# Appendix A. Current ESU Viability Assessment[1]

Snake River fall Chinook salmon spawn predominately in the mainstem of the Snake River below Hells Canyon Dam and in the lower reaches of several major tributaries, including the Clearwater, Grande Ronde, Tucannon, Salmon, and Imnaha Rivers. Like other fall-run Chinook salmon populations in the Columbia Basin (e.g., Hanford Reach, Deschutes River, Lewis River "brights"), Snake River fall Chinook salmon juveniles typically migrate to the ocean as subyearlings in the summer after their emergence from the gravel. Unlike these other populations, Snake River fall Chinook salmon also exhibit a yearling emigration life-history strategy. Historically, the Snake River fall Chinook salmon ESU likely consisted of two large populations: the extant Lower Snake River population and a second (currently extirpated) population associated with the Middle Snake River above the current Hells Canyon dam site.[2] For this status summary, we focus exclusively on the Lower Snake River population.

The ICTRT biological viability criteria for the Lower Snake River fall Chinook salmon population are tailored to the species' specific life-history characteristics following the same basic principles applied to the other Endangered Species Act (ESA)-listed Chinook salmon ESUs in the Interior Columbia Basin. The ICTRT described these principles in its report, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* (ICTRT 2007). This report is available at: http://www.nwfsc.noaa.gov/trt/col/trt_viability.cfm. NMFS' evaluation of the current status of the Lower Snake River fall Chinook salmon population follows the framework recommended by the ICTRT for integrating information across four viable salmonid population (VSP) parameters (abundance, productivity, spatial structure, and diversity), as described in ICTRT 2007. The ICTRT's framework examines overall population risk status by combining assessments for two separate groupings of the parameters: (1) natural-origin abundance and productivity, and (2) spatial structure and diversity. Overall viability status at the population level is determined by the specific combination of ratings for those two groupings. The ICTRT recommended quantitative metrics for evaluating a population's status according to these individual parameters and viability criteria. It provided examples of metrics corresponding to relative risk categories (very low, low, moderate, and high). The ICTRT also recognized that there could be other metrics for evaluating risks for particular viability criteria and provided some guidance for considering alternatives.

[1] On February 6, 2015, while the *ESA Recovery Plan for Snake River Fall Chinook Salmon* was in development, NMFS initiated a 5-year status review for 32 species of salmon and steelhead, including Snake River fall Chinook salmon. To ensure that the recovery plan was based on best available information, NMFS included this appendix, which incorporates material from the 5-year status review that was then underway. The information in this appendix is consistent with, but contains additional detail not included in, the final 5-year review memo from the Northwest Fisheries Science Center (NWFSC 2015).

[2] For additional information on historical population structure, see below, under "Updated Information for Snake River Fall Chinook Salmon ESU."

## A.1 Updated Information for Snake River Fall Chinook Salmon ESU

This assessment provides new insights into the population structure of the extirpated Middle Snake River component of the ESU that spawned historically above the current Hells Canyon Complex of dams and once accounted for most of the ESU's natural production.[3]

The ICTRT (2005) originally identified two historical populations above the current Hells Canyon Complex. As part of its 2015 *Status Review Update for Pacific Salmon and Steelhead Listed under the Endangered Species Act*, the Northwest Fisheries Science Center (NWFSC) determined that the two relatively continuous historical spawning aggregations for Snake River fall-run Chinook salmon above the current Hells Canyon Dam site were more likely part of a single population (the Middle Snake River population, consisting of two major spawning areas (NWFSC 2015). It made this determination based on new information submitted by the U.S. Fish and Wildlife Service and summarized in Connor et al. 2016. A key factor in that decision was a 56-km gap in suitable spawning habitat reported in Parkhurst (1950). Based on a detailed review of the geomorphic potential in that region, the gap was overestimated and was more likely less than 25 km (Connor et al. 2016).

The primary (largest and most productive) Middle Snake River subpopulation likely spawned within the area of direct aquifer influence described by Connor et al. (2016), extending from Auger Falls (RM 608.7) to Lower Salmon Falls (RM 573). Temperature conditions during spawning and incubation in this reach were strongly influenced by warm-water releases from the aquifer, which allowed for earlier emergence timing and rapid growth (Connor et al. 2016; NWFSC 2015). The second major spawning area in the Middle Snake River extended downstream from Kings Hill (RM 359.9), above Glenns Ferry, to the mouth of the Burnt River (approximately RM 327.8). The upper reaches of the Glenns Ferry spawning area were highly productive, but the lower reach was less productive because the influence of the aquifer diminished (Connor et al. 2016).

The assessment also uses the viability criteria adaptations included in the *ESA Recovery Plan for Snake River Fall Chinook Salmon* (Plan or recovery plan). NMFS used an adapted application of the ICTRT's basic decision framework to assess the status of the Snake River fall Chinook salmon ESU. The approach specifically incorporates alternative scenarios for achieving ESA recovery and provides potential viability criteria and metrics for measuring viability characteristics relative to each potential recovery scenario. Presented in Chapter 3 of the recovery plan, the alternative recovery scenarios include both multiple-population and single-population versions. Given that at present there is only one extant population, the Lower Snake River population, this assessment evaluates the current status of that population relative to the

[3] Historically, natural production from this ESU was mainly from spawning reaches in the mainstem Middle Snake River upstream of the current site of the Hells Canyon Complex of dams, where water temperatures were directly influenced by discharges from the Eastern Snake River Plain Aquifer. The spawning and rearing habitat associated with the current extant population, which is outside the area of the aquifer's influence, represents approximately 20% of the total historical habitat available to the ESU (Dauble et al. 2003).

criteria and metrics for the single-population recovery scenarios, in particular for Scenario B. However, the basic measures evaluated in this assessment would also apply to the two-population scenario (Scenario A), which would entail reestablishing a viable fall Chinook salmon population above the Hells Canyon Complex.

In addition, this assessment extends the time series of basic population information to cover additional years and uses improved methods for estimating annual abundance from the data generated by annual sampling efforts. The improved methodology for estimating spawner abundance, age structure, and hatchery/natural composition is described below.

## A.2. Current Viability Assessment

The following status assessment of the Lower Snake River fall Chinook salmon population is based on information available in the spring of 2015. The primary focus is on status relative to the metrics and criteria thresholds for Scenario B (single population evaluated in the aggregate). However, we include brief summaries under specific VSP components of the findings or the additional information that would be required to evaluate status under Scenario C, a single population variation that would incorporate Natural Production Emphasis Areas that include one or more major spawning areas.

### A.2.1 Abundance and Productivity

Following the recommended ICTRT approach, abundance and productivity were assessed by comparing paired estimates of natural-origin spawner abundance and productivity levels to a set of viability curves, each representing thresholds for a specific risk level (1%, 5%, and 25%) of a population remaining below a quasi-extinction threshold of 50 spawners for four or more consecutive years when projected over 100 years (ICTRT 2007). Viability curves are ESU specific and were generated through an iterative modeling process incorporating average age structure and year-to-year variability (including autocorrelation) in spawner-to-spawner return rates.

The ICTRT adopted a recommended minimum natural-origin abundance threshold of 3,000 natural-origin spawners (measured as a 10-year geometric mean) for the single extant Snake River fall Chinook salmon population, with no fewer than 2,500 of those natural-origin spawners in the mainstem Snake River spawning areas. Given its original finding that the historical Snake River fall Chinook salmon ESU consisted of only three populations, the ICTRT recommended using a more conservative population viability threshold, associated with a 1% risk of quasi-extinction, as a target for ESU recovery. The ICTRT report, *Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs* (ICTRT 2007), also recommended that the recovery criteria specify the degree of statistical certainty required to ensure that the viability criteria are met. The degree of statistical certainty in turn influences the viability criteria metrics. Under the single-population recovery scenarios, the recovery plan (Chapter 3) calls for achieving highly

viable status with a high degree of certainty for the Lower Snake River population. This would require exceeding the very low risk viability curve by a margin corresponding to an 80% probability of being at or below a 1% risk of extinction over 100 years.

Our abundance, trend, and productivity estimates for the Lower Snake River population are based on counts and sampling at Lower Granite Dam. Estimates of the annual numbers of fall Chinook salmon passing over Lower Granite Dam are derived using ladder counts and the results of sampling a portion of each year's run using a trap associated with the ladder. Information from the trap sampling is used to break out the ladder counts for hatchery and wild origin, age of return, and age at ocean entry (subyearling vs. yearling). A portion of the fish sampled at the trap is retained and used as hatchery broodstock. Each year, projected return levels of hatchery- and natural-origin Snake River fall Chinook salmon are used to define a randomized sampling strategy across the duration of the run that will also achieve hatchery broodstock objectives for the Snake River fall Chinook programs and be consistent with impact limits on co-occurring listed steelhead returns. Fish shunted into the trap are measured, sampled for scales to determine age, and examined for marks and/or tags. Fish removed for broodstock are externally tagged to track arrival dates and transported to Lyons Ferry and Nez Perce Tribal Hatcheries (on alternative days) for holding and spawning. Coded-wire tags (CWTs) are read at spawning. The data from trap sampling, including the CWT recovery results, passive integrated transponder (PIT) tag detections, and the daily incidence of adipose clips, are used to construct daily estimates of hatchery proportions in the run.

At present, estimates of natural-origin returns are made by subtracting estimated hatchery-origin returns from the total run estimates. In the near future, returns from a Parental-Based genetic Tagging (PBT) program will allow for a more comprehensive assessment of hatchery contributions and, therefore, a more direct assessment of natural returns (see the Plan, Chapter 7 and Appendix B).

Sampling methods and statistical procedures used in generating the estimated escapements have improved substantially over the past 10 to15 years. Beginning with the 2005 return, estimates are available for the total run apportioned into natural and hatchery returns by age (and hatchery-origin) with standard errors and confidence limits (e.g., Young et al. 2012). Current estimates of escapement over Lower Granite Dam for return years prior to 2005 were also based on adult dam counts and trap sampling. Methods varied across years and are generally described in annual reports compiled by the Washington Department of Fish and Wildlife Snake River laboratory (Milks et al. 2014). In the near future, the escapement estimates for 1999-2004 return years will be updated using the new escapement reconstruction framework.

