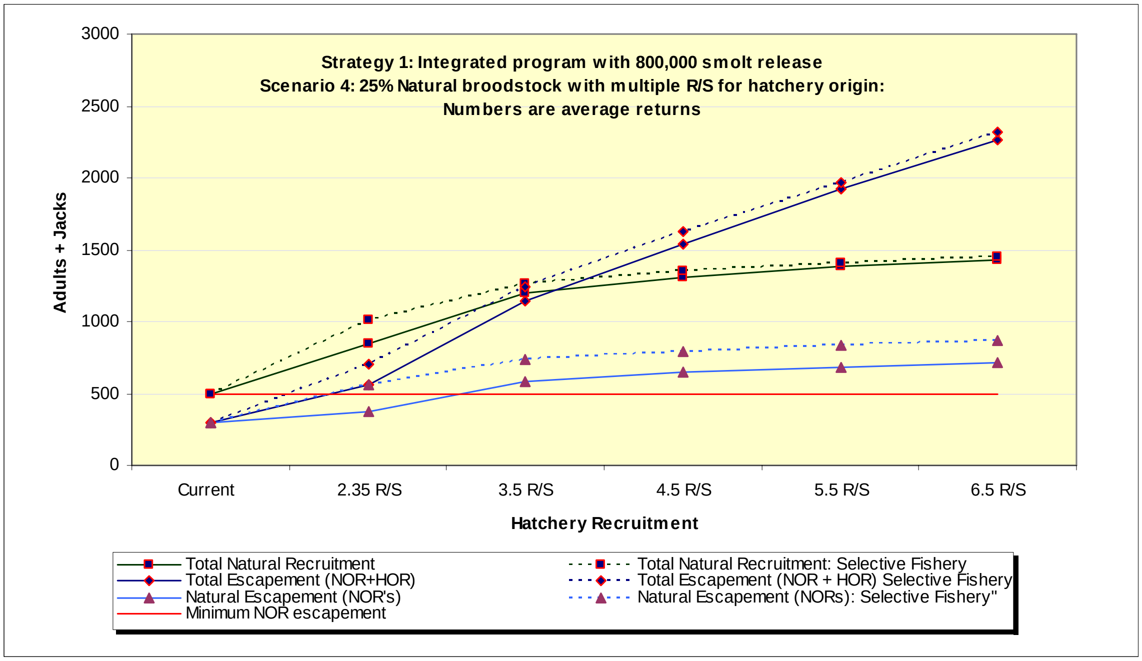

Figure 8. Predicted average Spring Chinook return number for integrated 800,000 smolt release program using 25% natural broodstock: version 3.22 AHA model.

3.4.5 Strategy 1: Proportion of Natural Influence (PNI) Index values for Scenarios 1-4 (Figure 9).

Figure 9 illustrates the selective forces of the hatchery and natural environment influencing the composite population for scenarios 1-4. The threshold line represented in red represents the minimum suggested PNI index value for an integrated program initiated for a stock of moderate to high biological significance (see HSRG guideline #3). For scenario 1, numerous recruitment rates modeled suggest a fairly stable PNI index value of about 0.52 regardless of the proportion of hatchery escapement. Because the broodstock is derived from 100% wild fish, this value can never drop below 0.5 according to the algorithm used to calculate the value. In a qualitative sense, a value of 0.52 indicates the natural environment having a slightly higher influence on the selective forces over the hatchery environment for the integrated populations genotypic and phenotypic characteristics.

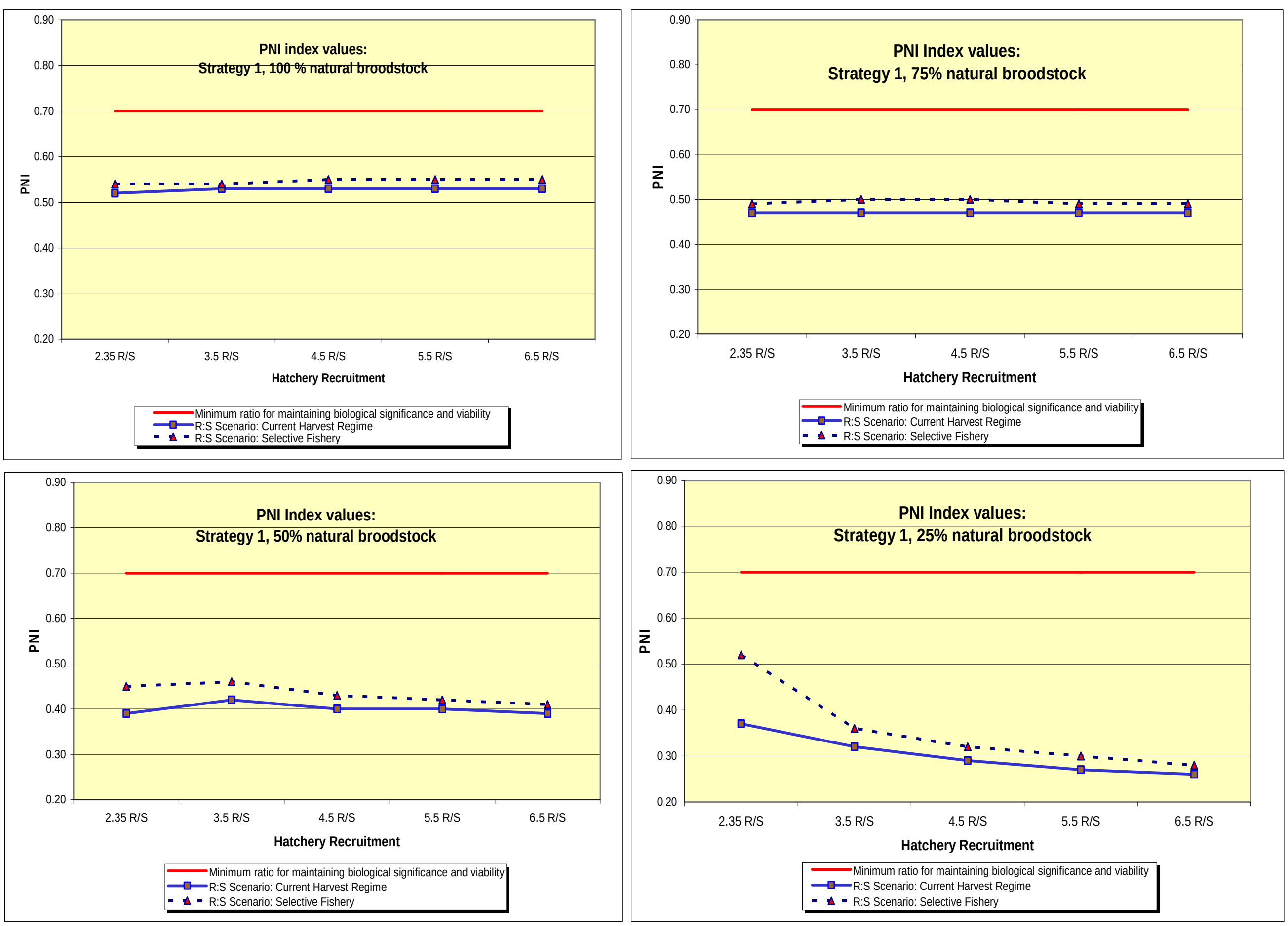

Figure 9. Predicted PNOB/ (PHOS+PNOB) index ratios for integrated 800,000 smolt release program using different proportions of natural broodstock: version 3.22 AHA model.

PNI index values for both harvest regimes in scenario 2 also display stability regardless of the hatchery recruitment rates. But because a proportion of broodstock is of hatchery origin, the PNI index values drop below the threshold of 0.5, indicating the hatchery environment having a slightly higher influence on the selective forces than the natural environment. Trends in PNI index values for scenarios 1 & 2 suggests integration programs of this magnitude will never reach the recommended PNI index value of 0.7 required for stocks of moderate or high biological significance, regardless of the hatchery recruitment rates.

As illustrated in Figure 9 for scenarios 3 & 4, sharp decreases in PNI index values occur when proportions of hatchery fish used for broodstock approach or exceed 50%. Under these hatchery integration scenarios, an increase in hatchery recruitment rates can significantly decrease the PNI index values for Klickitat Spring Chinook. This gives rise to an overwhelming hatchery environment influence on the composite population's genotypic and phenotypic characteristics.

3.5 Strategy 2: Integrated 200,000 Smolt Release Program

One scenario was modeled for this strategy which consisted of 100% natural broodstock, two different harvest regimes, and multiple hatchery recruitment rates.

3.5.1 Scenario 1: 100% Natural broodstock for Integrated Program (Figure 10.)

Synthesis and interpretation of the outputs will be framed in the context of questions outlined in section 3.3. In general, model results for the two different harvest regimes seem to consistently track together with the selective harvest regime providing a greater amount of total and natural escapement for all hatchery recruitment rates. One would expect this with the assumed 10% decrease in terminal harvest for NOR Spring Chinook. Trends in total natural recruitment behave similar to those from scenarios in strategy 1 but seem to approach a different level of equilibrium as recruitment of hatchery fish increase.

A major difference between results of this strategy compared to those scenarios in strategy 1 is the impact to natural escapement at low levels of hatchery recruitment. At recruitment levels at 2.35 for hatchery fish, the large scale smolt release program (strategy 1, scenario 1) requires a larger number of wild fish to fulfill broodstock needs. If poor hatchery recruitment levels below those of natural production were to persist, the program would not perform as desired. This consequence is illustrated by decreases in natural production associated with the large scale program using 100% natural broodstock (Figure 5). An integrated program requiring a much smaller number of wild fish for broodstock would lessen detrimental impacts to natural production if low hatchery recruitment rates were to persist (Figure 10).

As hatchery recruitment rates increase, total natural recruitment, total escapement and natural escapement also increase . Total natural recruitment and natural escapement approach similar asymptotes to those in scenarios 1-4 of the larger scale (Figures 5-8), integrated program. This suggests a smaller scale 200,000 smolt release program is capable of providing the same benefits to natural production as those projected from the large scale, 800,000 smolt release program. Limited natural production gains from an integrated program are obviously driven by the environmental capacity and productivity as indicated by these disproportionate integrated programs.

