Status and Expected Time to Extinction for Snake River Spring and Summer Chinook Stocks:
The Doomsday Clock and Salmon Recovery Index Models Applied to the Snake River Basin

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Acknowledgements

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Executive Summary

Snake River spring and summer chinook numbers, which have been declining for some time, have reached precariously low levels. In recognition of the species' decline, the National Marine Fisheries Service (NMFS) listed Snake River spring and summer chinook as threatened under the federal Endangered Species Act (ESA) in 1992. As part of ESA implementation NMFS committed in 1995 to making decisions regarding the long-term operations of federal Columbia and Snake River dams that impact ESA-listed salmon by the end of 1999.

A critical consideration in developing a workable solution to save Snake River fish from extinction is how soon the restoration activities need to occur. Decisions regarding the timing of recovery actions need to be made in view of the rate at which salmon populations are being eliminated from the wild, and the time at which the populations may be expected to become extinct.

Two models, the Salmon Recovery Index, or SRI, (Figure a) and the Doomsday Clock, or Clock (Table a) were developed to describe and evaluate the status and expected time to extinction for spring and summer chinook in the Snake River basin. The SRI describes the current rate of increase of a group of salmon populations, while the Clock provides a measure of how long salmon may be expected to survive at the current growth rate.

The Clock provides a measure of the expected time until extinction for salmon spawning at survey sites, called demes. Using data provided by Idaho Fish and Game and the Oregon Department of Fish and Wildlife, the Clock predicts that all five brood lines of the Snake River spring and summer chinook will be extirpated between 2008 and 2017 (Table a). Although some adult spring and summer chinook salmon should still be returning to the Snake River in 2017, the listed species would no longer be a naturally self-sustaining wild animal population at that time. Unless current conditions change for the better, it is expected that only the strongest of the thirteen demes studied will have spawners after 2023. This situation could change for the worse, because the strongest deme, Poverty Flats of the Salmon River, has had lower than expected return rates in the three most recent brood years (1991 – 1993).

The SRI indicates that the processes leading to the extinctions predicted by the Clock have been underway in 15 of the 19 salmon generations completed between 1980 and 1998. Fifteen of the annual SRI values were less than 100 (Figure a), the level below which populations are declining. The short hiatus in the extinction process for generations ending in 1985 - 1988 (brood years 1980 – 1983) is responsible for the spring and summer chinook spawners currently returning to the Snake River. All demes other than the Imnaha River should have

been extirpated by 1998 without the exceptionally high R/S levels experienced during the generations ending 1985 - 1988. At the R/S that prevailed outside this hiatus, only demes with brood line spawning populations in excess of 350 individuals in the brood years 1980 - 1983 would have been expected to have had more than 15 spawners returning as of 1998. Among the thirteen demes studied, only the Imnaha River had spawning escapements in excess of 350 during the brood years 1980 - 1983.

Some hope is provided by the explosive reproductive potential that is evident in the thirteen demes of this study. Given a large number of viable demes and the right conditions, Snake River spring and summer chinook salmon have demonstrated the biological capacity to survive low numbers. Under the right conditions, demes have produced at rates up to nearly thirty future spawners per spawner (R/S) as recently as the generation ending in 1987. In brood years 1980 - 1983, the average deme produced at the rate of more than two future spawners per spawner. Nonetheless, applications of the Clock and SRI to the listed species in the Snake River demonstrate that functional extinction of the listed species cannot be avoided for long unless conditions improve.

Figure a. Index of productivity for Snake River salmon for generations ending 1980 – 1998.

Generations below 100 were declining in numbers of spawners.

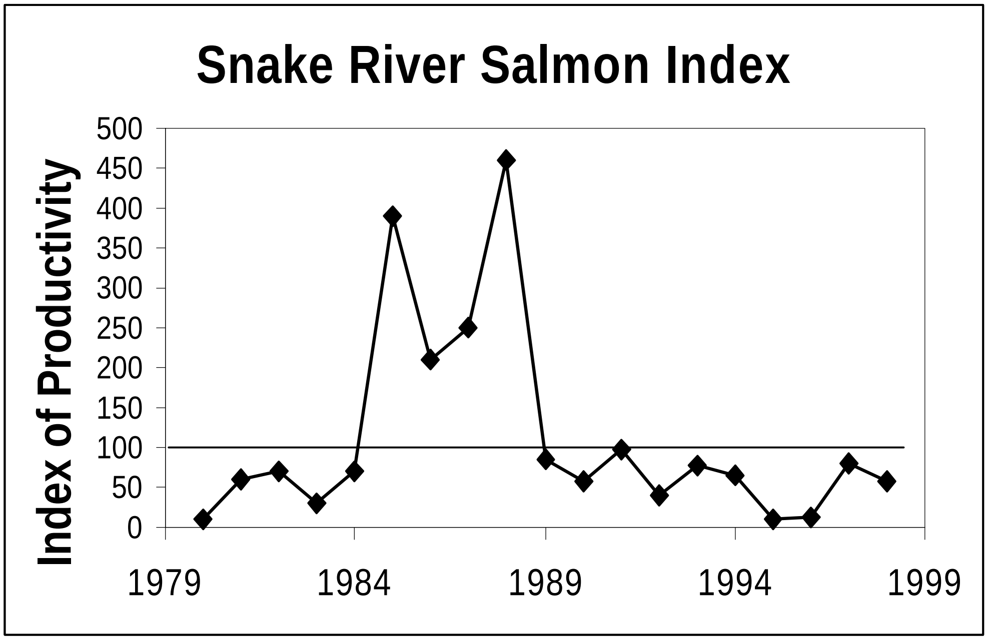


Table a. Summary of extinction statistics for Snake River spring and summer chinook.

	Year of Extinction			Expected Time	
Year of Spawning	Expected	Latest	Max stock	Gen	Years
1986	2008	2026	524	4.43	22.2
1987	2013	2037	588	5.06	25.3
1988	2017	2045	1109	5.86	29.3
1989	2008	2028	261	3.75	18.7
1990	2013	2038	572	4.49	22.4
Average	2012	2035	611	4.72	23.6

Introduction

Salmon recovery efforts for federally listed salmon species need measures of the reproductive status of populations, and of how long the listed salmon species may survive current rates of productivity. The Salmon Recovery Index, SRI (Figure a) describes the growth rate for the salmon generation ending each year. The Doomsday Clock, or Clock, provides a measure of the expected time until extinction for salmon spawning populations, called demes.

A critical consideration in developing a workable solution to save Snake River fish from extinction is how soon restoration activities need to occur. A primary purpose served by both models is to improve understanding of how much time remains to implement recovery measures for Snake River spring and summer chinook (*Oncorhynchus tshawytscha)*, a federally listed, threatened species (Myers et al. 1998). It was known at the start of model development that the process of extirpation, also called localized extinction, was likely to be occurring for Snake River spring and summer chinook and the other anadromous species.

The complete extirpation of Snake River coho salmon (*O. kisutch*) occurred 15 years ago, and the first salmon species (sockeye salmon, *O. nerka*) was listed in the Snake River basin under the Endangered Species Act, ESA, in November, 1991. In 1992 the Bevan salmon recovery team listed fifteen instances of extirpations of major spawning populations of chinook, sockeye, coho, sea-run cutthroat trout and steelhead from the Idaho portion of the Snake River basin alone. Those extirpations included six spring and summer chinook populations (NOAA 1995). The spring and summer runs of Snake River chinook salmon were listed as two separate threatened species in April, 1992, and steelhead (*O. mykiss*) were listed in August, 1998. At present all of the native salmon and steelhead in the Snake River basin are either extirpated or federally listed species under the ESA (Busby et al. 1996, Matthews and Waples 1991, Waples et al. 1991a, Waples et al. 1991b).