Prior to the early 1980s, returns of Snake River fall Chinook salmon were likely predominately of natural origin (Bugert et al. 1990). Natural-origin return levels declined substantially following the completion of the three-dam Hells Canyon Complex (1959-1967), which completely blocked access to major production areas above Hells Canyon Dam, and the

construction of the lower Snake River dams (1962-1975), which inundated additional habitat. Based on extrapolations from sampling at Ice Harbor Dam (1977-1990), the Lyons Ferry Hatchery (1987-present), and Lower Granite Dam (1990-present), hatchery strays made up an increasing proportion of returns at Lower Granite Dam through the 1980s (Bugert et al. 1990; Bugert and Hopley 1989). Strays from out-planting of Priest Rapids hatchery-origin fall Chinook salmon (an out-of-ESU stock from the mid-Columbia) and Snake River fall Chinook salmon from the Lyons Ferry Hatchery program (on-station releases initiated in the mid-1980s) were the dominant contributors. Estimated natural-origin returns reached a low of less than 100 fish in 1978, and remained low through the 1980s. Only about 78 natural-origin adults (Lavoy and Mendel 1996) returned to the Snake River in 1990.

In recent years, naturally spawning fall Chinook salmon in the lower Snake River have included returns originating from naturally spawning parents and from returning hatchery releases. Hatchery-origin fall Chinook salmon escaping upstream above Lower Granite Dam to spawn naturally are now predominantly returns from hatchery program juvenile releases in reaches above Lower Granite Dam and from releases at Lyons Ferry Hatchery that have dispersed upstream. These fish are considered to be part of the listed ESU.

**Single-Population Viability Assessment**

Under Scenario B, the single-population measured in the aggregate scenario, current natural-origin abundance and productivity are derived from estimates of returns over Lower Granite Dam, after taking into account known broodstock removals and harvest that occurs upstream of that point. For recent years, run reconstruction estimates generated by a multi-agency workgroup (Young et al. 2012) are used in the analysis. Reported annual run reconstructions for years prior to 2005 that were generated using similar, but more generalized, methods have been used in annual management activities (e.g., *U.S. v. Oregon* TAC assessments). Except where noted for specific diversity criteria, the abundance estimates used in this assessment are for returns estimated to have passed above the lower Snake River dams following a convention used by several ongoing and prior Columbia Basin salmon stock assessment efforts. The methods for estimating escapements are based on the length cutoff used in the ladder counts (fish greater than 53 cm fork lengths are recorded as adults). Trap sampling data are compiled using the same length cutoff. The combined escapement data set used in this assessment is archived in the NWFSC's Salmonid Population Summary (SPS) database, available at https://www.webapps.nwfsc.noaa.gov/apex/f?p=261:1.[4] The data sets archived in the SPS database include citations for the actual sources for each element (e.g., spawning abundance, hatchery proportions, age structure, and harvest exploitation rates).

The geometric mean natural-origin adult abundance for the most recent 10 years of annual spawner escapement estimates (2005-2014) is 6,418, with a standard error of 0.19. Natural-origin spawner abundance has increased relative to the levels reported in the previous NWFSC status

[4] Metrics calculated from data downloaded from this site may differ slightly from the results presented here due to differences in rounding conventions.

review (Ford et al. 2011), driven largely by relatively high escapements in the most recent three years (Figure A-1a).

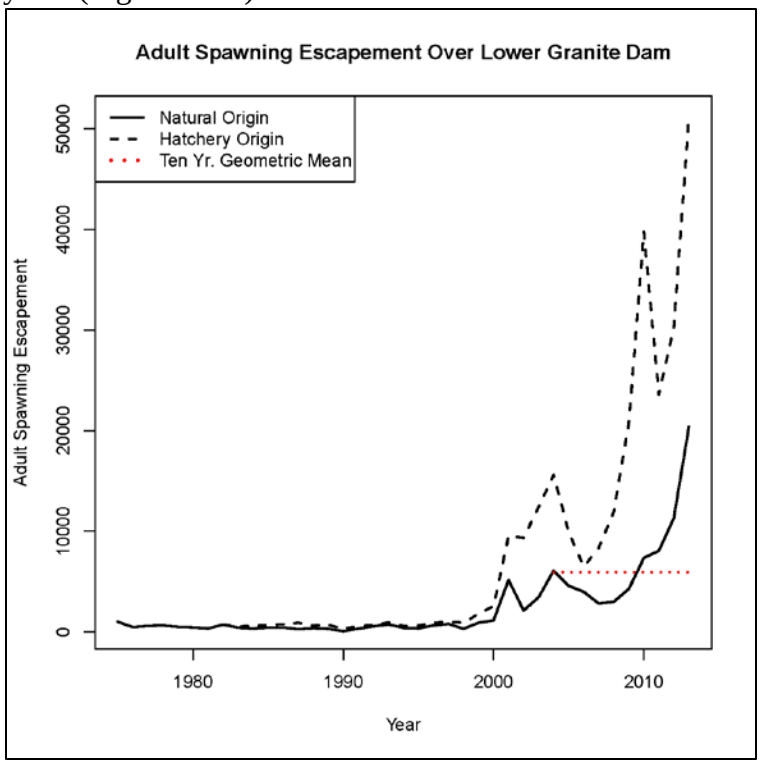


**Figure A-1a.** Spawner estimates for run years 1991 to 2013.

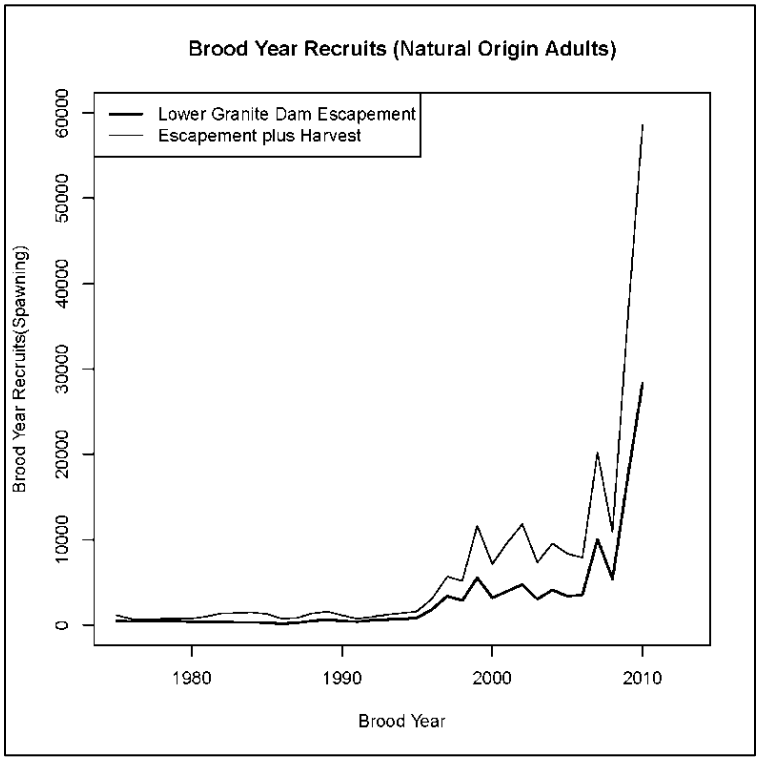

**Figure A-1b.** Brood year recruits measured as returns to natural spawning areas (dark line) and as spawners plus harvest (light gray line).

Snake River fall Chinook salmon have a very broad ocean distribution and have been taken in ocean salmon fisheries from central California through southeast Alaska. They are also harvested in-river in tribal and non-tribal fisheries. Historically they were subject to total exploitation rates on the order of 80 percent. Since they were listed in 1992, fishery impacts have been reduced in both ocean and river fisheries (Figure A-2). Total exploitation rate has been relatively stable in the range of 40 to 50 percent since the mid-1990s.

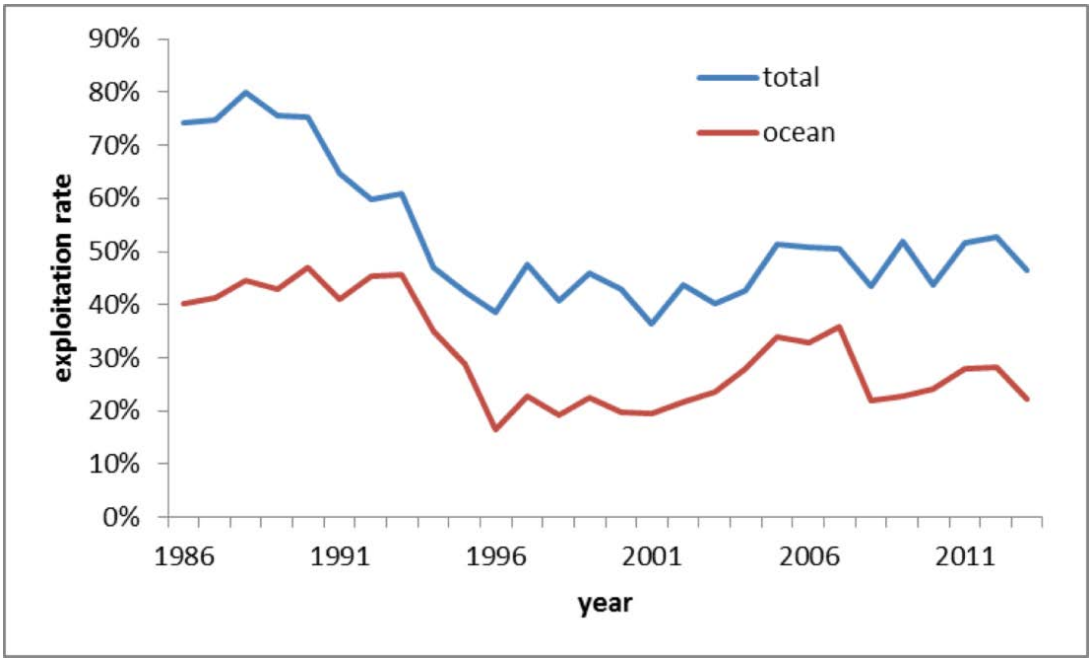


**Figure A-2.** Total exploitation rate for Snake River fall Chinook salmon. Data for marine exploitation rates from the Chinook Technical Committee model (Calibration 1503) and for in-river harvest rates from the Columbia River Technical Advisory Committee (TAC 2014; Robin Ehlke, WDFW, personal communication).