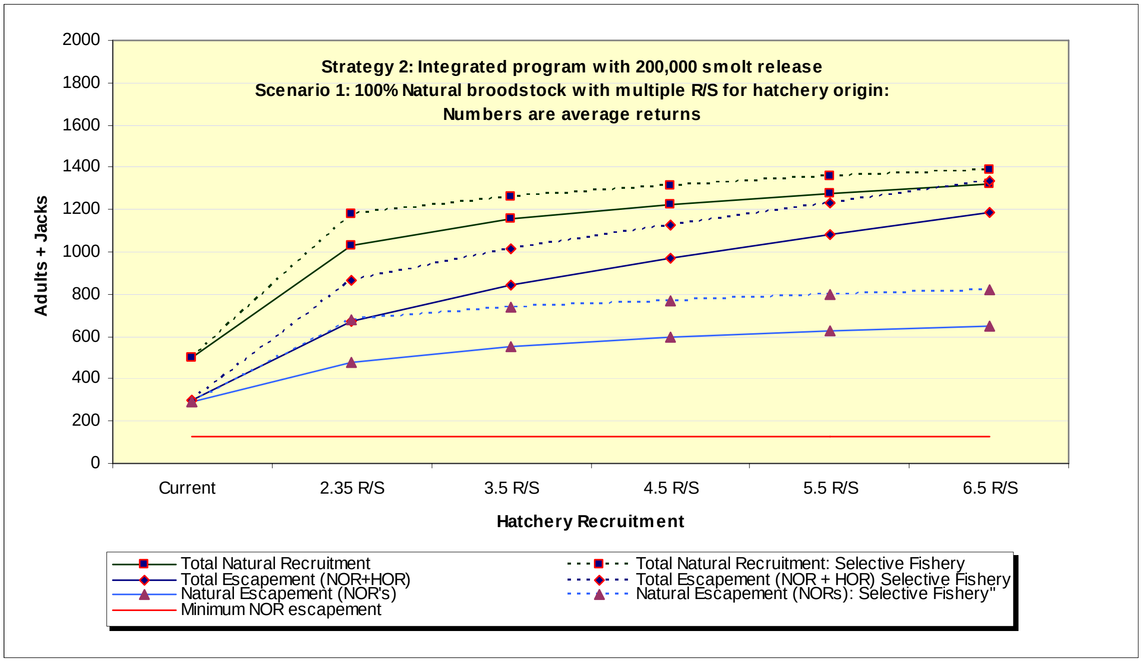

Figure 10. Predicted average Spring Chinook return numbers for integrated 200,000 smolt release program using 100% natural broodstock: version 3.22 AHA model.

With the modeled hatchery recruitment rates for strategy 2, average total escapement numbers increase but never exceed the estimated capacity of the habitat (Figure 10). In reality, hatchery recruitment rates can most certainly exceed those used in this modeling exercise. Even when considering this, the trend in total escapement suggests an extremely high average recruitment rate of hatchery fish would approach the habitat capacity under both harvest regimes. Of course, this is phrased in the context of average returns, using Beverton-Holt production dynamics. Further investigation related to section 3.3, question 1 is presented below under modeling caveats and underlying circumstances.

3.5.2 Strategy 2: PNI Index values for Scenario 1 (Figure 11.)

Figure 11 illustrates the selective forces of the hatchery and natural environment influencing the composite population for scenario 1. Results are presented in terms of average return numbers. The threshold line represented in red represents the minimum suggested PNI index value for an integrated program initiated for a stock of moderate to high biological significance (see HSRG guideline #3). The results are not surprising as the model suggests a gradual decrease in the PNI index value as hatchery recruitment increases. Nonetheless, PNI index values remain near recommended values required for populations of moderate to high biological significance. For all modeled hatchery recruitment rates, constant variance exists between the two different harvest regimes

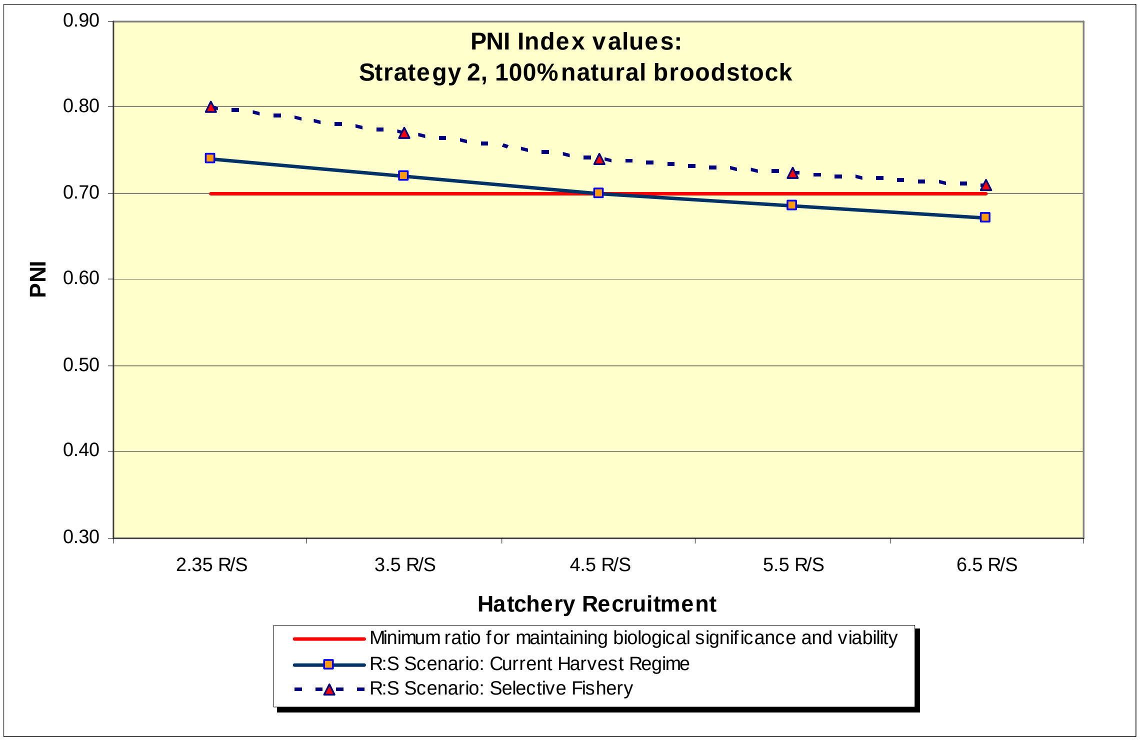

Figure 11. Predicted PNOB/ (PHOS+PNOB) index ratios for integrated 200,000 smolt release program using 100% natural broodstock: version 3.22 AHA model.

modeled. A selective terminal fishery maintains a higher PNI index value and does not drop below the minimum threshold until average hatchery recruitment rates exceed values of 6.5. Compared to the other PNI index values for scenarios 1-4 of integration strategy 1 (Figure 9), the model suggests a program of this magnitude is (strategy 2) capable of sustaining a much higher level of natural environmental influences relative to the composite population's genotypic and phenotypic characteristics.

3.6 Modeling Caveats and Underlying Circumstances

All models have their deficiencies and weak points. All models were designed to serve a particular purpose, its just that some do it better than others. The AHA model is the first of its kind designed to explore the interactions of the 4-H components. Among several uses, the model can provide assistance for comprehending basic relationships between hatcheries and habitat. It does this by forcing individuals to acknowledge the potential limitations of an integrated program's capabilities based on the habitat and hatchery parameters. Caveats of consideration for specific modeling scenarios depend on the intentional uses of the model. In this case, we're considering different sized integration programs with different proportions of natural origin broodstock, under different harvest regimes. The purpose is to generate working hypothesis's relative to the costs and benefits to natural production and how they relate to Spring Chinook objectives. As mentioned before, under our modeling scenarios, the largest uncertainty in this modeling exercise is the ability of the natural population to meet broodstock requirements while maintaining adequate escapement. Standard AHA model outputs provide natural escapement frequency distributions but they are grouped into categories ranging from 0-50, 50-500 and 500-1000 natural origin escapees. This does not clearly address our uncertainty pertaining to the long-term sustainability of natural escapement and brood requirements.

Generational computations in the guts of the model providing the min, max and average return numbers for the 100 generation cycle were extracted and graphed to assist with modeling uncertainties. Average natural escapement numbers generated by the model are heavily skewed by the generations experiencing high out of basin survival (Figure 12 and 13). Because the maximum predicted numbers were much higher than the observed numbers (Figure 4), the average return numbers for the modeling scenarios may be skewed by unrealistic maximum return numbers as well. The model also has an input cell where the user can provide a minimum escapement value. A minimum escapement value of 1 was input into this parameter and maintained for all modeling scenarios. By doing so, it attempts to quantify the impacts of broodstock mining if management practices were to focus on meeting broodstock requirements with little monitoring for natural escapement. This does not reflect YKFP's current management practices or future practices, but rather a method of quantifying the consequences of a hatchery program in relation to question 1, section 3.3.

3.6.1 Time series for 800,000 smolt release, 100% natural broodstock program

Several time series were graphed over 40 generations illustrating the total escapement and natural escapement to the spawning grounds under both harvest regimes. One with a hatchery recruitment rate of 2.35, and another with a hatchery recruitment rate of 6.5.

2.35 hatchery recruitment rate

Results from graphing this time series are illustrated in Figure 12. Differences for total escapement and natural escapement between the two different harvest regimes are significant for generations experiencing high out of basin survival but minimal for all other generations experiencing low to moderate out of basin survival. The variance between total escapement and natural escapement is quite substantial, hinting at the disproportionate size of the hatchery program relative to the habitat capabilities. During periods of low and moderate environmental productivity, it appears that one fish provides for annual escapement while broodstock requirements are not met for a majority of these years. Even with the hatchery escapement numbers supporting natural production, the viability of the composite population would be considered doubtful. If a catastrophic event were to wipe out the hatchery portion of the population, very few fish would provide for total escapement. From this scenario, it appears a hatchery program of this magnitude would be to taxing on the natural population and its ability to sustain both natural escapement and broodstock requirements.

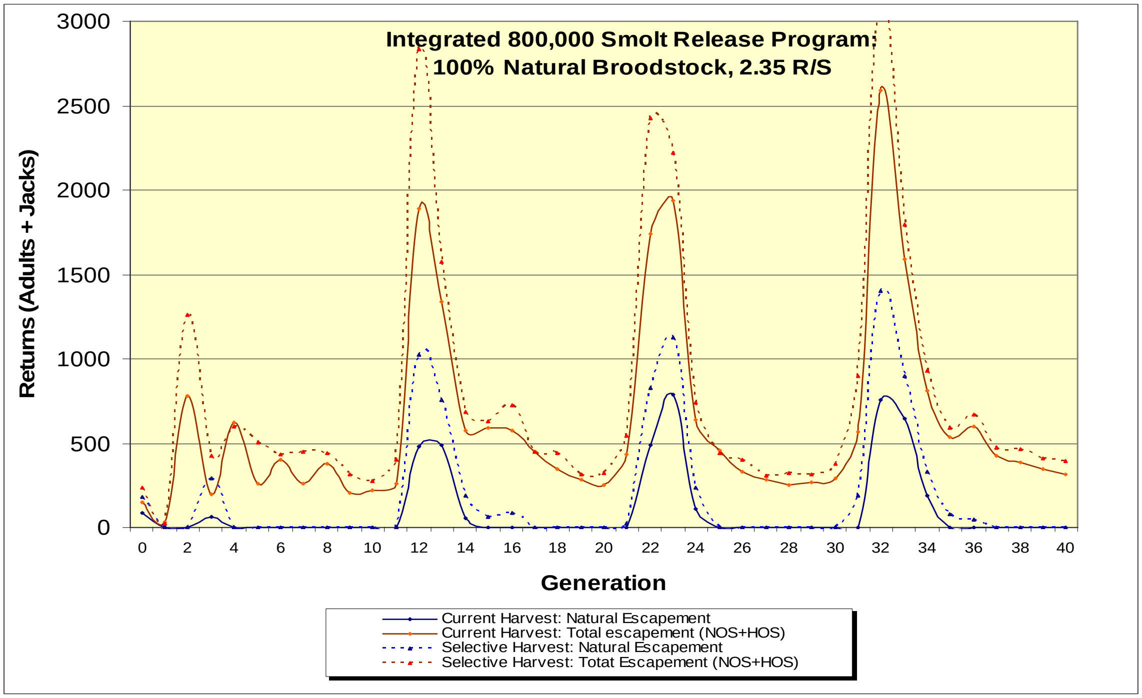

Figure 12. Time Series illustrating trends in total & natural escapement: 800,000 smolt release, 10% natural broodstock, 2.35 hatchery recruitment rate.