Snake River spring and summer chinook numbers were drastically reduced between 1970 and 1990 (Beamesderfer et al. 1997, Huntington et al. 1996, Mundy and Fryer 1992, Myers et al. 1998, Nehlsen et al. 1991, Waples et al. 1991b). In a 1993 analysis of spring chinook redd counts from the Imnaha River, a Snake River tributary, I found that a five-year moving average had a significantly negative linear time trend (Figure 1). A redd is the gravel nest where a salmon lays it eggs, so the number of redds is an indicator of how many salmon spawned in an area. The linear time trend in average number of redds, when projected forward in time, reached the point of zero redds in the year 2002. The 95% prediction interval around the linear trend line (Figure 2) intersects the x-axis at 1996 and 2011 (Figure 1). The present paper enlarges the geographic scope of the trend analysis beyond the Imnaha to include most of the Snake River basin.

Description of spawning sites and definition of terms

The measure of salmon productivity used throughout is the number of future spawners produced per spawner. Estimates of spawner to spawner ratios for spawning localities (sites or demes) in Snake River tributaries were derived from age structured escapement data for 1975 – 1990 brood years from the PATH program (Beamesderfer et al. 1997), except those from the Lemhi River, Upper Valley Creek, Upper Big Creek, and the Secesh River. Data not available from the PATH program, including all data for brood years 1991 – 1993, were obtained directly from the Idaho Department of Fish and Game (Charlie Petrosky, Boise) and the Oregon Department of Fish and Wildlife (Steve Parker, La Grande).

The demes contain spring or summer chinook (stream type life history). Localities in the South Fork Salmon River contain summers, and all the rest except Imnaha contain spring type. The Imnaha has intermediate adult run timing, so it is often referred to as spring/summer chinook. The term spring and summer chinook is used to refer to the type of salmon spawning at all sites of this federally listed species (Myers et al. 1998). The sites surveyed for spawners were located as follows.

Idaho Tributaries in the Snake River basin
- Watershed: Salmon River, Middle Fork
  - Demes: Bear Valley Creek, Marsh Creek, Sulphur Creek, Upper Big Creek
- Watershed: Salmon River, South Fork
  - Demes: Poverty Flats, Johnson Creek, Secesh River
- Watershed: Salmon River, Upper
  - Deme: Upper Valley Creek
- Watershed: Salmon River
  - Deme: Lemhi River

Oregon Tributaries in the Snake River basin
- Watershed: Imnaha River
  - Deme: Mainstem
- Watershed: Grande Ronde
  - Demes: Minam River, Lostine River, Wenaha River

The salmon spawning at these sites are understood to be demes (NRC 1996). A deme is an aggregate of freely interbreeding individuals capable of producing viable offspring. Salmon demes are organized into metapopulations (McPhail 1995, Mundy et al. 1995). A metapopulation encompasses the animals within the geographic area in which the demes are not reproductively isolated from each other under normal conditions of habitat and population size. In this usage a metapopulation is equivalent to an evolutionarily significant unit, the ESU (Waples 1995). Stocks or populations occur within metapopulations as convenient groupings of demes for management purposes.

Extinction, or more properly speaking, extirpation or localized extinction of a biological species, can occur well before the last animal has died, or before the last deme has been extinguished. Once a deme has been cut off from the possibility of receiving spawners from other demes, it is far more vulnerable to extinction than it would otherwise be (Berkson 1996, Gilpin 1996). Within isolated demes, at low numbers of spawners, the risk that eggs will go unfertilized, or that no eggs will be available to fertilize increases. Once features of the metapopulation that contribute survival advantages to the species have been eliminated, the process of extirpation has begun.

The term, viability, has a number of specific meanings as applied to animal populations (Boyce 1992, Emlen 1995). As used here a deme is viable when it is expected to have an effective breeding number of more than one hundred, as a sum across all its generations. The deme is considered extinct (non-viable) when it reaches a population below which loss of genetic diversity becomes a virtual certainty. Loss of genetic diversity leading to loss of fitness known as inbreeding depression (Tave 1986) may occur when effective breeding numbers fall below one hundred per year (Waples 1990). Once the population has lost its ability to adapt to changing environmental conditions, it is considered functionally extinct for the purposes of this paper. At effective breeding numbers less than 15 per year (just under a hundred total spawners in a salmon species with 5 to 6 brood lines), rare forms of genes (low frequency alleles) are subject to rapid extinction in Pacific salmon populations (Waples 1990).

The effective breeding number is a function of the number of males and females that actually contribute to producing the next generation. Since not all salmon on the spawning grounds contribute, and since not all spawners are seen during spawning ground counts, relating the numbers of spawners of the thirteen demes to the effective breeding number is problematic. For the purposes of this study effective extinction was set at 15 spawners or less. Fifteen spawners is considered a conservative number in the sense that its use in estimating G (Equation [2] below) is unlikely to cause a nominally viable brood line to be identified as extirpated.

Methods

The Snake River Salmon Index

The basic health of the salmon demes is represented by an index of productivity of the Snake River salmon. The index is based on the geometric mean of the returns to the spawning grounds per spring and summer chinook spawner, called R/S, of six Idaho and Oregon sites, Bear Valley/Elk Creek, Marsh Creek, Sulphur Creek, Poverty Flats, Johnson Creek, and Imnaha River. To form the index value for a deme, its geometric mean is multiplied by 100, and referred to the fifth year after the brood year. The index is reported in the fifth year after the brood year, because each R/S value is computed from the number of spawners in the brood year divided into the number of spawners produced by the brood year over the next five years. Index values under 100 indicate that the process of extinction is occurring.

The Model of Extinction

Expected time to extinction, Σ, is computed in a model that assumes a measure of productivity will persist into the future for a number of generations.
Let P_O be the number of spawners in the largest single spawning population in the geographic area of interest.
Let D be the mean date of spawning for that population.
Let R/S be the geometric mean return per spawner applicable to this brood. R refers only to the spawners actually reaching the spawning grounds in the next generation; no pre-spawning mortalities have been included.
Let G be the number of generations in the future.
Let P* be the number of spawners for effective extirpation. The level of effective extirpation is set at 15 spawners.
Let y be the number of years in a generation, taken as five. Spawners of spring chinook in the Snake River basin can be three, four, five, and six years beyond the year in which their parents died. The model of future spawners, P_G, is

$$P_O \, (R/S)^G = P_G$$

When $R/S < 1$, the number of spawners is declining, and when $R/S \exists 1$, the number of spawners is expected to remain the same or increase. To estimate the spawning stock size one generation in the future, multiply current spawning stock size by the expected returns per spawner ($G = 1$). For any number of generations in the future, spawning stock size G generations from now is the applicable return per spawner to the G-th power times the current spawning stock size. For $R/S < 1$ set spawning stock size equal to P* and solve for G to get the number of generations to extinction.

$$P_O \, (R/S)^G = P^* \quad \textbf{[1]}$$

Solving Equation [1] for the number of generations, G, to reach the number of spawners at extirpation, P*,

$$G \ln(R/S) = (\ln P^* - \ln P_O)$$

$$G = (\ln P^* - \ln P_O)/\ln(R/S) \quad \textbf{[2]}$$

which is generations to extinction. G times y is years to extinction. G times y times 365.25 is days to extinction. Let D be the mean date of spawning, nominally taken to be September 15 of the brood year. Expected date of extinction, Σ, is

$$\Sigma = D + [(Gy) * 365.25] \text{ for } R/S < 1 \qquad \textbf{[3]}$$

The date of extinction is the date of spawning for the present brood plus the days to extinction. When R/S ∃ 1, Σ is undefined for this model, meaning that the ESU, deme, or brood line is expected to persist indefinitely.