Productivity, defined in the ICTRT viability criteria as the expected replacement rate at low-to-moderate abundance relative to a population's minimum abundance threshold, is a key measure of the potential resilience of a natural population to annual environmentally driven fluctuations in survival. The ICTRT Viability Report (ICTRT 2007) provided a simple method for estimating population productivity based on return-per-spawner estimates for the most recent 20 years. To assure that all sources of mortality are accounted for, the ICTRT recommended that productivities used in Interior Columbia River viability assessments be expressed in terms of returns-to-the-spawning-ground. Other management applications express productivity in terms of pre-harvest recruits. Pre-harvest recruit estimates are available for Snake River fall Chinook salmon (see Figure A-1b). Using pre-harvest recruit estimates as a basis for evaluating current population viability would require accounting for mortalities incurred due to harvest, upstream passage loss, and prespawning mortality.

Under the simple ICTRT method, abundance is measured as the most recent 10-year geometric mean of the annual natural-origin adult (age 4+) spawner abundance (excludes mini-jacks and jacks). Productivity is measured as the geometric mean of the annual spawner-to-spawner natural return rate estimated at low to moderate parental spawner abundance within the most recent 20 years. Natural-return rates are estimated on a brood-year basis as return-per-spawner (R/S), where S is the number of naturally spawning fish in a year (including naturally spawning hatchery fish) and R is the number of adults produced by those natural spawners that themselves return to spawn. Because the productivity criteria is intended to evaluate resiliency at low abundance, only R/S values for years where S is below 2,250 (0.75 X minimum abundance threshold of 3,000) are used in calculating the geometric mean. This method of evaluating productivity was provided by the ICTRT as a simple default method.

The ICTRT's report on the viability criteria (2007) also acknowledged that alternative means of assessing productivity at low-to-moderate spawning abundance may be appropriate or required, especially in cases where total (natural- plus hatchery-origin) spawning levels consistently are at or above the minimum threshold for a particular population.

We developed estimates of current productivity for the Lower Snake River population using both the simple average R/S method and by fitting stock-recruit functions using maximum likelihood statistical routines (nls routine in the R statistical package). Using the ICTRT's simple 20-year R/S method, the current estimate of productivity for this population (1991-2010 brood years) is 1.53 with a standard error of 0.19. Findings using the simple R/S method indicate that there have been years when abundance was high but productivity (R/S) fell below the replacement level (Figure A-3), indicating potential influence from density-dependence limitations or from annual variations in survivals through mainstem migration and ocean stages. This estimate of productivity, however, may be problematic for two reasons: (1) the increasingly small number of years that actually contribute to the productivity estimate means that there is increasing statistical uncertainty surrounding that estimate, and (2) the years contributing to the estimate are now far in the past and may not accurately reflect the true productivity of the current population.

Under the simple R/S method, all of the R/S estimates for years after 1999 are excluded from the average due to the total (hatchery plus wild) escapements in those years. Total escapements for brood years 2011 through 2014 are also well above the minimum threshold levels and would, by definition, be excluded in calculating productivity using the simple ICTRT method in future assessments.

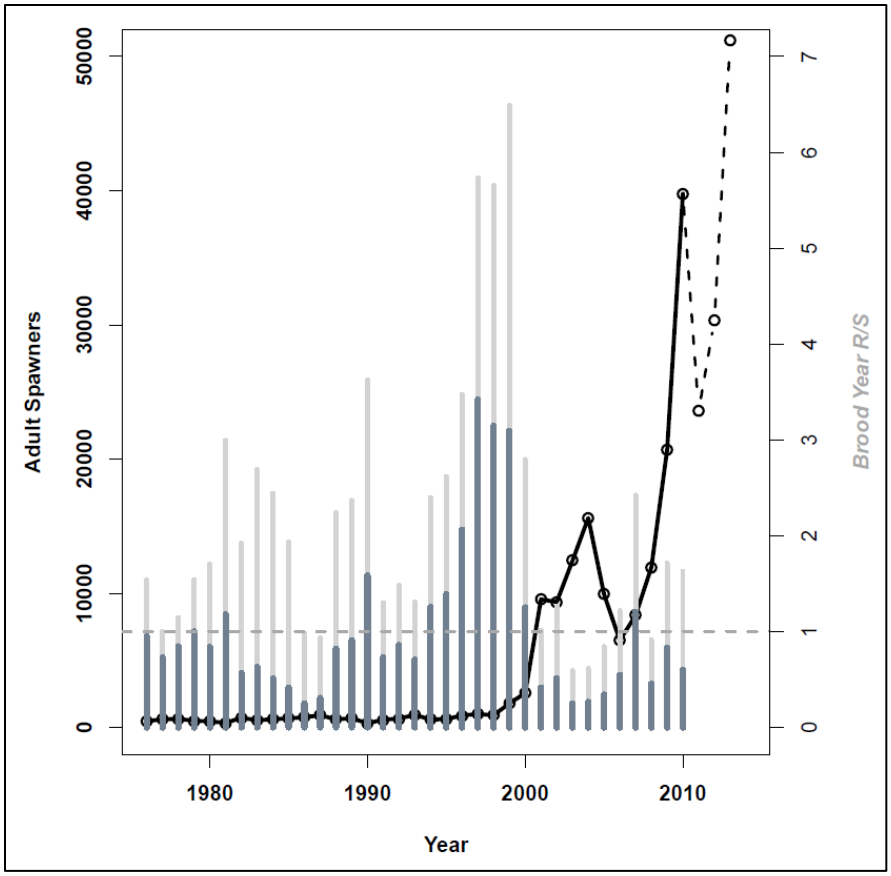


**Figure A-3**. Brood year parent spawning levels (left side axis, hatchery plus natural-origin adults) and brood-year return per spawner estimates (right side axis, black circles) vs. parent brood year. Light bars: recruits are adult escapement plus ocean (adult equivalent) and in-river harvest. Dark bars: recruits are escapement over Lower Granite Dam. Parent brood year escapements with incomplete return ages depicted with dashed line.

The ICTRT recognized that situations could occur where alternative means to estimate population productivity may be needed. In general, population parameters (such as productivity and equilibrium abundance) derived from fitting stock-recruit relationships can be improved by including environmental variables that correspond to factors contributing to year-to-year variability or by fitting multiple populations with common-year effects. In particular, the ICTRT anticipated that fitted stock-recruit models incorporating potential explanatory environmental variables might provide a useful alternative for evaluating a population's abundance and productivity relative to specific recovery criteria. The ICTRT recommended that if such an approach was used, the "steepness" parameter (e.g., Hilborn and Walters 1992) of the stock-recruit model would be an appropriate index of productivity. Steepness is defined as the expected return-per-spawner at a parent-spawner level of 20% of the predicted equilibrium escapement for a data series. Steepness is derived algebraically from the more basic stock-recruit curve parameters (productivity at the origin and capacity). While the consistently high spawner escapements driven by a combination of natural and hatchery supplementation returns have complicated interpretation of results from the simple R/S method, the increased range in parent

escapement estimates has increased the feasibility of using fitted stock-recruit relationships as an alternative approach for estimating production parameters.

Snake River fall Chinook (both natural-origin and hatchery production) are components of the aggregate fall Chinook run into the Columbia River. Recent analyses have indicated that Columbia River fall Chinook annual returns are strongly related to ocean indicators lagged to represent conditions during the first year of ocean life (Peterson et al. 2014). In particular, the aggregate annual runs of fall Chinook to the Columbia River are related to the relative abundance of northern copepods, which is in turn related to the average summer month Pacific Decadal Oscillation (PDO) index (Figure A-4). The index of northern copepod abundance off of the Columbia River has only been generated for a relatively short series of recent years, while the PDO index series is available going back to the early 1900s.