6.5 Hatchery recruitment rate

Results from graphing this time series are illustrated in Figure 13. Differences for total escapement and natural escapement between the two different harvest regimes are significant for generations experiencing high ocean survival but minimal for all other generations experiencing low to moderate ocean survival. An increased hatchery recruitment rate of 6.5 bolsters natural production resulting in a slight increase in natural escapement (Figure 13) than those from the 2.35 hatchery recruitment rate. In spite of this, escapement numbers still drop to 1-20 fish in years of poor ocean survival. Like the previous scenario, broodstock requirements will not be met during periods of low ocean survival. Even with an average recruitment rate of 6.5 for hatchery fish, the program suppresses natural escapement contributions to the spawning aggregate. Under both harvest regimes, benefits to natural production primarily consist of hatchery fish supporting a very high proportion of total escapement.

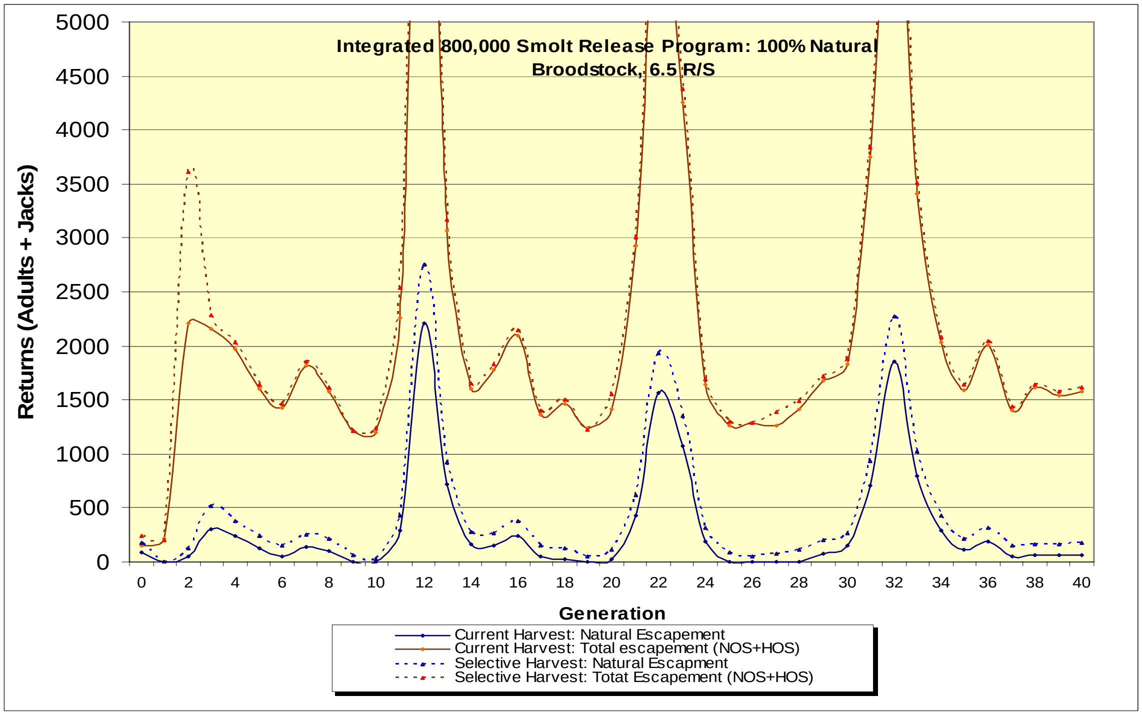

Figure 13. Time series illustrating trends in total & natural escapement: 800,000 smolt release, 100% natural broodstock, 6.5 hatchery recruitment rate.

3.6.2 Time series for 200,000 smolt release, 100% natural broodstock program

Several time series were graphed over 40 generations illustrating the total escapement and natural escapement to the spawning grounds under both harvest regimes. One with a hatchery recruitment rate of 2.35, and another with a hatchery recruitment rate of 6.5.

<u>2.35 hatchery recruitment rate</u>

Results from graphing this time series are illustrated in Figure 14. Divergence for total escapement and natural escapement between the two different harvest regimes appear to have substantial differences regardless of the variation for out of basin survival. Also, by switching to a selective harvest regime, natural escapement levels approach those of total escapement for the current harvest regime. This suggests a considerable increase in natural escapement by switching current harvest practices to those of a selective sport fishery. The model indicates minimum natural escapement under the current harvest regime having a threshold of about 76 fish with a hatchery program of this magnitude (Table A4). For the selective fishery regime, the minimum natural escapement is roughly 194 fish. A principle difference in the results for this scenario compared to those for the hatchery program of much larger size is the variance between natural escapement and total escapement. The much smaller programs provide a higher level of natural escapement supplemented by hatchery fish while the larger program has a fraction of natural escapement and natural production is heavily supported by hatchery fish.

With the current harvest regime and dismal hatchery recruitment rate of 2.35, careful monitoring would need to take place, ensuring adequate natural escapement relative to broodstock requirements in periods of poor natural recruitment. Additional resiliency for natural escapement during times of poor ocean survival would be provided by switching to a selective fishery regime.

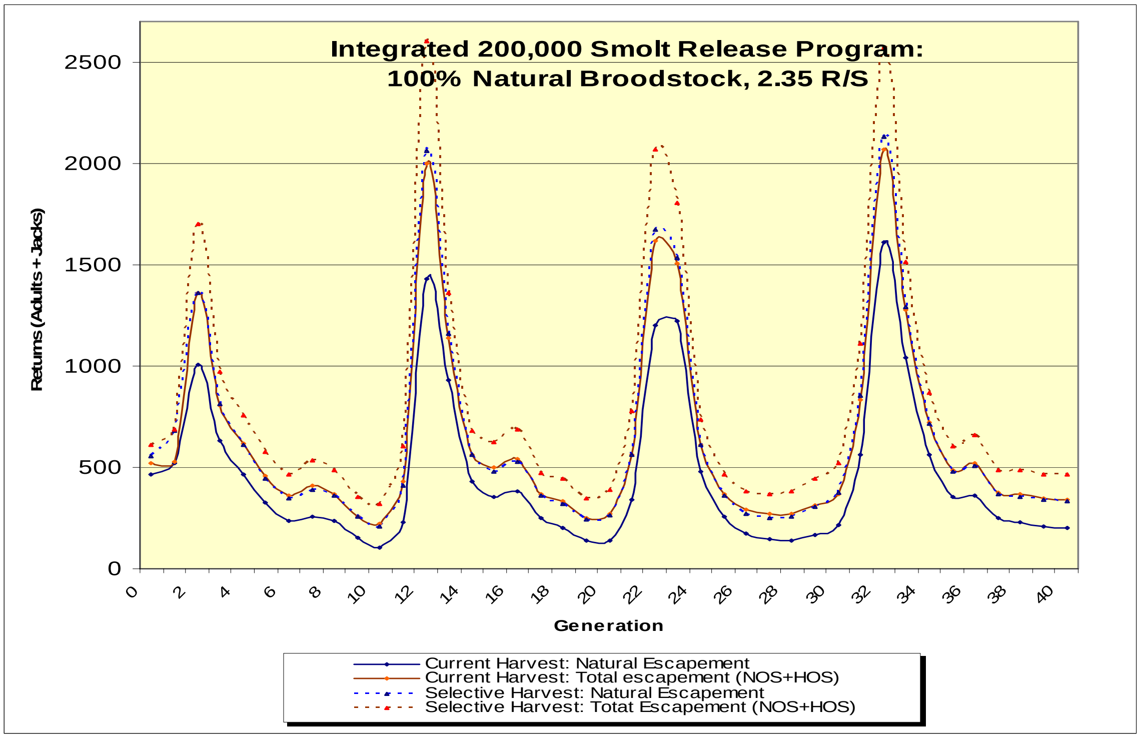

Figure 14. Time series illustrating trends in total & natural escapement: 200,000 smolt release, 100% natural broodstock, 2.35 hatchery recruitment rate.

6.5 Hatchery recruitment rate

Results from graphing this time series are illustrated in Figure 15. The AHA model indicates minimum natural escapement for the current harvest regime and selective fishery approach values of 226 and 309 respectively (Table A5). Minimum natural escapement responds with sizable increases under this scenario compared to the minimum values for the 2.35 hatchery recruitment rate of the large scale program (Figure 14). The smaller program provides a higher level of natural escapement enhanced by hatchery escapement as indicated by the total escapement trendline. Average natural escapement and total escapement values generated by the model for this scenario are a bit more realistic than those of the large scale integration program because of the decreased variance between the max and min return numbers.