Statistical methods

The expected value of the collection of ratios, R/S, is the geometric mean, the antilog of the arithmetic mean of the log of the ratios (Sokal and Rohlf 1981). Confidence limits on the geometric mean are found by taking the antilog of the confidence limits of the log-transformed ratios. Confidence limits computed in this manner will not be symmetric about the geometric mean (Sokal and Rohlf 1981).

The R/S data were explored through descriptive statistics and tests for randomness and normality. The geometric mean (G.M.) of all R/S values for 1985 – 1990 was used to estimate Σ for the ESU, and the G.M. R/S 1985 – 1990 for the individual demes was used to estimate Σ for each deme and its brood lines (cohorts).

The Doomsday Clock

The model of extinction and the statistical methods are incorporated in to a spreadsheet, CLOCKnnn.XLS, “clock.” The first worksheet of the clock is a title page that identifies the origin of the spreadsheet and its data. The second worksheet allows the user to enter spawning date, number of spawners, extinction level, R/S, and years in a generation and then displays expected date of extinction, generations to extinction, and years and days to extinction. The third through seventh worksheets contain Scenario One computations for the 1990 – 1986 brood years.

The worksheets of Scenario One display expected date of extinction, generations to extinction, and years and days to extinction, however the user is not permitted to enter data. All input parameters are generated within the spreadsheet from the input array of number of spawners and R/S ratio for each deme for each brood year. In addition to the variables above, Scenario One computes generations to extinction for each deme, the projected number of spawners by deme for each generation and the point of extinction. For all demes combined, clock Scenario One provides the grand geometric mean R/S, the arithmetic mean generations to extinction, its standard deviation, and the upper bound of its 95% confidence interval (latest probable date of extinction). The minimum, maximum and median generations to extinction are also presented in Scenario One worksheets.

The eighth worksheet summarizes the statistics from Scenario One, the ninth worksheet has the database, and the tenth worksheet has the math for the extinction model. All data and statistics reported in this paper, with the exception of some work from the Imnaha River are in the clock.

Scenario One

Scenario one addresses the question of how long the populations that spawned in 1986 - 1990 are expected to persist under the current conditions supporting productivity. The expected value of R/S for each deme is calculated as the geometric mean R/S for the latest low period, 1985 – 1990. The number of generations to extinction, G, is calculated by substituting the annual level of spawners, and the 1985 – 1990 geometric mean R/S for each deme into Equation 2. The expected time to extinction, Σ, is found by substituting the arithmetic mean of G for the deme into Equation 3. The number of generations to extinction typical of the thirteen demes under Scenario One was described with the median. The expected year of extinction for a brood line is the arithmetic mean of the Σ's across demes. The latest probable year of extinction for a brood line is the upper bound on the 95% confidence interval of arithmetic mean expected time to extinction across all demes. The “maximum stock” is the number of spawners in the largest deme, as a measure of the relative numerical strength across brood lines.

Results

The Snake River Salmon Index

The process of extinction has occurred in 15 of the 19 salmon generations completed during the time period 1980 - 1998 (Figure a). The process of extinction was remarkably strong during the three generations ending in 1980, 1995, and 1996, each of which lost more than 85% of their spawners in one generation (Table 1). The generation ending in 1988 is remarkable for its 461% increase in spawners over one generation (Table 1). Only during the generations ending in the years 1985 – 1988 was the process of extinction not active for the demes in the index as an aggregate.

It is highly likely that the four-generation hiatus in the extinction process is responsible for the presence of chinook in all but one of the demes of this study. At the average R/S of 0.35 that prevailed outside these four generations, only demes with brood line spawning populations in excess of 350 would have been expected to have had any spawners returning as of 1998. Among the thirteen demes studied, only the Imnaha River had spawning escapements in excess of 350 during the years 1980 – 1983 (Appendix Table 2). Without the exceptional R/S levels experienced during the generations ending 1985 – 1988 (Appendix Table 1), all demes other than the Imnaha River would have been extirpated by 1998. In Individual Deme Analyses below, it will be shown that all but one of the demes is expected to be extirpated by the year 2023, in the absence of a similar hiatus.

Table 1. Index of productivity for Snake River salmon

Brood Year + 5	1980	1981	1982	1983	1984	1985
Index	**10**	**61**	**69**	**31**	**70**	**391**
Brood Year + 5	1987	1988	1989	1990	1991	1992
Index	**250**	**461**	**84**	**57**	**97**	**40**
Brood Year + 5	1994	1995	1996	1997	1998	
Index	**65**	**9**	**13**	**79**	**58**	

Descriptive statistics

The majority of the R/S ratios for brood years 1975 – 1990 were below the level of replacement. In two brood years (1975, 1990), all demes were below the level of replacement, and in one brood year (1981) all demes were above the replacement level (Figure 3). The grand geometric mean return per spawner for 1975 – 1990, based on sixteen years at thirteen sites with two missing observations (206 total observations) is 0.67 (95% confidence interval 0.56 – 0.81, Appendix Table 1). Although R/S values ranged from 0.03 to 29.4, the average spawner in the average deme did not replace itself in the years 1975 – 1990. The sixteen-year period is divided into three distinct eras, based on average return per spawner, 1975 – 1978 (low), 1979 – 1984 (high), and 1985 –

1990 (low). The 1975 – 1978 grand geometric mean return per spawner is 0.34 (95% confidence interval 0.25 to 0.46) for the 51 observed R/S ratios (one missing). The average spawner in the average deme did not replace itself in four consecutive years, 1975 – 1978. Productivities were very high, 1979 – 1984. The grand geometric mean return per spawner is 2.01 (95% confidence interval 1.59 – 2.54) for the 77 observations (one missing), 1979 – 1984. The average spawner in the average deme returned two spawners in six consecutive years, 1979 – 1984. In the third era, the grand geometric mean return per spawner was 0.35 (95% confidence interval 0.28 to 0.45) for the 78 observations, 1985 – 1990. The average spawner in the average deme did not replace itself in six consecutive years, 1985 – 1990.

Looking at the demes across all years, there is a clear geographic pattern to the productivities of spring and summer chinook populations. The three highest values of geometric mean R/S by deme (Appendix Table 1) are in the South Fork of the Salmon River; Secesh River (1.18), Poverty Flats (1.12), and Johnson Creek (0.85). The next four highest values are in the Middle Fork of the Salmon River; Upper Big Creek (0.76); Bear Valley and Elk Creek (0.69), Sulphur Creek (0.66), and Marsh Creek (0.61). The four Oregon demes have among the lowest values for productivity; Imnaha River (0.59), Lostine River (0.58), Minam River (0.55), and the Wenaha River (0.51). Two of the lowest values for productivity among the thirteen demes are in the Salmon River basin in east central Idaho, Upper Valley Creek, (0.51), and the Lemhi River (0.48).

Times to Extinction for Scenario One

Under the conditions of the brood years 1985 – 1990, Snake River spring and summer chinook from all brood years are expected to be extirpated by 2017, with the latest probable year of extirpation being 2045 (Table 2). The average of the expected year of extirpation for the five brood years is 2012, with an upper bopund of 2035.