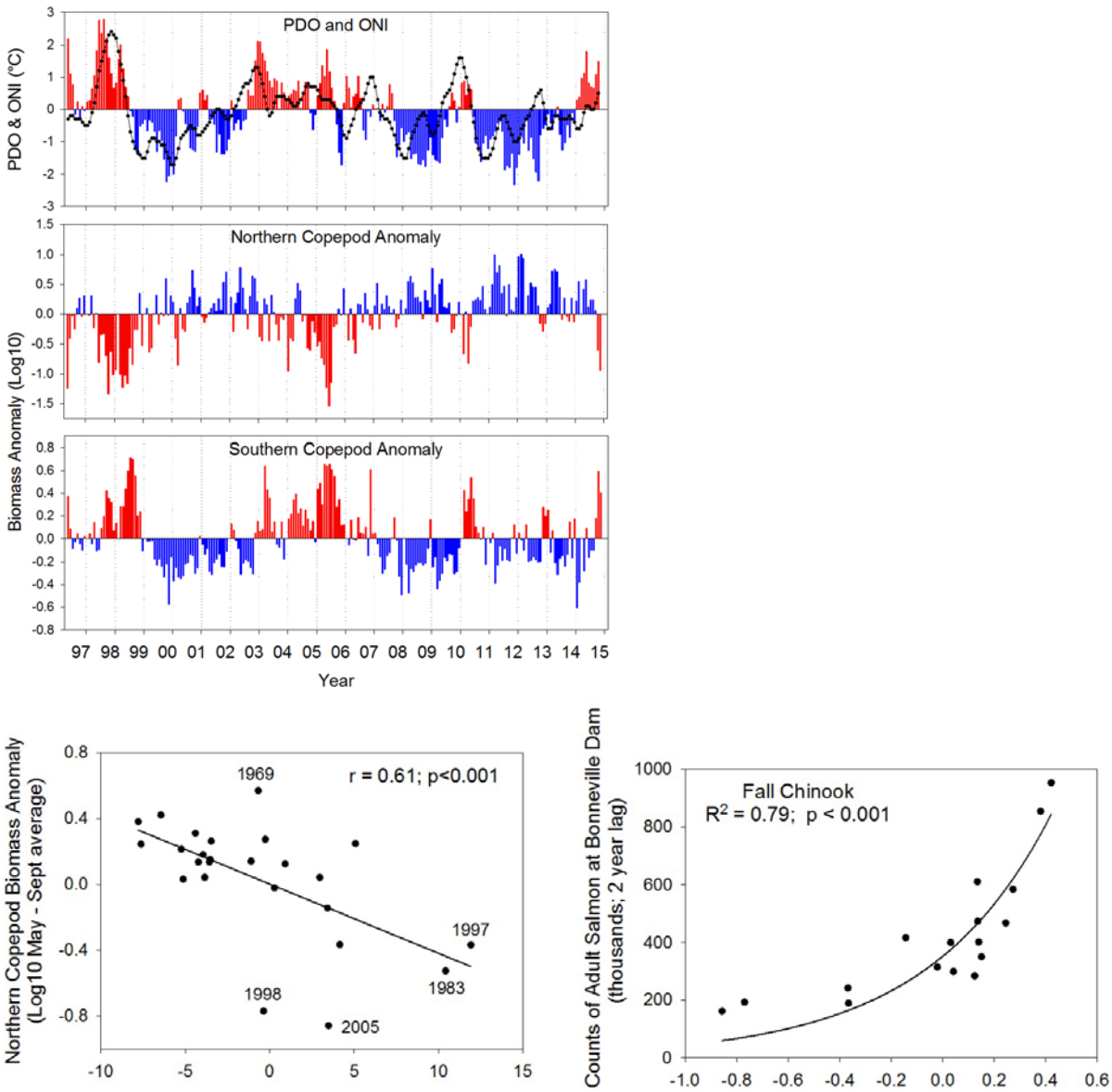


**Figure A-4**. Excerpts from Peterson et al. 2014. Top panel: Fig. NSC-01 - The Pacific Decadal Oscillation (upper), and northern copepod biomass anomalies (lower), from 1969 to present. Lower left panel: Fig. NSC-02 - Relationship of northern copepod anomalies and the PDO during the summer upwelling season (May - Sept). Data are from 1969 - 1973, 1983, and 1996 - present. Lower left panel: from Fig. NSC-03fall Chinook (middle panel) at Bonneville Dam. vs. log of the northern copepod biomass anomaly during the year of ocean entry. Counts at Bonneville are lagged by 2 years.

Expressing productivity as an expected average return-per-spawner from parent-spawner escapements below levels associated with strong density-dependent effects is a key feature of the ICTRT methods for assessing current population performance against viability curves. The ICTRT determined, based on preliminary sensitivity analyses, that estimated productivities derived by fitting stock-recruit relationships to current data series could be compared to a single set of viability curves if those estimates were expressed as steepness (ICTRT 2007).

Brood-year returns were reconstructed by breaking out each run year into age components and summing by parent brood year. Two sets of analyses are tabulated, one using returns to the spawning grounds as a measure of recruitment, the other including harvest (ocean and in river) and broodstock removals in the recruits. Ocean harvest estimates were derived from information reported by the Chinook Technical Committee of the Pacific Salmon Commission (http://www.psc.org/publications/technical-reports/technical-committee-reports/chinook/) and are expressed in terms of adult equivalents (adjusted based on maturation rates derived from tagged Lyons Ferry subyearling releases). In-river harvest rates were obtained from annual WDFW/ODFW fall fishery status reports (e.g. WDFW 2014).

NMFS fit four alternative stock-recruit models (Table A-1) to the 1991-2010 brood-year spawner and return data set for the Lower Snake River fall Chinook salmon population. The four models were: (1) Constant RS ─ a model that assumed a constant underlying R/S value that is invariant with respect to spawner density, (2) a Beverton-Holt RS model, (3) a Ricker RS model, and (4) a Shepard RS model. The Shepard RS model (Shepard 1982) is a form that includes a third fitted parameter corresponding to the general shape of the relationship. Each function was fit with and without an annual PDO term to evaluate the potential contribution of year-to-year variations in ocean conditions. The nls routine in the R statistical package was then used to estimate the parameters of the three stock-recruit models incorporating density-dependent terms (Beverton-Holt, Ricker, and Shepard). The models were statistically compared using the AICc criteria (AICcmodavg package).

**Table A-1**. Stock recruit functions.

| Model | | Equation |
|---|---|---|
| **Constant RS** | | $Recruits := \alpha * Spawners * \epsilon^{(0,\sigma)}$ |
| | *With PDO* | $Recruits := \alpha * e^{c*PDOnorm} * Spawners * \epsilon^{(0,\sigma)}$ |
| **Beverton Holt** | | $Recruits := \frac{\alpha * Spawners}{(1 + \frac{a}{b} * Spawners)} * \epsilon^{(0,\sigma)}$ |
| | *With PDO* | $Recruits := \frac{\alpha * e^{(c*PDOnorm)} * Spawners}{(1 + \frac{a}{b} * Spawners)} * \epsilon^{(0,\sigma)}$ |
| **Ricker** | | $Recruits := \alpha * Spawners * e^{(-b*Spawners)} * \epsilon^{(0,\sigma)}$ |
| | *With PDO* | $Recruits := \alpha * e^{(c*PDOnorm)} * Spawners * e^{(-b*Spawners)} * \epsilon^{(0,\sigma)})$ |
| **Shepard** | | $Recruits := \frac{\alpha * Spawners}{(1 + \frac{a}{b} * Spawners)^d} * \epsilon^{(0,\sigma)}$ |
| | *With PDO* | $Recruits := \frac{\alpha * e^{(c*PDOnorm)} * Spawners}{(1+\frac{a}{b} * Spawners)^d} * \epsilon^{(0,\sigma)}$ |

Results from the analysis are summarized in Table A-2 and shown in Figures A-5 and A-6. Regardless of whether recruits were measured as returns-to-the-spawning-grounds or as pre-harvest recruits, based on a comparison of AICc values the three models incorporating density-dependent terms (Beverton-Holt, Ricker, and Shepard) fit the data significantly better than the constant R/S model (Table A-2). The estimated equilibrium abundance estimates from the three density-dependent models were each below the recent 10-year geometric mean natural abundance estimate of 6,418 (Figure A-5).

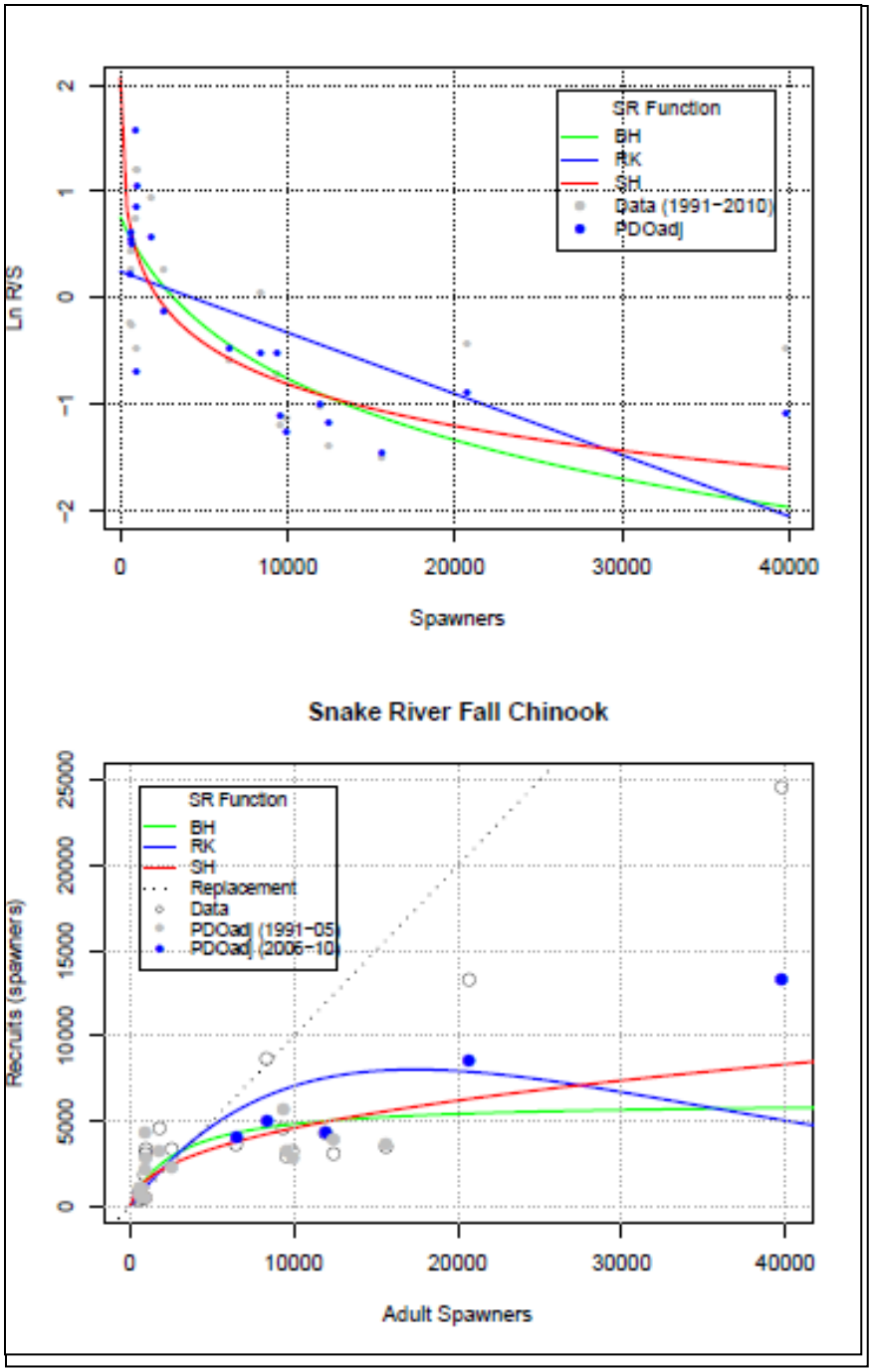


**Figure A-5.** Snake River Fall Chinook stock/recruitment function fits to 1991-2014 brood year adult return (to spawning grounds) vs. parent spawner estimates. Brood year 2014 recruits incomplete, expanded by average age 5 proportion (13.8%). Dark-filled circles include adjustment for annual PDO. Top panel: Natural log recruits/spawner vs. parent spawners. Bottom panel: recruits vs. parent spawners with best fit estimates for three S/R functional relationships (BH = Beverton Holt, RK = Ricker, SH = Shepard).