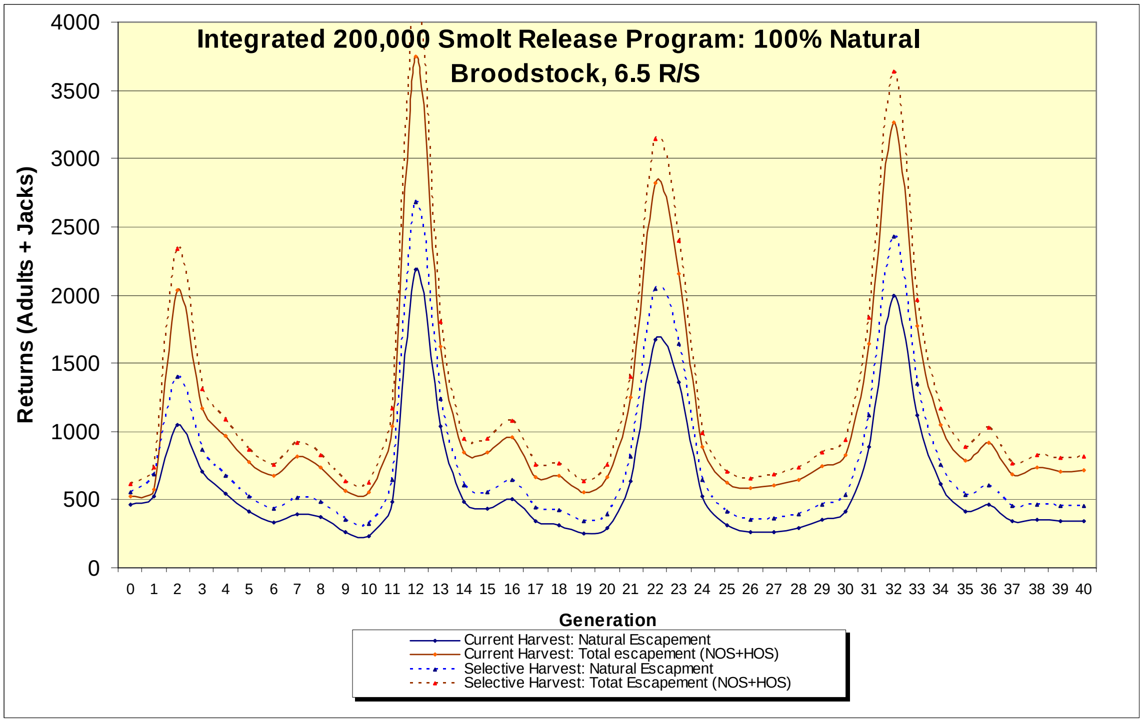

Figure 15. Time series illustrating trends in total & natural escapement: 800,000 smolt release, 100% natural broodstock, 6.5 hatchery recruitment rate.

3.6.2 Hypothetical Effective Population Size Estimates

Hypothesized escapement numbers generated by the AHA model were used to estimate effective population sizes. Estimates were investigated for both 800,000 and 200,000 integrated smolt release programs using 100% broodstock, multiple hatchery recruitment rates and several harvest regimes. Similar equations were used here as those outlined in section 2.1 for estimating the current effective population size. Generation escapement estimates used can be viewed in the appendix, Tables A2 & A3. One of the biological objectives of the Spring Chinook integration program is to increase the effective population size from roughly 326 to 500.

<u>800,000 smolt release program</u>

Total effective population sizes for the large scale program range from 432 to 1984 depending on the harvest regime and hatchery recruitment rates (Tables 8 & 9). Poor hatchery recruitment rates result in low effective population estimates with little or no contribution from natural escapement. An increased hatchery recruitment rate results in a much higher estimated effective population size but still has little contributions from natural escapement. The model suggests the effective population size may not meet the Spring Chinook biological objective if poor hatchery recruitment rates were to persist.

Table 8. Estimated effective population sizes for both natural and total escapement with a hatchery recruitment rate of 2.35.

	2.35 Recruits Per Spawner							
	200,000 Smolt Release				800,000 Smolt Release			
	Current Harvest Regime		Selective Fishery		Current Harvest Regime		Selective Fishery	
	Effective NOS	Effective Total	Effective NOS	Effective Total	Effective NOS	Effective Total	Effective NOS	Effective Total
Harmonic Mean	87	142	140	189	1	103	1	121
Effective population Size	366	597	586	796	3	432	3	509

200,000 smolt release program

Total effective population sizes for the small scale program range from 586 to 1304 depending on the harvest regime and hatchery recruitment rates (Tables 8 & 9). Natural escapement represents a high proportion of the total estimated effective spawners for a both hatchery recruitment rates and harvest regimes. Results point to a balanced integration program using smaller release numbers with both natural and hatchery fish contributing to the effective population size.

Table 9. Estimated effective population sizes for both natural and total escapement with a hatchery recruitment rate of 6.5.

	6.5 Recruits Per Spawner							
	200,000 Smolt Release				800,000 Smolt Release			
	Current Harvest Regime		Selective Fishery		Current Harvest Regime		Selective Fishery	
	Effective NOS	Effective Total	Effective NOS	Effective Total	Effective NOS	Effective Total	Effective NOS	Effective Total
Harmonic Mean	138	274	181	310	2	431	10	472
Effective population Size	581	1151	761	1304	9	1810	40	1984

4. Modeling Conclusions and Summary of Integration Hatchery strategies

The success or failure of an integrated hatchery program hinges upon the complex synergistic relationships of the freshwater habitat conditions, marine survival, status and viability of the stock, size of the hatchery program and exploitation rate. Attempting to jointly evaluate these parameters in a scientific context is a most challenging task without the support of a quantifying tool. Because of this, the AHA model was used to *assist* the development of the integrated hatchery program while adhering to the HSRG principles and guidelines.

Application of the AHA model version 3.22 for Klickitat river Spring Chinook consisted of exploring the consequences and benefits associated with a variety of scaled integration programs. The Master Plan proposes a long term transition of the segregated program to an integrated program for an 800,000 smolt release. The plan also proposes an immediate 200,000 smolt release program using 100% natural broodstock serving multiple purposes (refer to section 2.1). In conjunction with the 200,000 release, the program would continue the current segregated 600,000 on-station smolt release. Scenarios using different proportions of natural origin broodstock (100%, 75%, 50% and 25%) were run for the 800,000 smolt release integrated program. One scenario was run for the 200,000 smolt release above Castile Falls consisting of 100% natural broodstock. All scenarios under both hatchery strategies modeled two different harvest regimes. One captures the current harvest regime and exploitation rate while the other modeled a selective sport fishery harvest regime for the Columbia mainstem and Klickitat subbasin. A range of hatchery recruitment rates were modeled for all scenarios and harvest regimes due to the high level of uncertainty this parameter has with any proposed program. Min, max and average return numbers were generated for all strategies in the analysis.

Modeling low hatchery recruitment rates for all scenarios under the 800,000 smolt release program result in poor performance for natural production in terms of both total escapement and natural escapement (Figures 5-8). As hatchery recruitment rates increase, total escapement increases dramatically for all scenarios using different proportions of natural origin broodstock. Natural escapement also tends to increase to a certain degree, tracking Beverton-Holt density dependent recruitment dynamics. An inverse relationship was observed between the proportion of natural origin fish used for broodstock and average natural escapement. Using 100% natural origin broodstock constrains both natural escapement and broodstock requirements under both harvest regimes. Very few fish would be available for natural escapement as broodstock requirements would not be met during periods of poor ocean productivity and out of basin survival (Figures 13 & 14). As the proportion of natural origin fish in the broodstock decreases, natural escapement increases slightly and broodstock requirements are met a majority of time during periods of poor ocean productivity and out of basin survival. However, when high proportions of hatchery fish are used for broodstock, natural selective forces driving the genetic characteristics of the composite population are heavily influenced by the hatchery environment with PNI index values ranging from 0.47 down to 0.26 (Figure 9). Under these circumstances, a high level of uncertainty exists for genetic risks associated with domestication and decreases in fitness. Synthesis of all model outputs for the integrated program release of 800,000 smolts suggest a program of this magnitude may not provide the desired benefits to natural production while meeting program objectives base on the current habitat capacity and productivity estimates used in this analysis.

An integrated program releasing 200,000 smolts derived from 100% natural origin brood has been hypothesized by the AHA model to have equal if not greater benefits for natural production than the larger scale integrated 800,000 smolt release program. As hatchery recruitment rates increase, both total natural recruitment and natural escapement increase as they approach asymptotes similar to those of the larger scale, integrated program(Figures 5-8 & 10). Natural production gains and sustainability with an integrated program are driven by the estimates of environmental capacity and intrinsic productivity, as suggested by the results of the two different sized programs. Interpretation of model outputs supporting this are illustrated in Figures 12-15. These figures represent generational computations extracted from the model and graphed as a time series. The smaller scale integrated program appears to be tailored to the environmental constraints with the natural escapement performance exceeding that of the larger scale program. This is related to the broodstock requirements of each program and the natural production potential of the environment. The increase in natural escapement for the smaller integration program and natural environments influence on the selective forces are captured in the hypothesized PNI index values. The magnitude of hatchery escapement can also impact the PNI index values which are related to hatchery recruitment rates. The HSRG suggests a minimum value of 0.70 for stocks of moderate to high biological significance. Generic guidelines suggest the Klickitat Spring Chinook stock is of high biological significance (section 1.3). PNI index values generated by the AHA model ranged from 0.8 to 0.67 for the 200,000 smolt release program (Figure 11). These values generally provide an estimate of the spawning ground composition and environmental influences on the composite populations genetic characteristics. Although the model hypothesized the values are within acceptable ranges, management practices should carefully monitor this to the best of their ability regardless of model predictions.

One of the biological objectives of the Spring Chinook integration program is to increase the effective population size from approximately 326 to 500 adults. Generation return estimates illustrated in the time series graphs (Figures 12-15) were also used to calculate the hypothetical effective population size for the 100% natural origin broodstock integration strategies (Tables 8 & 9). Total effective population size for the large scale program ranged from 432 to 1984 depending on the harvest regime and hatchery recruitment rates. Poor hatchery recruitment rates result in low effective population estimates with little or no contribution from natural escapement. The model suggests that the effective population size may not meet the Spring Chinook biological objective under the large scale integrated program if poor hatchery recruitment rates were to persist. Total effective population size for the small scale program ranged from 586 to 1304 adults depending on the harvest regime and hatchery recruitment rates. Results point to a balanced integration program using smaller release numbers with both natural and hatchery fish contributing to the effective population size. The AHA model suggests an effective population size of 500 can potentially be maintained with the 200,000 smolt release integration program.

The AHA model has assisted us by expanding our understanding of the general relationships between hatcheries and habitat interactions. The model outputs have provided additional framework for developing hypothesis used to assist our adaptive management proposals and practices. Implementing integration strategies should use stringent monitoring and evaluation practices that will provide empirical evidence in support or modification of working hypotheses.

Spring Chinook harvest in the Klickitat has extremely high cultural significance to the Yakama Nation which offers unique, traditional fishing opportunities for tribal fishermen. The Klickitat is also a popular river with sport fishermen that offers exceptional Spring Chinook fishing opportunities. As a co-manager of the resource, it is our goal to sustain and improve these fishing opportunities while maintaining and enhancing the ecological integrity of native Klickitat Spring Chinook.

References

Ardren, W.R., and A.R. Kapuscinski. 2003. Demographic and genetic estimates of effective population size (N_e) reveal genetic compensation in steelhead trout. Molecular Ecology12:35-49.

Franklin, I. R. 1980. Evolutionary change in small populations. Pages 135-149 in M. E Soule and B. A. Wilcox, editors. Conservation biology: An evolutionary-ecological perspective. Sinauer Assoc., Sunderland, MA.

Hare, S. R. and R. C. Francis. 1994. Climate change and salmon production in the northeast Pacific Ocean, p. 357-372. *In* R. J. Beamish [ed.] Climate Change and Northern Fish Populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Hatchery Scientific Review Group (HSRG)–Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Tom Flagg, Conrad Mahnken, Robert Piper, Paul Seidel, Lisa Seeb and Bill Smoker. April 2004. Hatchery Reform: Principles and Recommendations of the HSRG. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from www.hatcheryreform.org).