Brood Year1990

Should the conditions of the past six years prevail in the future, Snake River spring and summer chinook of the 1990 brood line are expected to be extinct in the year 2013 (Table 2). The latest probable year of extinction for the 1990 brood line is 2038. (A brood line, also known as a cohort, is composed of fish whose parents spawned in the same year.) The average time to extinction for the thirteen demes under the productivities of the third era (Table 3) is 4.49 generations (minimum = 0, maximum = 31.5) or 22.44 years from September 15, 1990. The median time to extirpation is 2.05 generations, so the 1990 brood line of most demes is expected to be close to extirpation by the year 2001. Only two 1990 brood line demes are expected to have more than 15 spawners by 2015, Poverty Flats (321) and Johnson Creek (16).

Table 2. Expected year of extinction, latest probable year of extinction, largest spawning stock size

Table 2. Expected year of extinction, latest probable year of extinction, largest spawning stock size, Number of generations and years to extinction for all brood lines, Snake River spring and summer Chinook. Effective level of extinction, 15 spawners, geometric mean R/S, 0.35, generation length, 5 years.

	Year of Extinction			Expected Time		
Year of Spawning	Expected	Latest	Max stock	Gen	Years	
1986	2008	2026	524	4.43	22.2	
1987	2013	2037	588	5.06	25.3	
1988	2017	2045	1109	5.86	29.3	
1989	2008	2028	261	3.75	18.7	
1990	2013	2038	572	4.49	22.4	
Average	2012	2035	611	4.72	23.6	

Table 3. Geometric mean spawner to spawner ratios brood years 1985 – 1990

Location	BVC	MAR	SUL	BIG	POV	JOH	SEC
GeoMean	0.46	0.28	0.39	0.29	0.89	0.64	0.65
Location	VAL	LEM	IMN	MIN	LOS	WEN	
GeoMean	0.32	0.25	0.35	0.18	0.24	0.20	

Brood Year 1989

Should the conditions of the past six years prevail in the future, Snake River spring and summer chinook of the 1989 brood line are expected to be functionally extinct in the year 2008 (Table 2). The latest probable year of extinction for the 1989 brood line is 2028. The average time to extinction for the thirteen demes under the productivities of the third era is 3.75 generations (minimum = 0.8, maximum = 24.7) or 18.74 years from September 15, 1989. The median time to extirpation is 1.3 generations, so the 1989 brood line of most demes is expected to be close to extirpation by 1994 to 1995. This in fact has already occurred, based on recent numbers of spawners in a subset of the thirteen demes. Spawning populations in 1994 and 1995 were among the lowest ever observed, falling to a two-year total of 49 spawners in Bear Valley Creek, and two-year totals of 9 spawners in Marsh Creek, 4 spawners in Sulphur Creek, and 301 in Poverty Flats. As of 2014, Scenario One expects only two 1989 brood year demes to have more than 15 spawners, Poverty Flats (147) and Secesh River (21).

Brood Year1988

The 1988 brood line, by virtue of its relatively large numbers of spawners, is not expected to be functionally extinct until the year 2017 under third era productivities (Table 2). The latest probable year of extinction for the 1988 brood line is 2045. The average time to extinction for the 1988 brood line under the productivities of the third era is 5.86 generations (minimum = 0.4, maximum = 34.9) or 29.29 years from September 15, 1989. The median time to extirpation is 2.75 generations, so the 1988 brood line of most demes are expected to be close to extirpation by about 2002. As of 2018, Scenario One projects only three 1988 brood line demes to be nominally viable, Poverty Flats (422), Johnson Creek (24), and Secesh River (22).

Brood Year1987

The 1987 brood line is expected to be functionally extinct in 2013, with a latest probable year of extinction of 2037 (Table 2). The average time to extinction for the 1987 brood line under the productivities of the third era is 5.06 generations (minimum = 1.1, maximum = 31.2) or 25.31 years from September 15, 1987. The median number of generations to extinction is 2.23, so the typical population in the 1987 brood line was projected to be below 15 spawners by 2002. As of 2012, Scenario One projects only three demes to be nominally viable, Poverty Flats (277), Johnson Creek (13), and Secesh River (18).

Brood Year1986

The 1986 brood line is expected to be functionally extinct in 2008, with a latest probable year of extinction of 2026 (Table 2). The average time to extinction for the 1986 brood line under the productivities of the third era is 4.4 generations (minimum = 0.4, maximum = 23.8) or 22.15 years from September 15, 1986. The median number of generations to extinction is 2.63, so the typical population in the 1986 brood line was projected to be below 15 spawners by 2006. As of 2006, Scenario One projects only three demes of the 1986 brood line to be nominally viable, Poverty Flats (147), Johnson Creek (22), and Secesh River (40).

Brood Years 1991 - 1993

Data on spawners through the 1998 season indicate that long term projections of Scenario One are on target. Note that the returns from the next generation of the 1989 (1994) and 1990 (1995) brood lines are not yet complete. Based on the six demes that have been analyzed for 1991 – 1993 brood years (Table 4), the productivity of the 1986 brood line (1991, Table 4) is much less than expected, the 1987 (1992, Table 4) brood line is more than expected, and the 1988 (1993, Table 4) brood line is close to what was expected. The inclusion of 1991 – 1993 productivities changes the 1975 – 1990 grand geometric mean of 0.67 only slightly to 0.64. The geometric mean of all R/S observations 1991 – 1993 (Table 4) of 0.39 is very close to the 1985 – 1990 geometric mean of 0.35 used in Scenario One. (In Table 4 the productivities for all but the Imnaha were provided by Charlie Petrosky, IDF&G. Imnaha R/S for natural spawners was computed by Mundy from data provided by ODFW LaGrande).

The observed R/S ratio for the 1988 brood line of Poverty Flats, at 0.52 (1993, Table 4) is less than expected for the third era, 0.89 (Table 3). The 1993 brood year R/S ratio of Bear Valley (0.71) is somewhat higher than the expected value of Scenario One of 0.46, and 1993 brood year R/S ratio of Marsh Creek (1.02) is substantially higher than expected (0.28). Johnson Creek 1993 brood year R/S (0.71) is about as expected (0.64), however 1993 brood year Sulphur Creek (0.92) is substantially higher than expected (0.39). The 1991 Imnaha R/S (0.33) is comparable to expectation, the 1992 ratio (0.75) is more than double that expected, and the 1993 R/S ratio (0.16) is less than half that expected (0.35). In the 1991 and 1992 brood years only the 1992 R/S for Sulphur Creek is clearly much higher than the values used in Scenario One. In the 1993 brood year, Marsh Creek and Sulphur Creek R/S values are substantially higher than model values (Table 4).

Table 4. R/S values 1991 – 1993

Table 4. Snake River spring and summer chinook spawner to Spawner ratios 1991 - 1993, 1985 - 90 Average, and deviations from mean

Brood Year	1991	Dev	1992	Dev	1993	Dev	Gmean
Bear Valley/Elk	0.10	-	0.78	+	0.71	+	0.46
Marsh Creek	0.07	-	0.52	+	1.02	+	0.28
Sulphur Creek	0.07	-	3.30	+	0.92	+	0.39
Poverty Flats	0.16	-	0.34	-	0.52	-	0.89
Johnson Creek	0.18	-	0.73	+	0.71	+	0.64
Imnaha River	0.33	-	0.75	+	0.16	-	0.35
GeoMean	**0.13**		**0.79**		**0.58**		**0.46**
Deviation		Grand geo mean 1991 - 1993				**0.39**	
Fr Gmean	-0.33		0.33		0.12		

Individual Deme Analyses

The expected dates to extinction for the individual demes point up the variability due to differing numbers of spawners and productivities. Dates range from before present to the year 2134. Dates before present indicate that the brood line has already reached functional extirpation, or that the observed productivity has been higher than expected. Marsh Creek is a good example of both. The 1990 Marsh Creek brood line was projected to be extirpated by 1998, and in fact it was extirpated on a brood line basis, since the number of spawners in 1995 was zero (Table 6). The 1989 brood line was expected to be extirpated by 1996, and it in fact was extirpated on a brood line basis, since 1994 spawners in Marsh Creek numbered 9. The 1988 brood line is projected to be extirpated by 2001, however this seems unlikely at present, because the 218 spawners in

Marsh Creek in 1993 managed to replace themselves (R/S =1.02), which was above expectation (Table 4 and Table 6). The 1987 brood line was projected to be extirpated in 1998, but will probably last at least until 2002, since the 188 spawners of 1992 doubled the expected rate of productivity to produce 61 spawners. The 1986 brood line was expected to have been extirpated in 1996, and it was. The 1991 brood year at Marsh Creek produced 5 spawners by calendar year 1996 to achieve functional extirpation.