The Beverton-Holt model had the lowest (mostly supported) AICc score, followed by the Shepard function. The fitted relationships for natural log return-per-spawner versus parent spawners and the results of bootstrapping to illustrate the potential influence of parameter

uncertainty for the Beverton-Holt function are provided in Figure A-6. The inset pie chart in the top panel of that figure summarizes the proportions of the bootstrap samples that fall into the four possible risk categories. Approximately 67% of the samples exceeded the viability curve for very low risk, below the recovery plan requirement in Scenario B for 80% of the samples to exceed the viability curve for very low risk. The spawner/recruit plot includes the 1991-2014 recruit and parent spawner pairs, both unadjusted and adjusted to reflect the fitted PDO relationship included in the analysis.

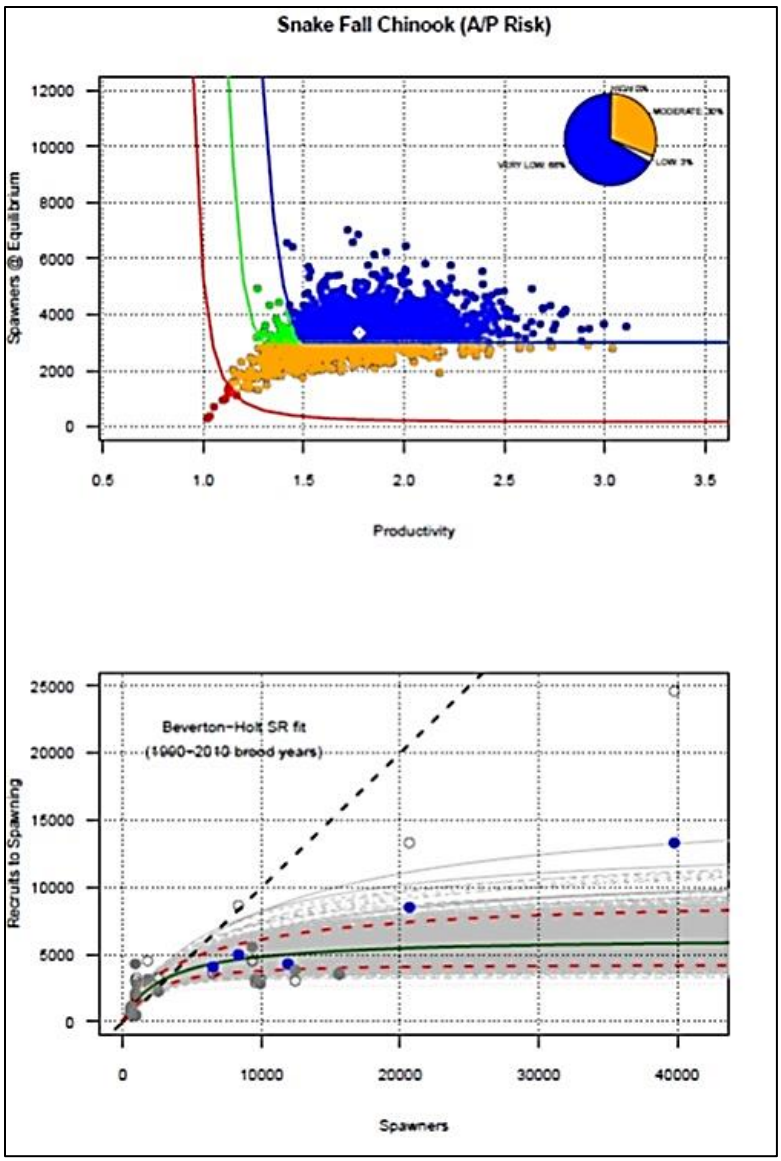


**Figure A-6a & A-6b.** Beverton Holt stock recruit relationship fitted to brood years 1991-2010 Snake River Fall Chinook adult escapement estimates. Includes parameter uncertainty generated using the nlsBoot routine for the R statistical package. Top panel: Summary of bootstrap results (2,000 iterations) plotted against Snake Fall Chinook viability curves. Pie chart in upper right corner summarizes the proportions of bootstrap runs vs. ICTRT viability curves (Hi, Moderate, Low and Very Low risk). Bottom panel: Data points (with and without average fitted PDO multiplier). Gray lines represent range in parameter combinations from bootstrap iterations. Solid line: median relationship. Red dashed lines are 90% confidence range. Dashed black line is replacement.

The differences between the outcomes of the empirical averaging approach and the curve-fitting methods may be accounted for largely by temporal patterns in the recent data series used as the basis for both sets of analyses. The productivity estimates generated from either method (simple averaging vs. curve fitting) are largely driven by the return-per-spawner data pairs from the escapements in the mid-1990s (Table A-2). The estimated equilibrium abundance estimate from the simple ICTRT method is, by definition, the most recent 10-year geometric mean and may be influenced by longer-term patterns in environmental conditions or by changes in survival from actions that came on line during the latter half of the 20-year series. The equilibrium abundance estimates from the curve-fitting methods are influenced by the full data series and therefore may reflect more of an average environmental variation but also may lag in picking up survival changes affecting more recent brood years.

**Table A-2.** Lower Snake River fall Chinook salmon population. Summary of results from four stock-recruit models: Beverton-Holt (BH), Shepard, Ricker (RK), and density-dependent constant productivity (Constant). The results are from fitting alternative stock-recruit functions to the population brood year 1991-2010 data series measuring recruits as (a) returns to the spawning grounds and (b) returns including harvest and spawners. Best fit models based on small sample size AIC criteria (lower by 2 or more) shaded in gray. All models assume log-normal variability. Parameters: a=productivity, alpha=exp (a), b=capacity parameter, c=PDO coefficient, d=Shepard "shape" parameter.

| | | | | Recruits (Spawners) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SR Model | Recruits | a | b | c | d | Resid SE | Alpha | steepness | Equil | AICc | AICc diff. |
| BH | EscwPDO | 0.79 | 6210 | -0.0304 | NA | 0.5383 | 2.2 | 1.774 | 3387 | 39.4 | 0 |
| Shepard | EscwPDO | 2.094 | 88 | -0.03 | 0.594 | 0.5321 | 8.12 | 2.173 | 2395 | 41.3 | 1.9 |
| BH | Esc | 0.503 | 8530 | NA | NA | 0.6475 | 1.65 | 1.46 | 3360 | 44.8 | 5.4 |
| Constant | Esc | -0.214 | NA | NA | NA | 0.8346 | 0.81 | NA | NA | 46.5 | 7.1 |
| Shepard | Esc | 1.222 | 456 | NA | 0.544 | 0.6448 | 3.39 | 1.699 | 2265 | 46.6 | 7.2 |
| RK | EscwPDO | 0.228 | 0.000057 | -0.0238 | NA | 0.7039 | 1.26 | 1.2 | 3961 | 50.1 | 10.7 |
| RK | Esc | 0.118 | 0.000043 | NA | NA | 0.7454 | 1.12 | 1.099 | 2744 | 50.4 | 11 |
| Constant | EscwPDO | -0.215 | 15280 | -0.006 | NA | 0.8537 | 0.81 | 2.305 | 10812 | 55.8 | 16.4 |
| | | | | Recruits (Spawners plus Harvest) | | | | | | | |
| SR Model | Recruits | a | b | c | d | Resid SE | Alpha | steepness | Equil | AICc | AICc diff. |
| BH | AERUNwPDO | 1.229 | 15280 | -0.0247 | NA | 0.4907 | 3.42 | 2.305 | 10812 | 35.7 | 0 |
| Shepard | AERUNwPDO | 2.985 | 22 | -0.025 | 0.483 | 0.4759 | 19.8 | 2.055 | 9542 | 36.9 | 1.2 |
| RK | AERUNwPDO | 0.827 | 0.000049 | -0.0196 | NA | 0.6063 | 2.29 | 1.939 | 16919 | 44.2 | 8.5 |
| Constant | AERUNwPDO | 0.451 | NA | -0.004 | NA | 0.732 | 1.57 | NA | NA | 55.8 | 20.1 |

The estimated productivity and equilibrium abundance levels from either the simple empirical method or the stock/recruit analysis all reflect the average effects of factors influencing survival across the 1991-2010 brood years. In both cases, estimates of productivity are largely driven by adult returns from spawning escapements prior to 2000. Incorporating the PDO index explicitly into the derivation of stock-recruit parameters provides a means of addressing large-scale year-to-year environmental patterns. In addition to variations in annual environmental influences, there have been a number of actions implemented to improve spawning, rearing, and migration

survivals in recent years (Figure A-7). The simple adult-to-adult-based analyses described above do not account for any changes in survival that might have resulted from those activities. In the future, the more detailed life-cycle model based approach that is in development for Snake River fall Chinook salmon will allow for incorporating estimated changes in life-stage survivals based on directed studies directly into assessment updates.