Lande, R. 1988. Genetics and demography in biological conservation. Science 241:1455-1460.

Lande, R. 1995. Mutation and conservation. Conservation Biology 9:782-791.

Mantua, N. J., and S. R. Hare, et al. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bull. Am. Meteorol. Soc. 78: 1069–79.

Marshall, A. and C. Busack 2000. Genetic Analysis of Chinook Populations in the Klickitat River. Draft Report to Yakima/Klickitat Fisheries Project. Washington Department of Fish and Wildlife.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42, 156 p.

Rawding, D. 2004. An approach to population viability analysis for steelhead and salmon using stock-recruitment curves with multiple life stages. Appendix H. Interim Report on Viability Criteria for Willamette and Lower Columbia Basin Pacific Salmonids: H1-H10.

Soule, M. E. 1980. Thresholds for survival: Maintaining fitness and evolutionary potential. Pages 151-169 in M. E. Soule and B. A. Wilcox, editors. Conservation biology: An evolutionary-ecological perspective. Sinauer Assoc., Sunderland, MA.

Waples, R. S. 1990a. Conservation genetics of Pacific salmon II. Effective population size and the rate of loss of genetic variability. J. Hered. 81: 267-276.

Waples, R. S. 1990b. Conservation genetics of Pacific salmon .III. Estimating effective population size. J. Hered. 81: 277-289.

Waples, R. S. and D. J. Teel. 1990. Conservation genetics of Pacific salmon I. Temporal changes in allele frequency. Cons. Biol. 4: 144-156.

Waples, R. S. 2004. Salmonid insights into effective population size. Pp. 295-314 in A. P. Hendry and S. C. Stearns, eds. Evolution illuminated: Salmon and their relatives. Oxford University Press, Oxford, UK.

Washington Department of Fish and Wildlife and Oregon Department of Fish and Wildlife. July, 2002. Status Report. Columbia River Fish Runs and Fisheries, 1938 – 2000. Joint Columbia River Management Staff. Vancouver, Washington/ Clackamas, Oregon.

Appendix A

1.) Version 3.22 AHA Model Data Inputs

2.) Generation Escapement used for effective population estimates

3.) Integrated Hatchery Strategy 1: Scenarios 1-4 and current conditions

4.) Integrated Hatchery Strategy 2: Scenario 1

Table A 1. Data values used to model current conditions and integrated hatchery strategies: version 3.22 AHA model

H-Species	Spring Chinook	Spring Chinook	Spring Chinook
H-Stock Name	Klickitat Spring Chinook	Klickitat Spring Chinook	Klickitat Spring Chinook
H-Subbasin	Klickitat	Klickitat	Klickitat
I-Management Intent	segregated hatchery program	Integrated program	Integrated program
H-Strategy	100% hatchery broodstock	200,000 smolt release	200,000 smolt release
H-Name/Agency	Chris Frederiksen	Chris Frederiksen	Chris Frederiksen
H-Scenario Name	Current Conditions	Current Harvest Regime	Selective Fishery Regime
H-Hatchery Name	Klickitat	Klickitat	Klickitat
I- Fitness - Egg to Smolt- Relative Loss	0.4	0.4	0.4
I- Fitness - Initial Hatchery	100	100	100
I- Fitness - Initial Natural	100	100	100
I- Fitness - Spawner to Egg- Relative Loss	0.5	0.5	0.5
I- Fitness heritc	0.5	0.5	0.5
I- Fitness heritw	0.5	0.5	0.5
I- Fitness omegac	10	10	10
I- Fitness omegaw	10	10	10
I- Fitness thetac	90	90	90
I- Fitness thetaw	100	100	100
I- Fitness variance	10	10	10
I- HOR in Hatchery Eggs/Female	3803	3803	3803
I- HOR in Hatchery Female Prespawning Surv.	0.930	0.930	0.930
I- HOR in Hatchery Fry to Smolt Surv.	0.820	0.820	0.820
I- HOR in Hatchery Percent Females	0.553	0.553	0.553
I- HOR in Nature Egg to Smolt- Comp. Factor	1.000	1.000	1.000
I- HOR in Nature Egg to Smolt- Rel. Prod	1.000	1.000	1.000
I- HOR in Nature Smolt to Spawner- Comp. Factor	1.000	1.000	1.000
I- HOR in Nature Smolt to Spawner- Rel. Prod	1.000	1.000	1.000
I- HOR in Nature Spawner to Egg- Comp. Factor	1.000	1.000	1.000
I- HOR in Nature Spawner to Egg- Rel. Prod	0.800	0.800	0.800
I- HOR Post Release Smolt to Spawner	1.000	1.000	1.000
I- Initial Hatchery Population	100	100	100
I- Initial Natural Population	1000	1000	1000
I- NOR in Hatchery Egg to Smolt Survival	1	1	1
I- NOR in Hatchery Spawner to Egg Survival	1	1	1
I- NOR Smolt to Spawner Capacity	999999999	999999999	999999999
I- NOR Smolt to Spawner Productivity	0	0	0
I- NOR Spawner to Egg Capacity	10000000	10000000	10000000
I- NOR Spawner to Egg Productivity	2500	2500	2500
I- Primary Program Broodstock-Local	556	125	125
I- Primary Program Broodstock-Import	0	0	0
I- Primary Program Fitness Toggle	y	y	y
I- Primary Program Percent to Hatchery	1	0	0
I- Primary Program Percent to River	0	1	1
I- Primary Program pHOS Goal	0	1	1
I- Primary Program pNOB Goal	0	1	1
I- Primary Program Recruits per Spawner	2.35	2.35 - 6.5	2.35 - 6.5
I- Program Begin Year	0	0	0
I- Program End Year	110	110	110
I- SAR Mean for High Years	0	0	0
I- SAR Mean for Low Years	0	0	0
I- SAR Mean for Medium Years	0	0	0
I- SAR Var of Ln(SAR) for High Years	0	0	0
I- SAR Var of Ln(SAR) for Low Years	0	0	0
I- SAR Var of Ln(SAR) for Medium Years	0	0	0
I-Hab. Capacity	1175	1847	1847
I-Hab. Productivity	2.975	3.500	3.500
I-Out-of-Subbasin SAR	0	0	0
I-Harvest Rate -Mainstem -HOR	0	0	0
I-Harvest Rate -Mainstem -NOR	0	0	0
I-Harvest Rate -Marine -HOR	0	0	0
I-Harvest Rate -Marine -NOR	0	0	0
I-Harvest Rate -Terminal -HOR	0	0	0
I-Harvest Rate -Terminal -NOR	0	0	0
I-Min. NOR Escapement	1	1	1
I-Percent Reconditioned Kelts	0	0	0
I-Program Type	Integrated	Integrated	Integrated
I-Random Broodstock Switch	0.000	0.000	0.000
I-SAR - Marine	0.060	0.060	0.060
I-Juvenile passage	0.750	0.750	0.750
I-Adult passage	0.950	0.950	0.950
I-Other Hatchery Runsize	0.000	0.000	0.000
I-Other Hatchery Stray Rate	0.000	0.000	0.000
I-Variable SAR Toggle	y	y	y

Table A 2. AHA model generation computations used for estimated effective population size: 200,000 smolt release program, 2.35 recruits per spawner.

	200,000 smolt release program: 100% natural brood													
	Natural Spawners							Natural Spawners						
	2.35 R/S, Current Harvest Regime							2.35 R/S, Selective Fishery Harvest Regime						
Generation	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total
-	58	58	0	463	153	521	172	55	55	0	556	183	611	202
1	7	7	0	519	171	526	174	6	6	0	682	225	688	227
2	357	357	0	1006	332	1363	450	340	340	0	1360	449	1700	561
3	167	167	0	635	209	802	265	159	159	0	809	267	968	320
4	155	155	0	466	154	621	205	148	148	0	611	202	759	251
5	132	132	0	326	107	458	151	126	126	0	447	147	573	189
6	124	124	0	237	78	361	119	118	118	0	347	115	465	154
7	150	150	0	257	85	407	134	143	143	0	390	129	533	176
8	132	132	0	234	77	366	121	126	126	0	360	119	486	160
9	108	108	0	151	50	259	86	103	103	0	254	84	357	118
10	114	114	0	107	35	221	73	108	108	0	209	69	317	105
11	198	198	0	230	76	428	141	189	189	0	413	136	602	199
12	567	567	0	1433	473	2000	660	541	541	0	2064	681	2605	859
13	211	211	0	927	306	1138	376	201	201	0	1162	383	1363	450
14	129	129	0	433	143	562	185	123	123	0	559	185	682	225
15	147	147	0	351	116	498	164	140	140	0	481	159	621	205
16	166	166	0	378	125	544	180	158	158	0	529	175	687	227
17	117	117	0	248	82	365	120	112	112	0	360	119	472	156
18	129	129	0	204	67	333	110	123	123	0	319	105	442	146
19	110	110	0	139	46	249	82	105	105	0	241	80	346	114
20	134	134	0	139	46	273	90	128	128	0	261	86	389	128
21	224	224	0	340	112	564	186	214	214	0	562	185	776	256
22	416	416	0	1200	396	1616	533	396	396	0	1670	551	2066	682
23	285	285	0	1221	403	1506	497	272	272	0	1533	506	1805	596
24	130	130	0	481	159	611	202	124	124	0	612	202	736	243
25	113	113	0	257	85	370	122	108	108	0	359	118	467	154
26	116	116	0	174	57	290	96	111	111	0	272	90	383	127
27	123	123	0	144	48	267	88	118	118	0	252	83	370	122
28	129	129	0	139	46	268	89	123	123	0	259	85	382	126
29	143	143	0	168	55	311	102	136	136	0	308	102	444	147
30	151	151	0	215	71	366	121	144	144	0	373	123	517	171
31	273	273	0	560	185	833	275	260	260	0	853	281	1113	367
32	458	458	0	1612	532	2070	683	437	437	0	2132	703	2569	848
33	234	234	0	1042	344	1276	421	223	223	0	1292	426	1515	500
34	155	155	0	564	186	719	237	148	148	0	717	237	865	285
35	133	133	0	355	117	488	161	127	127	0	478	158	605	200
36	162	162	0	360	119	522	172	155	155	0	506	167	661	218
37	121	121	0	251	83	372	123	116	116	0	367	121	483	159
38	139	139	0	230	76	369	122	132	132	0	357	118	489	161
39	133	133	0	211	70	344	114	126	126	0	337	111	463	153
40	136	136	0	204	67	340	112	129	129	0	335	111	464	153
41	207	207	0	371	122	578	191	197	197	0	574	189	771	254
42	583	583	0	1750	578	2333	770	556	556	0	2380	785	2936	969
43	197	197	0	877	290	1074	355	187	187	0	1091	360	1278	422
44	133	133	0	436	144	569	188	127	127	0	565	186	692	228
45	122	122	0	271	89	393	130	117	117	0	381	126	498	164
46	103	103	0	149	49	252	83	99	99	0	240	79	339	112
47	123	123	0	117	39	240	79	117	117	0	222	73	339	112
48	157	157	0	171	56	328	108	150	150	0	317	105	467	154
49	128	128	0	172	57	300	99	122	122	0	309	102	431	142
50	109	109	0	116	38	225	74	104	104	0	228	75	332	110
Harmonic Mean					87		142					140		189
Effective population Size					366		597					586		796

Table A 3. AHA model generation computations used for estimated effective population size: 200,000 smolt release program, 6.5 recruits per spawner.