At present the Marsh Creek deme has only two nominally viable brood lines, 1987 and 1988. The 1988 brood line is the only portion of the Marsh Creek deme to have achieved replacement since 1985, in the 1993 brood year (Tables 1 and 4). The bottom line is that Marsh Creek is very close to extirpation, as accurately depicted by the early dates of extinction in Table 5.

Table 5. Expected year of extinction of brood lines by by deme

Brood line	**Bear V/Elk**	**Marsh**	**Sulphur**	**Upper Big**	**Poverty Flat**	**Johnson Cr**
1990	2006	1998	2003	1995	2148	2016
1989	2001	1996	1995	1996	2113	2011
1988	2016	2001	2008	1999	2163	2023
1987	2009	1998	1995	1994	2143	2015
1986	2003	1996	2003	1996	2105	2011
Minimum	2001	1996	1995	1994	2105	2011
Maximum	2016	2001	2008	1999	2163	2023
Average	2007	1998	2001	1996	2134	2015
Brood line	**Lemhi R**	**UpperValley Cr**	**Imnaha R**	**Minam R**	**Lostine R**	**Wenaha R**
1990	2000	1990	2002	1999	1995	1999
1989	1995	1993	2001	1997	1995	1993
1988	2002	1990	2006	1998	1999	1999
1987	2000	1993	2003	1998	1996	1998
1986	1999	1988	2003	1995	1994	1997
Minimum	1995	1988	2001	1995	1994	1993
Maximum	2002	1993	2006	1999	1999	1999
Average	2000	1991	2003	1998	1996	1998
Brood line	**Secesh/LCr**					
1990	2013					
1989	2018					
1988	2023					
1987	2019					
1986	2018					
Minimum	2013					
Maximum	2023					
Average	2018					

In addition to Marsh Creek, other demes that are now very close to extirpation are Upper Big Creek, Lemhi River, Upper Valley Creek, the Minam River, the Lostine River, and the Wenaha River. These seven demes are in the emergency category because they have maximum expected dates of extinction by 2002. In the critical category are two demes, Sulphur Creek (Maximum = 2008), and the Imnaha River (Maximum = 2006), each of which have effectively lost two brood lines. In the guarded category are three demes, Bear Valley/Elk Creek (Maximum = 2016), Johnson Creek (Maximum = 2023), and Secesh/Lake Creek (Maximum = 2023), which each have 4 to 5 relatively strong brood lines.

Only one deme is in the neutral category, Poverty Flats (Maximum = 2163), because of relatively high numbers of spawners in all five brood lines, and an average R/S that until recently had been relatively high (0.89, 1985 – 1990; 1.12, 1975 – 1990, see Tables 1 and 3). The productivities of the most recent three brood years (Table 4) have all been below expectation for Poverty Flats, so these average productivities have dropped to 0.63 (1985 – 1993) and 0.92 (1975 – 1990). In the past Poverty Flats has often been among demes with the top number of spawners. Given the large size of the 1988 spawning population, the ratio of 0.52 (459/880) for the 1993 brood year from Poverty Flats does not support the long time to extinction (34.9 generations) estimated for this brood line of this deme. Working with the parameters, 459 spawners and 0.52 R/S, Scenario One projects extinction for the 1988 brood line of Poverty Flats in 5.23 generations from 1993, by the year 2019, barring improved productivity.

Table 6. Marsh Creek spawners (1991 - 98)

Table 6. Marsh Creek spawners (1991 - 98), Recruits and R/S 1991 - 93 (C. Petrosky, IDFG)				
Year	Spawners	Recruits	R/S	
91	73	5	0.07	
92	118	61	0.52	
93	218	222	1.02	
94	9			
95	0			
96	18			
97	113			
98	160			

Discussion

The data on numbers of spawners produced by each brood year is the most direct basis for models of present and future status. Spawners produced per spawner, R/S, determines the future of the population. If each present spawner does not produce at least one future spawner, the isolated population must decline. If the ratio of present to future spawners averages close to one or greater, the isolated population should be able to persist indefinitely, assuming the annual variability in R/S is not prohibitively large.

The long term downward trend (Figure 1) and the pattern of damped oscillation (Figure 2) in spawning ground counts for spring and summer chinook in the Imnaha River is symptomatic of the extreme vulnerability of all demes of the listed species to extinction. The time series of numbers of spawners in the Imnaha River (Figure 2) is marked by periods of low productivity, followed by periods of high productivity, but the trend in numbers is negative, meaning the annual number of spawners is ever smaller. Future periods of high productivity cannot be relied upon to sustain the populations indefinitely. For all demes including the Imnaha, unless the productivity of a deme increases to, and remains above 0.35 within the next eighteen years, its extinction from the wild is assured. Each deme would need 15 spawners each year and annual productivities approaching one, to avoid long term extirpation.

The Snake River Salmon Recovery Index condenses current status of the salmon into a single number. The index is based only on the estimated number of spawners on the spawning grounds, which is of fundamental importance to the future of the populations. Changes in the Index directly reflect the course of recovery for the listed spring/summer chinook species. Given that the six demes on which the index is based are representative of the best available spawning habitats, it is reasonable to assume that the Index represents all members of the listed spring/summer chinook species spawning in the wild.

The time to extinction, G, for a brood line is only approximate, since brood lines are not actually discrete. Brood lines are not discrete because the spawners in any given year were not all produced by the brood year five years before spawning. Spring and summer chinook return to spawn three, four, five and, rarely, six years after their brood year. To calculate an exact value of G it would have been necessary to weight by the age composition, which was not done. The age frequency weighting procedure was not used because it was considered unlikely that having exact values of G would substantially alter the conclusions based on the approximation.

The statistical methods applied to estimate a value for R/S are based on the ratio property of productivity (Sokal and Rohlf 1981). The biological process being investigated, productivity in the reference frame of the spawning grounds, is defined by the ratio of spawners produced, R, divided by the number of spawners that produced them, S.

Note that the geographic distribution of the populations and their reproductive relationships, the metapopulation structure, is important to the determination of P_O, and the estimated time to extinction, Σ**.** The expected time to extirpation is sensitive to the number of spawners at a locality. Small populations are extirpated faster than larger ones, R/S being equal. Large demes with very low productivities, such as Poverty Flats, may persist for long periods of time before extirpation.