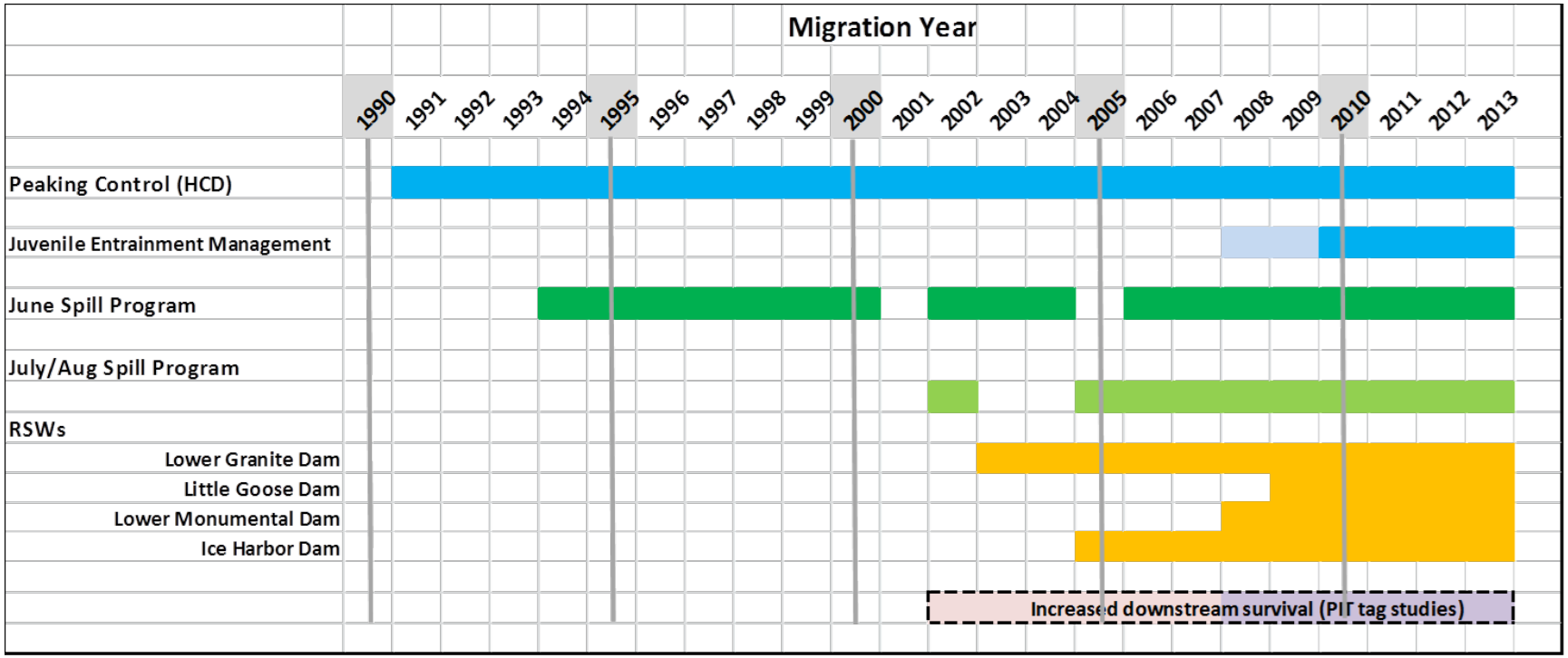


**Figure A-7.** Timing of recent actions with the potential to affect outmigration survival of juvenile Snake River fall Chinook salmon.

Efforts are underway to develop indices of downstream passage survival that could improve future stock-recruit analyses for Snake River fall Chinook salmon (see Plan, Chapter 7 and Appendix B). Initial estimates of subyearling outmigrant production relative to parent spawning escapements also indicate a strong density dependent component (Figure A-8 [Figure 3c from Connor et al. 2014]). Efforts are underway to develop a multi-stage life-cycle modelling assessment of Snake River fall Chinook natural production that should reduce uncertainties regarding productivity and density dependent life stage capacities in future assessments (see Plan, Chapter 7 and Appendix B).

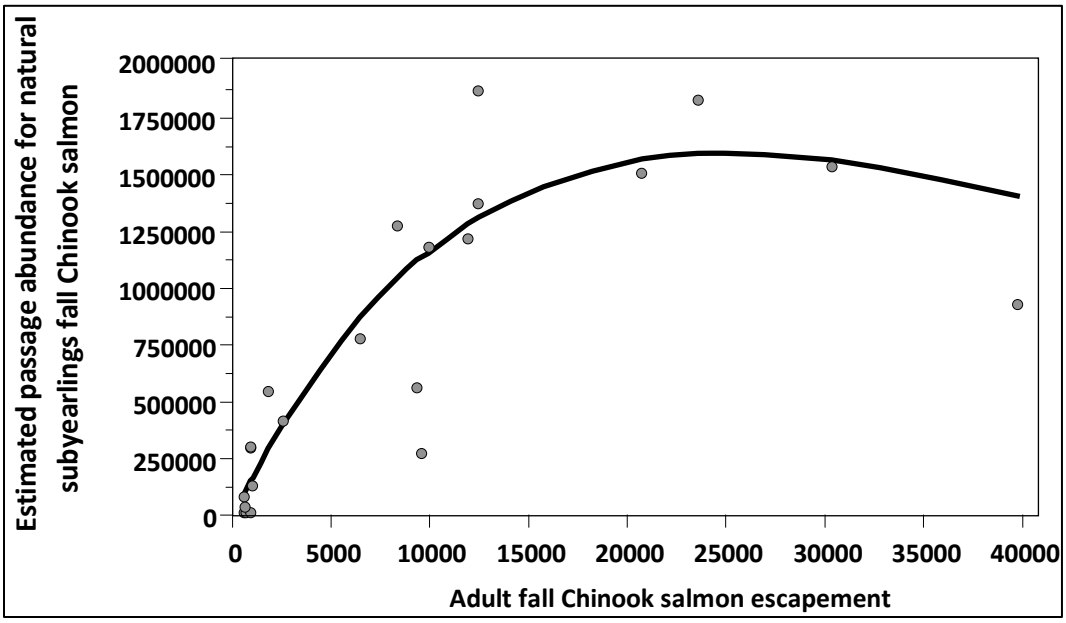


**Figure A-8.** The preliminary relation between adult stock and natural juvenile recruits for Snake River basin fall Chinook salmon subyearlings at Lower Granite Dam calendar years 1992 to 2013, brood years 1991 to 2012. Passage abundance was not estimated during the months of November through late March when the Smolt Monitoring Program was not in operation or in late March through April during the period of yearling passage.(Source: Connor et al. 2014)

#### A.2.1.1 Abundance and Productivity Summary

As shown in Figures A-6a and A-9, the point estimate of abundance and productivity corresponding to the geometric mean natural-origin abundance and productivity exceeds the 1% viability curve, but by a relatively small margin, insufficient to meet the uncertainty buffering requirement (i.e., an 80% probability of being at or below a 1% risk of extinction) under the biological viability criteria for Scenario B (see Plan, Chapter 3). Accounting for the uncertainty buffer, and given the current level of variability, the point estimate of current productivity would need to exceed 1.7 for the population to be rated at very low risk. The corresponding productivity and equilibrium abundance estimates from the fitted Beverton-Holt and Ricker production functions also fail to meet the criteria relative to the 1% viability curve (Figure A-6b). The bootstrapped confidence ranges for both of the fitted stock-recruit models overlap considerably with the 1% viability curve.

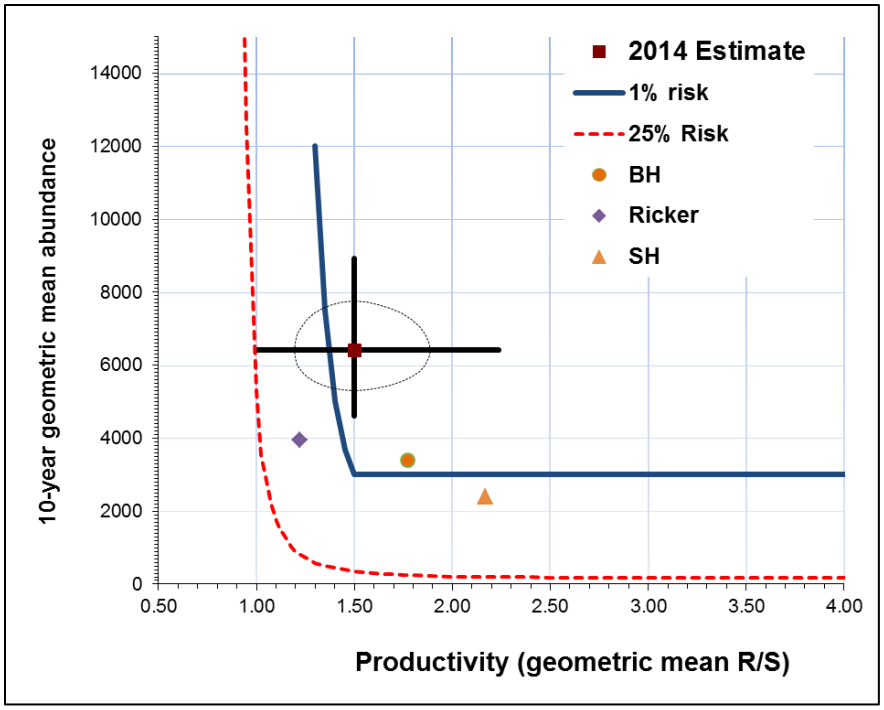


**Figure A-9.** Estimated equilibrium abundance vs. productivity for Lower Snake River fall Chinook salmon population based on 1991 through 2013 data series (1991 to 2010 brood years). Oval represents 1 standard error assuming bivariate normal distribution. Lines represent 90% confidence limits. Point estimate for standard (empirical) ICTRT method. The 1% and 5% viability curves were generated based on Hanford Reach Fall Chinook Salmon data series (ICTRT 2007).