	200,000 smolt release program: 100% natural brood												
	Natural Spawners							Natural Spawners					
	6.5 R/S, Current Harvest Regime							6.5 R/S, Selective Fishery Harvest Regime					
Generation	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.
0	58	58	0	463	153	521	172	55	55	0	556	183	611
1	53	53	0	519	171	572	189	51	51	0	682	225	733
2	988	988	0	1052	347	2040	673	942	942	0	1400	462	2342
3	462	462	0	704	232	1166	385	440	440	0	867	286	1307
4	429	429	0	543	179	972	321	409	409	0	679	224	1088
5	366	366	0	409	135	775	256	349	349	0	522	172	871
6	343	343	0	332	110	675	223	327	327	0	434	143	761
7	417	417	0	396	131	813	268	398	398	0	516	170	914
8	366	366	0	369	122	735	243	349	349	0	480	158	829
9	299	299	0	264	87	563	186	286	286	0	352	116	638
10	315	315	0	234	77	549	181	300	300	0	322	106	622
11	549	549	0	489	161	1038	342	524	524	0	640	211	1164
12	1569	1569	0	2182	720	3751	1238	1496	1496	0	2678	884	4174
13	585	585	0	1034	341	1619	534	558	558	0	1241	409	1799
14	358	358	0	485	160	843	278	342	342	0	603	199	945
15	407	407	0	435	143	842	278	388	388	0	557	184	945
16	459	459	0	501	165	960	317	438	438	0	640	211	1078
17	325	325	0	342	113	667	220	310	310	0	443	146	753
18	357	357	0	317	104	674	222	341	341	0	420	139	761
19	306	306	0	252	83	558	184	292	292	0	341	113	633
20	372	372	0	293	97	665	220	355	355	0	397	131	752
21	621	621	0	632	208	1253	413	592	592	0	813	268	1405
22	1151	1151	0	1668	550	2819	930	1098	1098	0	2043	674	3141
23	789	789	0	1365	451	2154	711	753	753	0	1641	541	2394
24	360	360	0	525	173	885	292	344	344	0	647	214	991
25	314	314	0	314	103	628	207	300	300	0	409	135	709
26	322	322	0	259	86	581	192	307	307	0	351	116	658
27	342	342	0	266	88	608	201	327	327	0	362	119	689
28	357	357	0	290	96	647	214	340	340	0	392	129	732
29	396	396	0	350	115	746	246	378	378	0	465	153	843
30	418	418	0	410	135	828	273	399	399	0	535	176	934
31	756	756	0	886	292	1642	542	721	721	0	1117	369	1838
32	1268	1268	0	1999	660	3267	1078	1209	1209	0	2425	800	3634
33	648	648	0	1122	370	1770	584	618	618	0	1349	445	1967
34	430	430	0	615	203	1045	345	411	411	0	759	250	1170
35	369	369	0	418	138	787	260	351	351	0	533	176	884
36	450	450	0	466	154	916	302	429	429	0	601	198	1030
37	337	337	0	344	114	681	225	321	321	0	448	148	769
38	384	384	0	348	115	732	242	367	367	0	461	152	828
39	367	367	0	340	112	707	233	351	351	0	450	149	801
40	376	376	0	344	114	720	238	359	359	0	456	150	815
41	573	573	0	593	196	1166	385	546	546	0	764	252	1310
42	1613	1613	0	2309	762	3922	1294	1539	1539	0	2831	934	4370
43	545	545	0	944	312	1489	491	519	519	0	1138	376	1657
44	370	370	0	482	159	852	281	353	353	0	603	199	956
45	339	339	0	335	111	674	223	323	323	0	438	145	761
46	287	287	0	226	75	513	169	274	274	0	309	102	583
47	340	340	0	235	78	575	190	324	324	0	328	108	652
48	436	436	0	362	120	798	263	416	416	0	486	160	902
49	355	355	0	338	112	693	229	338	338	0	446	147	784
50	301	301	0	247	81	548	181	287	287	0	336	111	623
Harmonic Mean					138		274					181	
Effective population Size					581		1151					761	

Table A 4. AHA model generation computations used for estimated effective population size: 800,000 smolt release program, 2.35 recruits per spawner.

	800,000 smolt release program: 100% Natural brood													
	Natural Spawners							Natural Spawners						
	2.35 R/S, Current Harvest Regime							2.35 R/S, Selective Fishery Harvest Regime						
Generation	SHN (HOStotal	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total
-	58	58	0	88	29	146	48	55	55	0	181	60	236	78
1	28	28	0	2	1	30	10	26	26	0	1	0	27	9
2	781	781	0	1	0	782	258	1261	1261	0	1	0	1262	417
3	132	132	0	65	22	197	65	133	133	0	290	96	423	139
4	624	624	0	2	1	626	206	595	595	0	1	0	596	197
5	258	258	0	2	1	260	86	504	504	0	1	0	505	167
6	398	398	0	2	1	400	132	430	430	0	2	1	432	143
7	260	260	0	2	1	262	86	445	445	0	2	1	447	147
8	376	376	0	1	0	377	125	436	436	0	1	0	437	144
9	200	200	0	2	1	202	67	317	317	0	2	1	319	105
10	222	222	0	1	0	223	74	270	270	0	2	1	272	90
11	259	259	0	2	1	261	86	401	401	0	1	0	402	133
12	1413	1413	0	476	157	1889	624	1806	1806	0	1025	338	2831	934
13	852	852	0	490	162	1342	443	812	812	0	759	251	1571	519
14	521	521	0	56	18	577	190	497	497	0	185	61	682	225
15	592	592	0	1	0	593	196	565	565	0	63	21	628	207
16	571	571	0	2	1	573	189	637	637	0	86	28	723	239
17	448	448	0	1	0	449	148	451	451	0	1	0	452	149
18	344	344	0	2	1	346	114	442	442	0	2	1	444	146
19	280	280	0	1	0	281	93	314	314	0	2	1	316	104
20	248	248	0	2	1	250	82	322	322	0	2	1	324	107
21	434	434	0	1	0	435	144	527	527	0	20	7	547	180
22	1248	1248	0	490	162	1738	573	1597	1597	0	830	274	2427	801
23	1148	1148	0	789	261	1937	639	1095	1095	0	1125	371	2220	733
24	524	524	0	111	37	635	210	500	500	0	239	79	739	244
25	458	458	0	1	0	459	152	437	437	0	1	0	438	145
26	326	326	0	2	1	328	108	400	400	0	1	0	401	132
27	283	283	0	2	1	285	94	307	307	0	2	1	309	102
28	254	254	0	1	0	255	84	321	321	0	2	1	323	106
29	267	267	0	1	0	268	88	314	314	0	2	1	316	104
30	289	289	0	2	0	291	96	378	378	0	1	0	379	125
31	569	569	0	2	1	571	188	711	711	0	190	63	901	297
32	1830	1830	0	758	250	2588	854	1760	1760	0	1404	463	3164	1044
33	943	943	0	644	213	1587	524	899	899	0	895	295	1794	592
34	626	626	0	189	62	815	269	598	598	0	334	110	932	308
35	536	536	0	2	1	538	177	512	512	0	75	25	587	194
36	598	598	0	2	1	600	198	625	625	0	47	16	672	222
37	422	422	0	1	0	423	140	467	467	0	2	1	469	155
38	382	382	0	2	1	384	127	459	459	0	2	1	461	152
39	342	342	0	1	0	343	113	405	405	0	2	1	407	134
40	315	315	0	1	0	316	104	391	391	0	1	0	392	129
41	456	456	0	1	0	457	151	565	565	0	30	10	595	196
42	1849	1849	0	902	298	2751	908	2239	2239	0	1418	468	3657	1207
43	792	792	0	469	155	1261	416	756	756	0	685	226	1441	476
44	539	539	0	48	16	587	194	514	514	0	172	57	686	226
45	493	493	0	1	0	494	163	470	470	0	1	0	471	155
46	289	289	0	2	1	291	96	360	360	0	1	0	361	119
47	256	256	0	2	1	258	85	279	279	0	1	0	280	92
48	278	278	0	2	1	280	92	359	359	0	1	0	360	119
49	267	267	0	2	1	269	89	316	316	0	1	0	317	105
50	195	195	0	2	1	197	65	258	258	0	1	0	259	86
Harmonic Mean					1		103					1		121
Effective population Size					3		432					3		509

Table A 5. AHA model generation computations used for estimated effective population size: 800,000 smolt release program, 6.5 recruits per spawner.