The degree to which the spring/summer chinook are capable of functioning as a metapopulation would normally be important to evaluating vulnerability to extinction. In theory a population with an R/S less than one can avoid extinction, if it periodically receives successful spawners from an outside source (Berkson 1996). Unfortunately, it is considered unlikely that Snake River spring and summer chinook continue to function as a metapopulation, given that the very low population numbers and the relative geographic isolation of some demes makes exchange of spawners between populations improbable. The metapopulation, if it exists, now appears to be geographically smaller, since demes with relatively high productivity are clustered together in central Idaho, whereas low productivity demes reside in two clusters in Oregon and eastern central Idaho.

Some optimism is provided by the explosive reproductive potential that is evident in the thirteen demes of this study. Given a large number of viable demes and the right conditions, Snake River spring and summer chinook salmon have demonstrated the biological capacity to survive low numbers. Under the right conditions, demes have produced at rates up to nearly thirty future spawners per spawner (R/S) as recently as the generation ending in 1987. In brood years 1980 - 1983, the average deme produced at the rate of more than two future spawners per spawner.

Nonetheless, applications of the Clock and SRI to the listed species in the Snake River demonstrate that functional extinction of the listed species should occur within two decades unless conditions improve enough to permit the expected rate of productivity to increase. The models give a reasonably accurate accounting of the vulnerability to extirpation of the Snake River spring and summer chinook from a deterministic perspective. The deterministic perspective was chosen because of the strong long-term linear trend in productivity. Should the linear trend in productivity be halted, it would be informative to employ non-deterministic approaches (see Emlen 1995) in order to estimate the number of generations to extinction. This would permit an understanding of the influence of the stochastic behavior of the recruitment process on conclusions regarding time to extinction.

References

Beamesderfer, R. C. P., H. A. Schaller , M. P. Zimmerman, C. E. Petrosky, O. P. Langness, and L. LaVoy. 1997. Spawner-recruit data for spring and summer chinook salmon populations in Idaho, Ortegon, and Washington in D. R. Marmorek and C. Peters, eds. *Plan for Analyzing and Testing Hypotheses (PATH): Report of retrospective Analysis for Fiscal Year 1997*. ESSA Technologies Ltd., Vancouver, Canada.

Berkson, J. M. 1996. Modeling the restoration of a metapopulation: implications for resource management. Pages 145. *Biological Sciences*. Montana State University, Bozeman.

Boyce, M. S. 1992. Population viability analysis. *Annual Review of Ecol. Syst.* 23: 481-506.

Busby, P. J., T. C. Wainright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, R. S. Waples, and I. V. Lagomarsino. 1996. Status Review of West Coast steelhead from Washington, Idaho, Oregon, and California. National Marine Fisheries Service Northwest Fisheries Science Center, Seattle.

Emlen, J. M. 1995. Population viability of the Snake River chinook salmon (Oncorhynchus tshawytscha). *Can. J. Fish. Aquat. Sci.* 52: 1442-1448.

Gilpin, M. 1996. Metapopulations and wildlife conservation: Approaches to modeling spatial structure. Pages 11-27 in D. R. McCullough, ed. *Metapopulations and Wildlife Conservation*. Island Press, Washington D.C.

Huntington, C., W. Nehlsen, and J. Bowers. 1996. A survey of healthy native stocks of anadromous salmonids in the Pacific Northwest and California. *Fisheries* 21: 6-14.

Matthews, G. M., and R. Waples, S. 1991. Status review for Snake River spring and summer chinook salmon. National Marine Fisheries Service Northwest Fisheries Science Center, Seattle.

McPhail, J. D. 1995. The origin and speciation of Onchorhynchus revisited. Pages 29-38 in R. J. Naiman and D. Stouder, eds. *Pacific Salmon and Their Ecosystems: Status and Future Options*. Chapman Hall, New York, USA.

Mundy, P. R., T. W. H. Backman, and J. M. Berkson. 1995. Selection of Conservation Units for Pacific Salmon: Lessons from the Columbia River. Pages 28-38 in J. M. Nielsen , ed. *Evolution and The Aquatic Ecosystem: Defining Unique Units in Population Conservation. American Fisheries Society*. American Fisheries Society, Bethesda, Maryland.

Mundy, P. R., and J. K. Fryer. 1992. Abundance based criteria for recognition of damaged salmon populations in S. Kiefer, ed. *The Northwest Pacific Chinook and Coho Workshop*. American Fisheries Scoiety Idaho Chapter, Boise.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F. W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Department of Commerce, NOAA, Seattle.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries* 16: 4-21.

NOAA. 1995. Proposed Recovery Plan for Snake River Salmon. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Siler Spring, MD.

NRC, N. R. C. 1996. *Upstream Salmon and Society in the Pacific Northwest*. National Academy Press, Washington, D.C.

Sokal, R. R., and F. J. Rohlf. 1981. *Biometry*. W.H. Freeman and Company, San Francisco.

Tave, D. 1986. *Genetics for fish hatchery managers*. AVI, Westport, Connecticutt.

Waples, R. S. 1990. Conservation Genetics of Pacific salmon: II. Effective population size and the rate of loss of genetic variability. *Journal of Heredity* 81: 267-276.

Waples, R. S. 1995. Evolutionarily significant units and the conservation of biological diversity under the Endangered Species Act. Pages 8-27 in J. M. Nielsen, ed. *Evolution and The Aquatic Ecosystem: Defining Unique Units in Population Conservation. American Fisheries Society*. American Fisheries Society, Bethesda, Maryland.

Waples, R. S., O. W. Johnson, and R. P. Jones Jr. 1991a. Status review for Snake River sockeye salmon. National Marine Fisheries Service Northwest Fisheries Science Center, Seattle.

Waples, R. S., R. P. Jones Jr., B. R. Beckman, and G. A. Swan. 1991b. Status review for Snake River fall chinook salmon. National Marine Fisheries Service Northwest Fisheries Science Center, Seattle.

Figures

Figure 1. Linear trend in five-year moving average Imnaha chinook redd counts

Figure 1. Linear trend in five-year moving average redd counts for spring chinook from the Imnaha River and the 95% prediction interval.