In conclusion, while the 10-year geometric mean natural-origin abundance level has been high, the abundance/productivity margin is insufficient to rate the population as very low risk given the uncertainty buffering requirement under Scenario B. The probability that the true underlying abundance and productivity being estimated from the samples falls above the 5% viability curve (with minimum abundance threshold) is, however, greater than 80%. As a result, the Lower Snake River fall Chinook salmon population is rated at **low risk** for abundance and productivity.

As described in Chapter 3 of the Plan, Scenario C is a single-population scenario where, recognizing the unique spatial complexity of the Lower Snake River fall Chinook salmon population, Natural Production Emphasis Areas supporting the bulk of natural returns would be developed to operate consistent with long-term diversity objectives. Under Scenario C, the requirements for a sufficient combination of natural abundance and productivity could be based on a combination of total population natural abundance and relatively high production from one or more major spawning areas designated as Natural Production Emphasis Areas with relatively low hatchery contributions to spawning. At present, based on escapements through 2014, and given the widespread distribution of hatchery releases and the lack of direct sampling of reach-specific spawner compositions, there is no indication of a strong differential distribution of hatchery returns among major spawning areas.

### A.2.2 Spatial Structure and Diversity

The ICTRT framework for evaluating population-level status in terms of spatial structure and diversity is hierarchical, organized around two major goals: maintaining natural patterns for spatially mediated processes and maintaining natural levels of variation (ICTRT 2007). The overall rating is driven by considerations for an explicit series of mechanisms, factors, and metrics associated with each goal. Mechanisms are the biological or ecological processes that contribute to achieving the goals. Factors are characteristics of a population or its environment that influence mechanisms. Each of the factors has an associated set of metrics for assessing progress towards achieving the goals, or for evaluating its contribution to risk. The framework also incorporates a scoring system that weights more direct measures of current population performance over indirect indicators. The metrics used to evaluate spatial structure and diversity risk under the goals are summarized below.

**Goal 1:** Maintain natural rates and levels of spatially mediated processes.

Metrics:

a. Number and distribution of spawning areas

b. Spatial extent and range of spawning areas relative to historical template

c. Changes in gaps between spawning areas

**Goal 2:** Maintain natural levels of variation.

Metrics:

a. Changes and loss of major life history strategies

b. Variation and loss of phenotypic traits, such as adult run and spawning timing, adult age structure and juvenile outmigrant size distributions.

c. Genetic variation

d. Spawner composition, proportion and origin of natural spawning hatchery fish

e. Changes in use of major habitat types (ecoregions) within the population

f. Selective mortality factors: Hydrosystem, Hatcheries, Harvest, Habitat

The extant Lower Snake River fall Chinook salmon population occupies the 100-mile reach of the mainstem Snake River from the upper end of the Lower Granite Dam pool (near Lewiston, Idaho) to the Hells Canyon Dam. It also includes the 110-mile reach of the Clearwater River from the upper end of the Lower Granite Dam pool (near Lewiston, Idaho) to Selway Falls, and the lower reaches of several major tributaries (e.g., the Grande Ronde, Salmon, Imnaha, and Tucannon Rivers based on intrinsic potential for defining large areas of contiguous high potential spawning habitat within stream-type Chinook salmon and steelhead populations. Existing maps

of geomorphic spawning habitat potential and redd distributions were used for evaluating spatial structure and diversity elements of viability.

The ICTRT adapted its basic method for identifying major spawning areas to apply to the mainstem habitats favored by Snake River fall Chinook salmon (ICTRT 2007). Using this method, the ICTRT identified five major spawning areas (MaSAs) for the Lower Snake River fall Chinook salmon population (Figure A-10):

1. *Upper Hells Canyon reach* ─ mainstem Snake River from Hells Canyon Dam downstream to the mouth of the Salmon River, and including the lower mainstems of the Imnaha and Salmon Rivers;
2. *Lower Hells Canyon reach* ─ mainstem Snake River from mouth of the Salmon River downstream to the upper end of Lower Granite reservoir;
3. *Grande Ronde River;*
4. *Clearwater River; and*
5. *Tucannon River (and contiguous mainstem Snake River habitat associated with Little Goose and Lower Monumental Dams).*

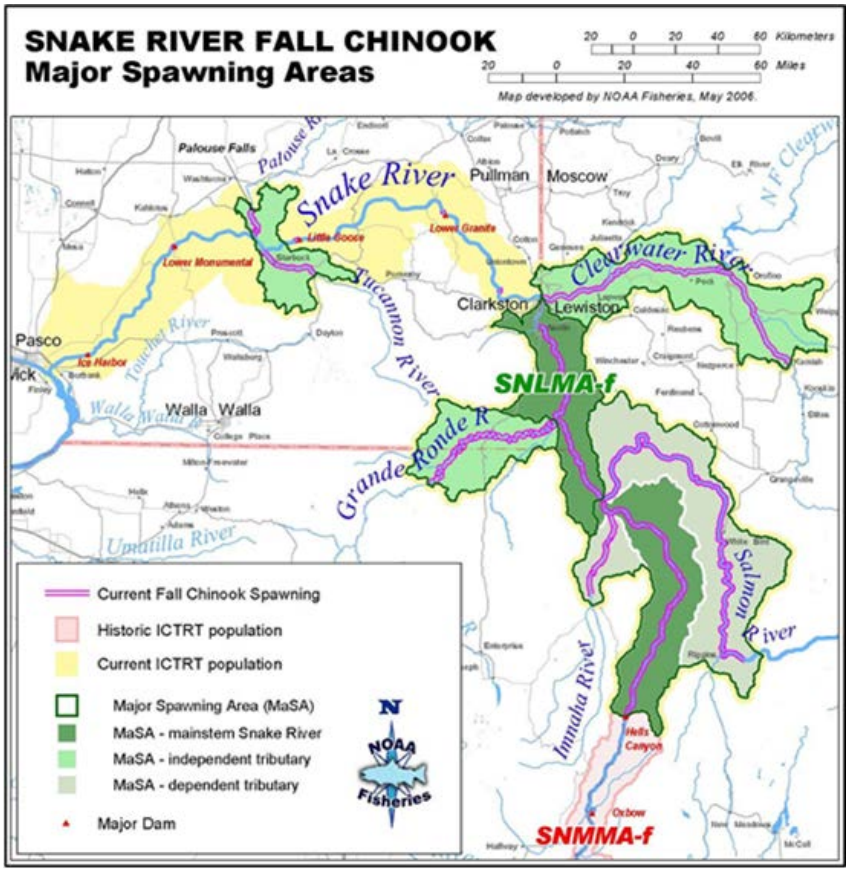


**Figure A-10.** Lower Snake River fall Chinook salmon population: Major spawning areas (MaSAs) with core spawning habitats and associated dependent spawning areas deliniated.

The extant Lower Snake River fall Chinook salmon population consists of a spatially complex set of five historical major spawning areas. Each of these major spawning areas consists of a set of relatively discrete spawning patches of varying size, but with the physical capacity to support a minimum of 500 spawners (Connor et al. 2001; Groves et al. 2013). The primary (largest and most productive) MaSA in the extant Lower Snake River population is the 59.6-mile Upper Hells Canyon MaSA, which extends upriver from the confluence of the Salmon River to the Hells Canyon Dam, where the canyon walls narrow and strongly confine the river bed. The second mainstem Snake River MaSA, the Lower Hells Canyon MaSA, extends 42.9 miles downstream from the Salmon River confluence to the upper end of the contemporary Lower Granite Dam reservoir. Tributaries of varying size (e.g., the Salmon and Imnaha Rivers, Alpowa and Asotin Creeks) enter the mainstem Snake River within each of the mainstem Lower Snake River MaSAs, and are considered part of the adjoining mainstem MaSA (ICTRT 2007). The Salmon and Imnaha Rivers are considered part of the Upper Hells Canyon MaSA, and Alpowa and Asotin Creeks are considered part of the Lower Hells Canyon MaSA.

The ICTRT also identified the lower portions of three relatively large tributaries as MaSAs: the Clearwater, Grande Ronde, and Tucannon Rivers. Both the Clearwater and Grande Ronde Rivers currently support natural-origin fall Chinook salmon spawning in the lower reaches. In addition, there is some historical evidence for production of late spawning Chinook in spatially isolated reaches in upriver tributaries to each of these systems. In addition, some anecdotal information suggests that the Clearwater River historically may have supported substantial numbers of Chinook salmon with adult timing similar to the current fall Chinook salmon run. September entries in the journals of Lewis and Clark describe the mainstem Clearwater River reach downstream of the North Fork Clearwater River as “200 yards wide and abounding in salmon of excellent quality.” Newspaper reports from October 1927 describe large numbers of salmon at the Lewiston Dam site trying to ascend upstream. Attempts are underway to develop a separate early spawning component into the upper Clearwater River using the South Fork Clearwater weir as a broodstock collection point (Hesse & Johnson 2012).

The ICTRT defined the lower Tucannon River as a fifth MaSA based on historical records and geomorphic assessments (ICTRT 2007). This MaSA comprised spawning habitats in the Lower Tucannon River and adjacent mainstem Snake River section. Historically, some level of fall Chinook salmon spawning may have occurred in the lower Snake River in the reach currently inundated by the Ice Harbor Dam pool (Dauble et al. 2003). Spawners using the lowest potential spawning reaches in the Snake River, currently inundated by Ice Harbor Dam, could have been associated with either the Lower Snake River population or a population centered on mainstem Columbia River spawning areas currently inundated by John Day and McNary Dams.