	800,000 smolt release program: 100% Natural brood													
	Natural Spawners							Natural Spawners						
	6.5 R/S, Current Harvest Regime							6.5 R/S, Selective Fishery Harvest Regime						
Generation	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total	SHN (HOStotal)	SHN (HOS)	Surpl SHN (HOS)	SNN (NOS)	Effective NOS	Total Esc.	Effective Total
-	58	58	0	88	29	146	48	55	55	0	181	60	236	78
1	215	215	0	2	1	217	72	206	206	0	1	0	207	68
2	2160	2160	0	51	17	2211	730	3490	3490	0	122	40	3612	1192
3	1860	1860	0	299	99	2159	713	1774	1774	0	515	170	2289	755
4	1727	1727	0	241	79	1968	649	1647	1647	0	385	127	2032	671
5	1473	1473	0	124	41	1597	527	1405	1405	0	236	78	1641	541
6	1382	1382	0	45	15	1427	471	1318	1318	0	147	48	1465	483
7	1679	1679	0	140	46	1819	600	1602	1602	0	258	85	1860	614
8	1474	1474	0	100	33	1574	519	1406	1406	0	210	69	1616	533
9	1206	1206	0	1	0	1207	398	1151	1151	0	61	20	1212	400
10	1203	1203	0	2	1	1205	398	1210	1210	0	30	10	1240	409
11	1975	1975	0	287	95	2262	746	2108	2108	0	427	141	2535	836
12	6315	6315	0	2204	727	8519	2811	6024	6024	0	2748	907	8772	2895
13	2356	2356	0	718	237	3074	1014	2248	2248	0	921	304	3169	1046
14	1443	1443	0	163	54	1606	530	1376	1376	0	281	93	1657	547
15	1639	1639	0	145	48	1784	589	1563	1563	0	264	87	1827	603
16	1848	1848	0	242	80	2090	690	1763	1763	0	379	125	2142	707
17	1309	1309	0	51	17	1360	449	1248	1248	0	149	49	1397	461
18	1440	1440	0	29	10	1469	485	1374	1374	0	130	43	1504	496
19	1231	1231	0	2	1	1233	407	1175	1175	0	49	16	1224	404
20	1382	1382	0	28	9	1410	465	1430	1430	0	119	39	1549	511
21	2501	2501	0	424	140	2925	965	2385	2385	0	617	204	3002	991
22	4632	4632	0	1568	517	6200	2046	4418	4418	0	1937	639	6355	2097
23	3177	3177	0	1079	356	4256	1404	3031	3031	0	1347	444	4378	1445
24	1451	1451	0	192	64	1643	542	1384	1384	0	313	103	1697	560
25	1267	1267	0	1	0	1268	418	1208	1208	0	88	29	1296	428
26	1284	1284	0	1	0	1285	424	1238	1238	0	45	15	1283	423
27	1260	1260	0	1	0	1261	416	1315	1315	0	73	24	1388	458
28	1403	1403	0	5	2	1408	465	1371	1371	0	114	38	1485	490
29	1595	1595	0	81	27	1676	553	1522	1522	0	197	65	1719	567
30	1683	1683	0	150	49	1833	605	1605	1605	0	271	89	1876	619
31	3044	3044	0	709	234	3753	1239	2904	2904	0	929	307	3833	1265
32	5103	5103	0	1858	613	6961	2297	4868	4868	0	2267	748	7135	2355
33	2609	2609	0	797	263	3406	1124	2488	2488	0	1017	336	3505	1157
34	1734	1734	0	294	97	2028	669	1654	1654	0	432	143	2086	689
35	1484	1484	0	109	36	1593	526	1416	1416	0	220	73	1636	540
36	1812	1812	0	189	63	2001	660	1729	1729	0	318	105	2047	675
37	1356	1356	0	50	17	1406	464	1294	1294	0	149	49	1443	476
38	1549	1549	0	63	21	1612	532	1477	1477	0	170	56	1647	543
39	1480	1480	0	61	20	1541	508	1412	1412	0	164	54	1576	520
40	1515	1515	0	66	22	1581	522	1446	1446	0	171	56	1617	534
41	2306	2306	0	367	121	2673	882	2199	2199	0	527	174	2726	900
42	6494	6494	0	2302	760	8796	2903	6194	6194	0	2796	923	8990	2967
43	2193	2193	0	601	198	2794	922	2092	2092	0	787	260	2879	950
44	1491	1491	0	155	51	1646	543	1422	1422	0	271	89	1693	559
45	1365	1365	0	24	8	1389	458	1302	1302	0	121	40	1423	469
46	1156	1156	0	1	0	1157	382	1103	1103	0	2	1	1105	365
47	1133	1133	0	1	0	1134	374	1285	1285	0	27	9	1312	433
48	1612	1612	0	85	28	1697	560	1675	1675	0	220	73	1895	625
49	1429	1429	0	47	15	1476	487	1363	1363	0	162	54	1525	503
50	1214	1214	0	2	1	1216	401	1158	1158	0	30	10	1188	392
Harmonic Mean					2		431					10		472
Effective population Size					9		1810					40		1984

Table A 6. Predicted Spring Chinook return numbers for integrated 800,000 smolt release program using 100% natural broodstock: version 3.22 AHA model.

	Scenario 1: 100% natural brood program with varying R:S for hatchery recruits																																
Hatchery				2.35 R/S						3.5 R/S						4.5 R/S						5.5 R/S						6.5 R/S					
	Current Predictions			Current Harvest Regime			Selective Fishery Harvest Regime			Current Harvest Regime			Selective Fishery Harvest Regime			Current Harvest Regime			Selective Fishery Harvest Regime			Current Harvest Regime			Selective Fishery Harvest Regime			Current Harvest Regime			Selective Fishery Harvest Regime		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	0	395	0	192	0	0	241	0	0	283	0	0	334	0	0	317	0	0	380	0	0	343	0	0	412	0	0	367	0	0	436	0	0
Max	0	556	2431	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1	499	0	1
Average	0	538	269	363	0	1	420	0	1	442	0	0	481	0	0	474	0	1	494	0	0	487	0	1	497	0	1	493	0	0	498	0	1
Harvest																																	
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	206	574		343	391		297	487		472	715		389	816		532	973		428	1072		570	1217		452	1316		595	1451		469	1558	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
NOR	206	83	712	343	136	1111	297	114	993	472	200	1752	389	158	1498	532	224	2037	428	180	1651	570	243	2167	452	195	1724	595	259	2260	469	206	1773
HOR	574	282	2125	391	143	1422	487	203	1995	715	316	2840	816	423	3026	973	481	3651	1072	545	3890	1217	624	4463	1316	666	4755	1451	739	5274	1558	787	5619
Range Total Harvest	780	372	2834	734	280	2533	784	317	2988	1186	516	4577	1205	582	4522	1506	708	5688	1500	725	5516	1786	867	6618	1768	861	6458	2046	998	7509	2027	994	7376
Sp. Escapement																																	
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	293	0	8	125	554	0	211	70	549	228	1015	0	346	115	922	282	1382	0	415	138	1224	321	1727	0	464	154	1518	352	2060	0	499	166	1814
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Range (NORs)	293	117	1010	125	1	1078	211	1	1609	228	1	1989	346	1	2682	282	1	2393	415	1	3008	321	1	2578	464	1	3163	352	1	2709	499	1	3268
Total Nat Escap.	Min	121		Min	204			259		Min	449			538		Min	684			694		Min	888			848		Min	1050			1002	
	Max	1039		Max	3097			4145		Max	6000			6525		Max	7577			7899		Max	8897			9162		Max	10162			10375	
	Ave	300		Ave	679			830		Ave	1242			1383		Ave	1664			1777		Ave	2049			2136		Ave	2412			2479	
Total Recruitment																																	
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	499	1388		831	945		928	1106		1141	1730		1216	1853		1288	2356		1338	2434		1378	2944		1413	2989		1440	3511		1466	3538	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	1887	901	6857	1776	676	6129	2035	818	7632	2871	1248	11077	3070	1456	11547	3644	1714	13764	3772	1799	13914	4323	2098	16015	4402	2122	16118	4952	2416	18170	5004	2432	18251
PNI Index value		-			0.52			0.54			0.53			0.54			0.53			0.55			0.53			0.55			0.53			0.55	

Table A 7. **Predicted Spring Chinook return numbers for integrated 800,000 smolt release program using 75% natural broodstock: version 3.22 AHA model.**

Scenario 2: 75% natural brood program with varying R:S for hatchery recruits,

	2.35 R/S					
	Current Harvest Regime			Selective Fishery Harvest Reg		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	151	50	5	203	48	0
Max	375	125	558	375	125	624
Average	302	100	67	342	106	58
Harvest	NORs	HORs		NORs	HORs	
Composition	337	450		306	537	
	Ave	Min	Max	Ave	Min	Max
NOR	337	107	1010	306	97	1118
HOR	450	146	1848	537	208	2454
Range Total Harvest	787	253	2858	842	304	3473
Sp. Escapement	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	177	472	0	308	102	416
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	177	1	1059	308	1	1999
Total Nat Escap.	Min	154			202	
	Max	3000			4159	
	Ave	649			826	
Total Recruitment	NORs	HORs		NORs	HORs	
Composition	816	1089		955	1219	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	1905	613	6916	2174	773	8755
PNI Index value	0.47			0.49		

	3.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Regim		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	284	80	0	358	85	0
Max	375	125	606	375	125	573
Average	366	115	56	374	113	52
Harvest	NORs	HORs		NORs	HORs	
Composition	503	799		413	862	
	Ave	Min	Max	Ave	Min	Max
NOR	503	201	2159	413	169	1798
HOR	799	377	3431	862	448	3655
Range Total Harvest	1302	585	5590	1274	633	5454
Sp. Escapement	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	349	964	0	502	167	764
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	349	1	2690	502	1	3445
Total Nat Escap.	Min	456			501	
	Max	6830			7394	
	Ave	1313			1432	
Total Recruitment	NORs	HORs		NORs	HORs	
Composition	1217	1934		1289	1957	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	3151	1416	13526	3246	1595	13920
PNI Index value	0.47			0.5		

	4.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Reg		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	353	74	0	375	88	0
Max	375	125	502	375	125	592
Average	374	105	42	375	115	55
Harvest	NORs	HORs		NORs	HORs	
Composition	560	1025		450	1113	
	Ave	Min	Max	Ave	Min	Max
NOR	560	250	2457	450	207	1968
HOR	1025	526	4411	1113	579	4700
Range Total Harvest	1586	779	6868	1562	786	6668
Sp. Escapement	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	422	1310	0	580	193	1051
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	422	1	3114	580	64	3804
Total Nat Escap.	Min	672			711	
	Max	8750			9061	
	Ave	1731			1824	
Total Recruitment	NORs	HORs		NORs	HORs	
Composition	1356	2481		1405	2527	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	3837	1886	16620	3932	1961	16821
PNI Index value	0.47			0.5		

	5.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Regi		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	375	84	0	375	90	0
Max	375	125	565	375	125	606
Average	375	112	51	375	117	57
Harvest	NORs	HORs		NORs	HORs	
Composition	596	1270		473	1363	
	Ave	Min	Max	Ave	Min	Max
NOR	596	277	2606	473	222	2062
HOR	1270	658	5391	1363	712	5744
Range Total Harvest	1866	935	7997	1835	934	7806
Sp. Escapement	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	471	1641	0	629	209	1349
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	471	18	3325	629	96	4004
Total Nat Escap.	Min	867			910	
	Max	10290			10575	
	Ave	2112			2187	
Total Recruitment	NORs	HORs		NORs	HORs	
Composition	1442	3074		1477	3095	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	4516	2262	19352	4571	2311	19487
PNI Index value	0.47			0.49		

	6.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Regime		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	375	75	0	375	84	0
Max	375	125	509	375	125	566
Average	375	106	43	375	112	51
Harvest	NORs	HORs		NORs	HORs	
Composition	619	1486		489	1600	
	Ave	Min	Max	Ave	Min	Max
NOR	619	293	2695	489	233	2123
HOR	1486	761	6372	1600	830	6789
Range Total Harvest	2105	1054	9067	2089	1063	8912
Sp. Escapement	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	504	1962	0	663	221	1650
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	504	41	3452	663	120	4135
Total Nat Escap.	Min	1045			1090	
	Max	11865			12074	
	Ave	2466			2534	
Total Recruitment	NORs	HORs		NORs	HORs	
Composition	1498	3596		1527	3634	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	5094	2550	21941	5161	2613	22051
PNI Index value	0.47			0.49		

Table A 8. Predicted Spring Chinook return numbers for integrated 800,000 smolt release program using 50% natural broodstock: version 3.22 AHA model.