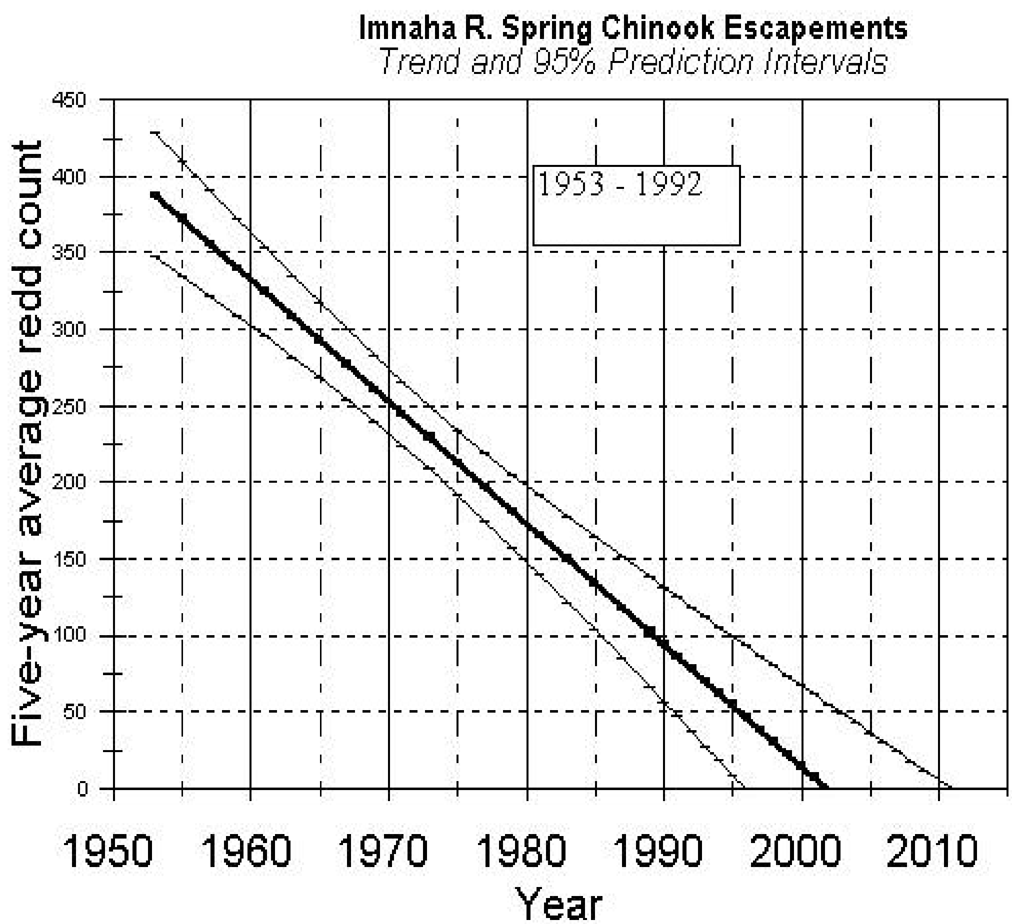


Figure 2. Imnaha chinook redd counts as five-year moving average

Figure 2. Imnaha River, Oregon, spring chinook redd counts as five-year moving average, and as the linear trend.

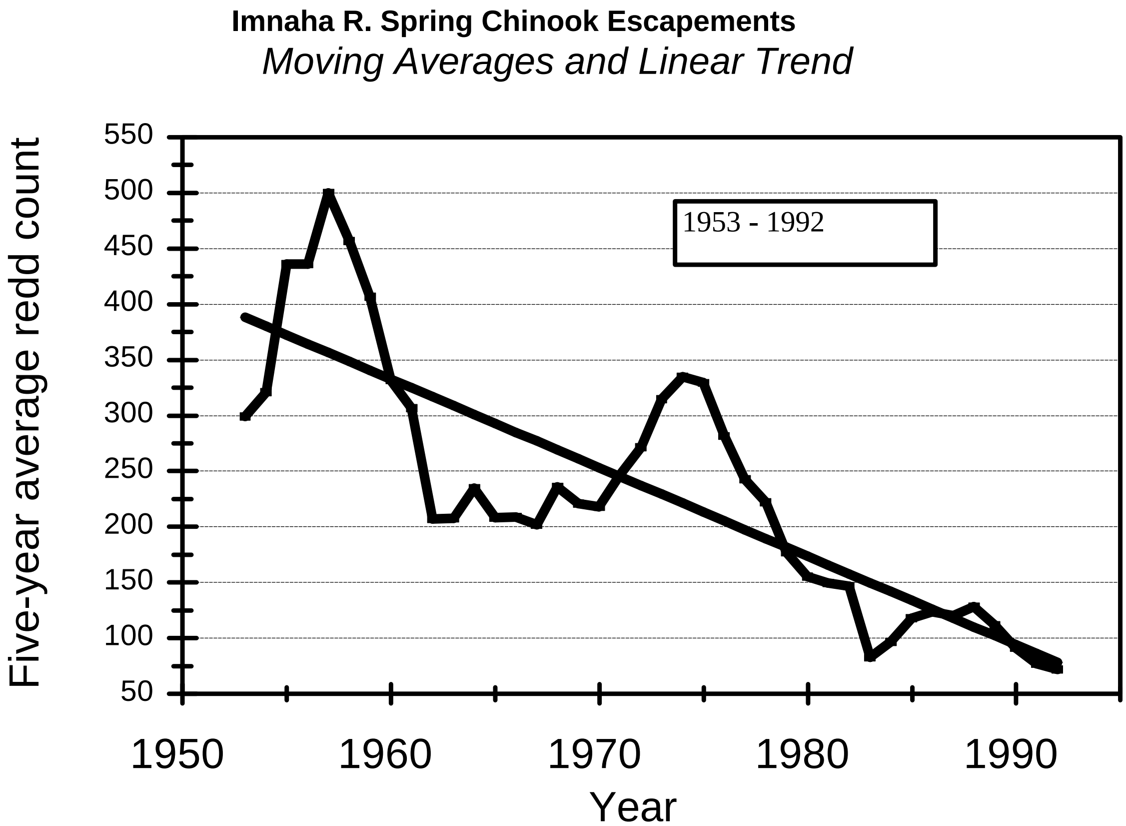
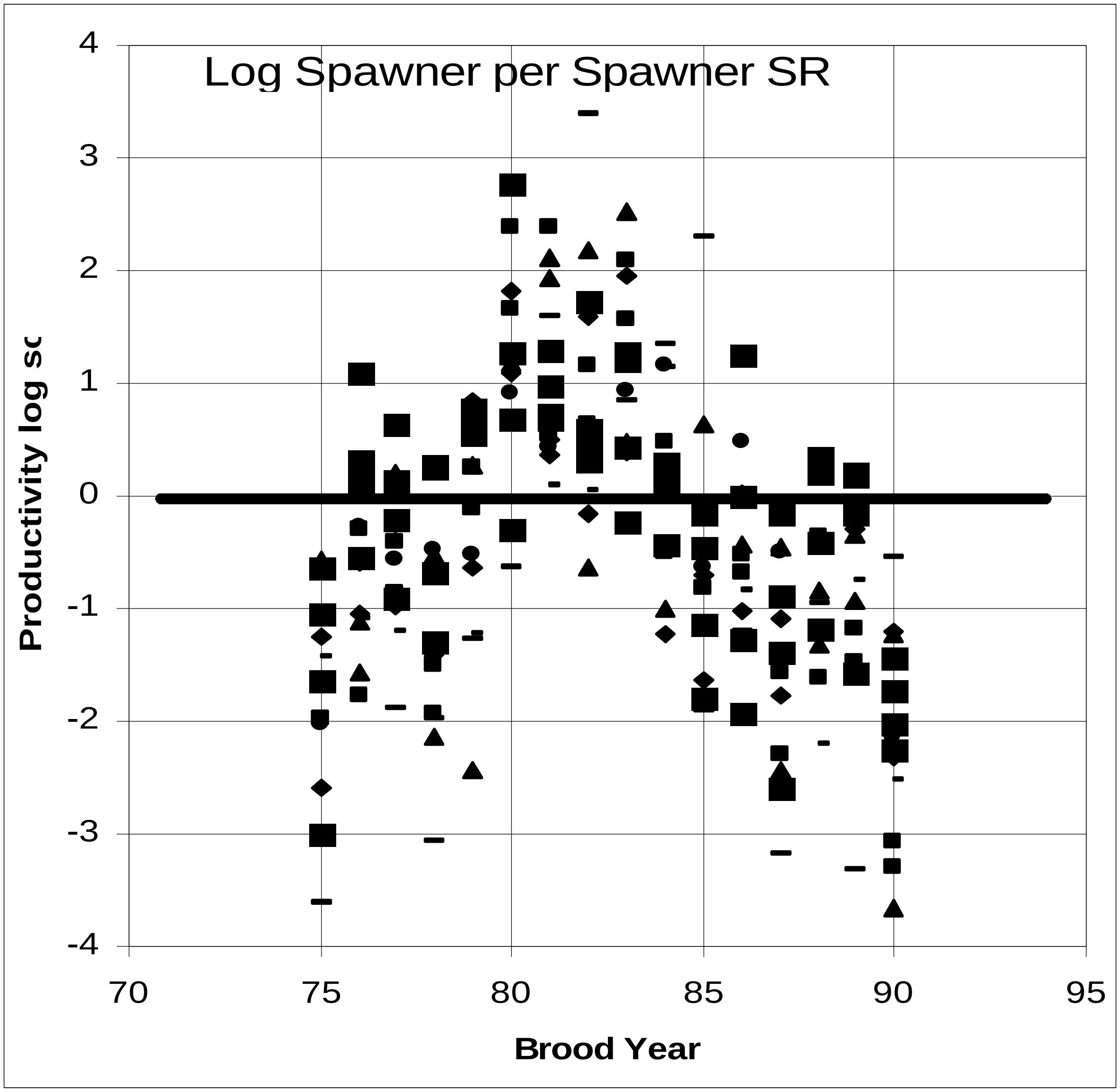


Figure 3. Natural log R/S ratios for Snake River spring and summer chinook salmon, 1975 - 1990

Figure 3. Log of spawner per spawner ratios for spring and summer chinook salmon from thirteen Snake River basin demes 1975 – 1990 (Beamesderfer et al. 1997 and IDF&G, Boise). Solid line indicates level of replacement, where log R/S equals zero. Values below zero indicate declining spawning populations.



Appendix

Appendix Table 1. Snake River spring chinook spawner to spawner ratios brood years 1975 - 1990

Snake River spring chinook spawner to spawner ratios brood years 1975 - 1990									Below average								Geo-mean	De-viations
Brood Year	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	by deme	from mean
Bear Valley/Elk	0.07	0.35	0.38	0.25	0.52	6.22	1.64	4.96	7.08	0.65	0.49	1.02	0.34	0.64	0.83	0.10	0.69	0.02
Marsh	0.05	0.74	0.66	0.14	0.88	10.9	1.74	3.22	8.07	0.60	0.44	0.59	0.21	0.69	0.31	0.04	0.61	-0.06
Sulphur	0.05	0.33	1.24	0.12	0.09	3.60	6.94	8.95	12.4		1.89	0.65	0.63	0.43	0.39	0.03	0.66	-0.01
Upper Big	0.05	0.58	1.14	0.27	1.96	16.1	3.61	5.61	3.30	1.10	0.32	0.28	0.25	0.66	0.21	0.18	0.76	0.08
Poverty Flat	0.19	1.38	0.81	1.32	2.13	1.99	1.96	1.37	3.54	1.14	0.85	3.52	0.86	1.23	1.20	0.13	1.12	0.45
Johnson Cr	0.13	0.77	0.57	0.61	0.59	2.49	1.54	1.46	2.57	3.18	0.53	1.61	0.60	1.33	0.88	0.12	0.85	0.17
Secesh/Lake	0.53	2.96	1.89	1.28	2.17	3.60	2.09	1.50	1.53	1.35	0.64	1.01	0.41	1.41	0.86	0.24	1.18	0.51
Lemhi R	0.24	0.34	0.30	0.14	0.29	1.97	1.09	1.06	3.69	3.09	0.63	0.43	0.23	0.11	0.48	0.08	0.48	-0.19
Upper Valley Cr	0.03		0.15	0.05	0.28	0.52	4.93	29.4	2.30	3.82	9.93	0.30	0.04	0.39	0.04	0.58	0.51	-0.16
Imnaha R	0.29	0.55	0.77	0.26	2.31	2.97	1.44	0.85	1.48	0.29	0.20	0.36	0.17	0.70	0.74	0.30	0.59	-0.08
Minam R	0.14	0.17	0.42	0.22	1.28	5.23	10.8	1.89	4.83	1.61	0.30	0.50	0.10	0.20	0.23	0.05	0.55	-0.12
Lostine R	0.57	0.21	1.02	0.60	1.30	3.29	8.23	0.53	1.63	0.37	0.16	0.27	0.09	0.27	0.71	0.29	0.58	-0.09
Wenaha R	0.35	1.12	0.40	0.50	1.73	0.74	2.67	1.79	0.81	0.65	0.17	0.15	0.07	0.31	1.24	0.11	0.51	-0.17
Geo-Mean by year	0.14	0.57	0.62	0.30	0.85	3.13	2.86	2.45	3.11	1.09	0.54	0.56	0.22	0.51	0.47	0.12	0.67	
Deviations from the mean .	-0.53	-0.10	-0.05	-0.37	0.18	2.46	2.18	1.78	2.44	0.42	-0.13	-0.11	-0.45	-0.16	-0.20	-0.55	Grand geometric mean	
Brood Year	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90		

Appendix Table 2: Spawner and recruit data

Snake River spring chinook spawners 1975 - 1990 (observations from Charlie Petrosky, IDFG)																
Brood Year	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Bear Valley/Elk	698	217	385	711	215	42	151	83	171	137	295	224	456	1109	91	185
Marsh	358	76	178	491	83	16	115	71	60	100	196	171	268	395	80	101
Sulphur	305	75	30	394	90	12	43	17	49		62	385	67	607	43	170
Upper Big	185	46	36	230	35	10	53	15	65	93	170	163	86	242	73	47
Poverty Flat	284	184	290	293	76	163	187	192	337	220	341	233	554	844	261	572
Johnson Cr	173	161	198	284	66	55	102	93	152	36	178	129	175	332	103	141
Secesh/Lake	33	37	80	263	42	50	139	161	256	85	292	221	235	290	177	110
Lemhi R	730	447	872	1406	287	65	226	293	91	69	183	309	305	352	63	157
Upper Valley Cr	378		31	282	47	11	4	2	17	11	2	24	68	26	43	6
Imnaha R	740	631	711	2062	246	189	469	611	450	574	721	479	448	606	193	169
Minam R	299	288	171	749	40	43	51	106	105	102	642	367	588	507	203	342
Lostine R	116	252	82	420	69	59	26	190	137	200	229	151	170	348	72	58
Wenaha R	235	151	441	604	37	176	147	198	180	94	272	524	494	533	54	266
Totals	4534	2565	3504	8190	1333	891	1713	2033	2071	1721	3582	3381	3914	6190	1456	2324
Snake River spring chinook recruits (spawners only) 1975 - 1990 (observations from Charlie Petrosky, IDFG)																
Brood Year	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Bear Valley/Elk	52	77	145	174	112	260	248	413	1210	89	146	229	153	715	75	18
Marsh	17	56	118	70	73	178	199	228	484	60	86	102	56	274	25	4
Sulphur	15	25	38	47	8	44	300	150	615	0	116	252	42	261	17	4
Upper Big	9	27	41	63	69	156	193	87	216	102	54	46	22	160	15	8
Poverty Flat	55	254	234	386	162	324	367	264	1192	250	288	821	474	1040	314	76
Johnson	23	123	112	175	39	136	158	136	391	113	94	208	106	442	90	17

Cr																
Secesh/Lake	18	110	152	337	92	181	291	242	391	115	186	223	96	407	153	26
Lemhi R	176	150	261	196	84	127	247	310	334	213	116	134	71	39	30	13
Upper Valley Cr	10	0	5	13	13	6	18	55	40	43	19	7	3	10	2	3
Imnaha R	214	349	550	544	568	561	677	521	664	167	142	172	76	424	142	51
Minam R	41	49	72	168	51	225	553	200	507	164	195	185	59	101	46	16
Lostine R	66	53	84	250	90	194	214	100	223	74	36	41	15	94	51	17
Wenaha R	82	169	176	302	64	131	393	355	145	61	45	76	37	164	67	28