	Scenario 3: 50% natural brood program with varying R:S for hatchery recruits																													
Hatchery	2.35 R/S						3.5 R/S						4.5 R/S						5.5 R/S						6.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Reg			Current Harvest Regime			Selective Fishery Harvest Regim			Current Harvest Regime			Selective Fishery Harvest Reg			Current Harvest Regime			Selective Fishery Harvest Regi			Current Harvest Regime			Selective Fishery Harvest Regime		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	131	131	0	157	105	0	250	212	0	250	214	0	250	216	0	250	214	0	250	215	0	250	215	0	250	220	0	250	208	0
Max	250	250	1353	250	250	1279	250	250	1406	250	250	1424	250	250	1441	250	250	1423	250	250	1435	250	250	1430	250	250	1470	250	250	1391
Average	232	228	130	245	218	127	250	246	150	250	247	154	250	248	158	250	247	154	250	247	156	250	247	155	250	248	164	250	245	146
Harvest																														
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	339	514		304	553		506	820		413	874		557	1056		446	1124		589	1290		467	1374		611	1527		482	1620	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
NOR	339	93	1164	304	75	1153	506	210	2190	413	179	1786	557	255	2427	446	207	1937	589	276	2560	467	221	2025	611	292	2651	482	232	2084
HOR	514	207	2304	553	228	2454	820	440	3431	874	468	3655	1056	565	4411	1124	602	4700	1290	691	5391	1374	736	5744	1527	816	6372	1620	864	6789
Range Total Harvest	853	301	3302	857	303	3459	1326	665	5621	1287	655	5441	1613	820	6838	1570	809	6637	1879	967	7952	1841	957	7769	2138	1108	9022	2102	1096	8873
Sp. Escapement																														
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	249	372	0	400	133	225	468	768	0	627	208	502	541	1094	0	697	232	796	587	1428	0	742	247	1098	618	1755	0	774	257	1410
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Range (NORs)	249	1	1402	400	1	2198	468	48	2860	627	130	3543	541	112	3196	697	189	3864	587	143	3385	742	219	4051	618	164	3514	774	242	4176
Total Nat Escap.	Min	151			149		Min	480			527		Min	697			740		Min	907			939		Min	1102			1132	
	Max	2836			3474		Max	6075			6516		Max	7768			8165		Max	9355			9673		Max	10841			11165	
	Ave	621			758		Ave	1236			1337		Ave	1635			1725		Ave	2015			2086		Ave	2373			2442	
Total Recruitment																														
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	820	1243		949	1257		1225	1983		1290	1985		1348	2555		1393	2553		1426	3121		1459	3121		1479	3694		1506	3680	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Minimum escapement **Range**	2064	727	7990	2206	752	8712	3208	1608	13602	3275	1647	13881	3903	1985	16547	3946	2014	16725	4547	2340	19242	4579	2361	19372	5173	2681	21833	5186	2687	21928
PNI Index value		0.39			0.45			0.42			0.46			0.4			0.43			0.4			0.42			0.39			0.41	

Table A 9. Predicted Spring Chinook return numbers for integrated 800,000 smolt release program using 25% natural broodstock: version 3.22 AHA model.

	Scenario 4: 25% natural brood program with varying R:S for hatchery recruits											
	2.35 R/S						3.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Reg			Current Harvest Regime			Selective Fishery Harvest Regim		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	107	253	1	125	165	26	125	318	0	125	321	0
Max	125	375	2079	125	375	2122	125	375	2110	125	375	2135
Average	125	360	216	125	339	225	125	368	223	125	369	229
Harvest												
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	351	541		324	554		496	816		404	871	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
NOR	351	76	1226	324	98	1182	496	214	2121	404	180	1730
HOR	541	259	2304	554	228	2454	816	440	3431	871	468	3655
Range Total Harvest	892	336	3526	878	326	3637	1312	664	5552	1275	654	5386
Sp. Escapement												
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	374	192	0	563	133	7	579	567	0	734	244	265
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Range (NORs)	374	1	1615	563	83	2386	579	179	2887	734	257	3550
Total Nat Escap.	Min	93			141		Min	492			541	
	Max	2428			3009		Max	5273			5687	
	Ave	566			704		Ave	1147			1242	
Total Recruitment												
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	850	1309		1012	1258		1201	1975		1263	1978	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Minimum escapement **Range**	2159	813	8533	2271	824	9268	3175	1606	13435	3241	1643	13707
PNI Index value		0.37			0.52			0.32			0.36	

	4.5 R/S						5.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Reg			Current Harvest Regime			Selective Fishery Harvest Regi		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	125	320	0	125	310	0	125	310	0	125	327	0
Max	125	375	2131	125	375	2075	125	375	2075	125	375	2181
Average	125	369	228	125	366	215	125	366	215	125	371	240
Harvest												
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	541	1051		433	1115		570	1279		451	1373	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
NOR	541	251	2331	433	204	1864	570	271	2455	451	215	1943
HOR	1051	565	4411	1115	596	4700	1279	684	5391	1373	736	5744
Range Total Harvest	1592	816	6742	1548	800	6564	1849	955	7846	1824	951	7687
Sp. Escapement												
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	643	895	0	795	265	571	685	1234	0	833	277	856
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Range (NORs)	643	232	3184	795	308	3834	685	260	3360	833	332	4002
Total Nat Escap.	Min	713			755		Min	920			940	
	Max	6941			7358		Max	8565			8748	
	Ave	1538			1631		Ave	1919			1967	
Total Recruitment												
	NORs	HORs		NORs	HORs		NORs	HORs		NORs	HORs	
Composition	1309	2543		1354	2532		1380	3094		1409	3117	
	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
Minimum escapement **Range**	3852	1976	16314	3885	1990	16497	4474	2311	18986	4527	2343	19116
PNI Index value		0.29			0.32			0.27			0.3	

	6.5 R/S					
	Current Harvest Regime			Selective Fishery Harvest Regime		
Hatchery	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	125	324	0	125	320	0
Max	125	375	2159	125	375	2128
Average	125	371	234	125	369	227
Harvest						
	NORs	HORs		NORs	HORs	
Composition	590	1520		465	1617	
	Ave	Min	Max	Ave	Min	Max
NOR	590	284	2540	465	225	2000
HOR	1520	816	6372	1617	870	6789
Range Total Harvest	2111	1100	8912	2082	1095	8788
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	713	1554	0	864	287	1171
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	713	279	3481	864	353	4122
Total Nat Escap.	Min	1113			1137	
	Max	9994			10249	
	Ave	2267			2322	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1429	3679		1454	3672	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement **Range**	5108	2663	21565	5126	2678	21665
PNI Index value		0.26			0.28	

Table A 10. Predicted Spring Chinook return numbers for integrated 200,000 smolt release program using 100% natural broodstock: version 3.22 AHA model.

Scenario 5: 100% natural brood program with varying R:S for hatchery recruits 200,000 smolt release program

	2.35 R/S					
Hatchery	Current Harvest Regime			Selective Fishery Harvest Reg		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	124	0	0	124	0	0
Max	124	0	1	124	0	1
Average	124	0	0	124	0	0
Harvest						
	NORs	HORs		NORs	HORs	
Composition	425	137		378	146	
	Ave	Min	Max	Ave	Min	Max
NOR	425	141	1682	378	150	1573
HOR	137	73	571	146	78	609
Range Total Harvest	562	226	2253	525	238	2182
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	479	194	0	680	172	13
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	479	76	2264	680	194	3218
Total Nat Escap.	Min	196			309	
	Max	3075			3991	
	Ave	673			865	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1028	332		1182	332	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	1360	547	5452	1514	671	6298
PNI Index value	0.74			0.8		

	3.5 R/S					
Hatchery	Current Harvest Regime			Selective Fishery Harvest Regim		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	124	0	0	124	0	0
Max	124	0	1	124	0	1
Average	124	0	0	124	0	1
Harvest						
	NORs	HORs		NORs	HORs	
Composition	477	204		405	218	
	Ave	Min	Max	Ave	Min	Max
NOR	477	190	2010	405	175	1724
HOR	204	109	851	218	116	907
Range Total Harvest	682	311	2861	622	299	2631
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	554	290	0	735	276	0
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	554	145	2730	735	249	3539
Total Nat Escap.	Min	318			408	
	Max	3938			4691	
	Ave	843			1012	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1155	494		1264	494	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	1649	754	6923	1759	834	7446
PNI Index value	0.72			0.77		

	4.5 R/S					
Hatchery	Current Harvest Regime			Selective Fishery Harvest Reg		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	124	0	0	124	0	0
Max	124	0	1	124	0	1
Average	124	0	1	124	0	0
Harvest						
	NORs	HORs		NORs	HORs	
Composition	506	263		421	280	
	Ave	Min	Max	Ave	Min	Max
NOR	506	218	2169	421	190	1810
HOR	263	140	1094	280	149	1166
Range Total Harvest	769	365	3263	701	340	2976
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	595	372	0	770	355	0
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	595	185	2956	770	279	3721
Total Nat Escap.	Min	394			470	
	Max	4509			5202	
	Ave	967			1125	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1225	636		1315	636	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	1861	884	7896	1951	935	8302
PNI Index value	0.7			0.74		

	5.5 R/S					
Hatchery	Current Harvest Regime			Selective Fishery Harvest Regi		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	124	0	0	124	0	0
Max	124	0	1	124	0	1
Average	124	0	0	124	0	0
Harvest						
	NORs	HORs		NORs	HORs	
Composition	528	321		434	342	
	Ave	Min	Max	Ave	Min	Max
NOR	528	236	2281	434	198	1874
HOR	321	171	1337	342	182	1425
Range Total Harvest	849	408	3618	776	380	3299
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	626	455	0	797	434	0
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	626	212	3115	797	296	3856
Total Nat Escap.	Min	455			527	
	Max	5013			5666	
	Ave	1081			1232	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1278	777		1355	777	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	2055	987	8755	2132	1032	9090
PNI Index value	0.685			0.724		

	6.5 R/S					
Hatchery	Current Harvest Regime			Selective Fishery Harvest Regime		
	NOR	HOR	Surplus HORs	NOR	HOR	Surplus HORs
Min	124	0	0	124	0	0
Max	124	0	1	124	0	1
Average	124	0	0	124	0	1
Harvest						
	NORs	HORs		NORs	HORs	
Composition	546	380		444	404	
	Ave	Min	Max	Ave	Min	Max
NOR	546	246	2368	444	204	1925
HOR	380	202	1580	404	216	1684
Range Total Harvest	925	449	3948	849	420	3609
Sp. Escapement						
	NORs	HORs	Surplus HORs	NORs	HORs	Surplus HORs
Composition	651	538	0	820	513	0
	Ave	Min	Max	Ave	Min	Max
Range (NORs)	651	226	3238	820	309	3965
Total Nat Escap.	Min	513			583	
	Max	5481			6105	
	Ave	1189			1333	
Total Recruitment						
	NORs	HORs		NORs	HORs	
Composition	1321	918		1388	918	
	Ave	Min	Max	Ave	Min	Max
Minimum escapement Range	2239	1086	9553	2307	1127	9839
PNI Index value	0.672			0.71		