Annual redd surveys show that fall Chinook salmon spawn in all five of the Lower Snake River MaSAs. However, the inability to obtain carcass samples from the mainstem MaSAs, because of time of year and high flows, makes it difficult to assess the distribution of natural-origin spawners. Reconstruction of natural-origin spawner abundance based on hatchery expansions

and data from homing/dispersal studies on acclimated hatchery releases indicates that four of the five MaSAs are contributing to naturally produced returns. Carcass samples obtained in the Tucannon River indicate that nearly all natural spawners in the Tucannon are hatchery-origin returns. Hatchery-marked recoveries in that MaSA account for virtually all of the redds, suggesting negligible natural-origin returns (Milks and Oakerman 2014).

The following discussions summarize spatial structure and diversity risks for the Lower Snake River fall Chinook population based on findings from the NWFSC's 2015 status review (NWFSC 2015). The discussions are organized under the nine factors that the ICTRT (2007) recommended using to determine population spatial structure and diversity risk.

Table A-3 summarizes the associations between goals, mechanisms, factors and metrics described by the ICTRT (2007). Some viability metrics include variable criteria that are dependent on a population's spatial complexity designation.

**Table A-3.** Organization of goals, mechanisms, factors and metrics for spatial structure and diversity risk rating (ICTRT 2007).

| GOAL | MECHANISM | FACTOR | METRICS |
|---|---|---|---|
| A. Allowing natural rates and levels of spatially mediated processes. | 1. Maintain natural distribution of spawning aggregates. | a. number and spatial arrangement of spawning areas. | Number of MaSAs, distribution of MaSAs, and quantity of habitat outside MaSAs. |
| | | b. Spatial extent or range of population | Proportion of historical range occupied and presence/absence of spawners in MSAs |
| | | c. Increase or decrease gaps or continuities between spawning aggregates. | Change in occupancy of MaSAs that affects connectivity within the population. |
| B. Maintaining natural levels of variation. | 1. Maintain natural patterns of phenotypic and genotypic expression. | a. Major life history strategies. | Distribution of major life history expression within a population |
| | | b. Phenotypic variation. | Reduction in variability of traits, shift in mean value of trait, loss of traits. |
| | | c. Genetic variation. | Analysis addressing within and between population genetic variations. |
| | 2. Maintain natural patterns of gene flow. | a. Spawner composition. | (1) Proportion of hatchery-origin natural spawners derived from a local (within population) brood stock program using best practices. |
| | | | (2) Proportion of hatchery-origin natural spawners derived from a within MPG brood stock program, or within population (not best practices) program. |
| | | | (3) Proportion of natural spawners that are unnatural out-of MPG strays. |

| GOAL | MECHANISM | FACTOR | METRICS |
|---|---|---|---|
| | | | (4) Proportion of natural spawners that are unnatural out-of ESU strays. |
| | 3. Maintain occupancy in a natural variety of available habitat types. | a. Distribution of population across habitat types. | Change in occupancy across ecoregion types |
| | 4. Maintain integrity of natural systems. | a. Selective change in natural processes or impacts. | Ongoing anthropogenic activities inducing selective mortality or habitat change within or out of population boundary |

**Factor A.1.a: Number and spatial arrangement of spawning areas.**
Four of the five historical MaSAs regularly contain natural-origin spawners. The fifth, the Tucannon River MaSA, also has fall Chinook salmon spawners, but recent surveys indicate that nearly all natural spawners in the Tucannon River are hatchery-origin returns from Lyons Ferry Hatchery releases. The lack of natural-origin spawners in the Tucannon River suggests that this MaSA is not currently very productive or, alternatively, that natural-origin fish originating from this area stray at high rates to other MaSAs. Based on the ICTRT guidelines, the accessibility of fish to all five MaSAs produces a rating of **very low risk** for this factor.

**Factor A.l.b: Spatial extent or range of population.**
The distribution of current spawning in the Lower Snake River fall Chinook salmon population is shown in Figure A-11. Based on annual redd survey results, all five of the major spawning areas in this population exhibit spawning. The survey results indicate that four of five major spawning areas include natural-origin spawners (the Upper Hells Canyon, Lower Hells Canyon, Clearwater River, and Grande Ronde River MaSAs). Carcass sampling data from the mainstem Clearwater MaSA also confirm the presence of natural-origin spawners. Difficulties associated with high flows and other environmental conditions in the large mainstem reaches of the Snake River have precluded direct sampling of carcasses in those reaches. However, based on inferences from redd surveys prior to the increase in hatchery returns and projections based on survival estimates from reach-specific hatchery releases, it is likely that natural-origin fish are contributing to spawning there as well. Efforts are underway to develop more specific estimates of the relative distribution of natural spawners among the major spawning areas (see RM&E Chapter 7 in the recovery plan). The remaining historical major spawning area, the lower mainstem Tucannon River, is not characterized as occupied because of the lack of evidence for natural-origin spawners in that reach. Applying the ICTRT guidelines for a complex (trellis-structured) population, the Lower Snake River fall Chinook salmon population is rated at **low risk** for current spatial structure.

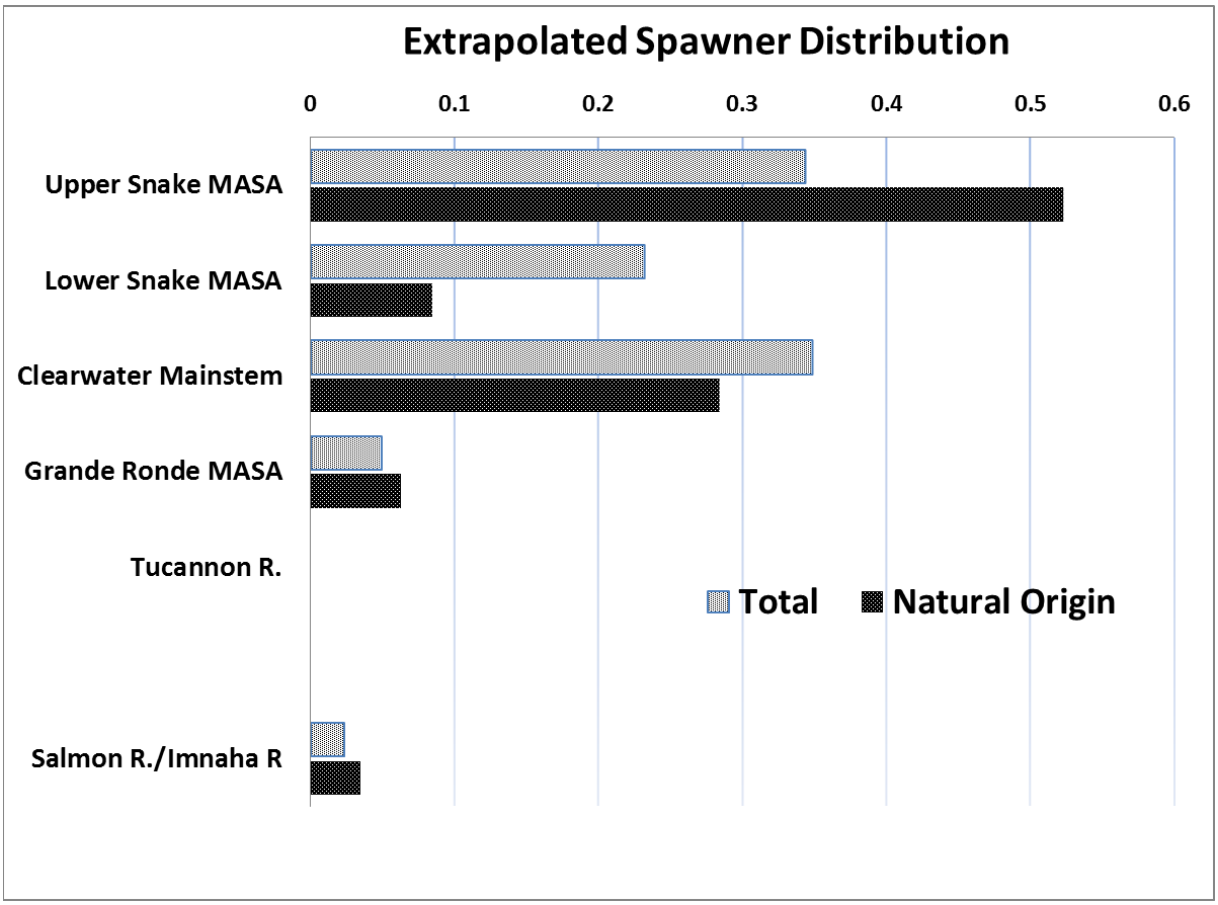


**Figure A-11.** Estimated average spawner distributions (2004-2014) across major and minor spawning areas. Total is average distribution of redds from annual multiple pass surveys, produced by combination of hatchery and natural origin spawners. Natural origin estimates extrapolated from regional total redd counts, estimated hatchery returns by release area and estimated dispersal/straying patterns from Garcia et al. 2005.

**Factor A.1.c: Increase or decrease in gaps or continuities between spawning areas.**
Four out of the five historical MaSAs in the extant Lower Snake River population meet the ICTRT criteria for occupancy. The Tucannon River MaSA is not rated as occupied due to the lack of evidence for natural-origin spawners. However, this MaSA is at the downstream end of the overall population so the lack of occupancy in this MaSA does not create a gap among spawning aggregates within the population. The overall risk to the ESU may have increased somewhat, however, as a result of the loss of natural connectivity between this population and downstream ESUs. Under the ICTRT guidelines for this criterion, extinction risk for the population does not increase substantially from this amount of loss of occupancy and this metric is rated **low risk**.

**Factor B.1.a: Major life history strategies.**
Historical habitat conditions associated with the reaches supporting the extant Lower Snake River population were likely more diverse than those associated with the extirpated Middle Snake River population. Conditions in the Upper Hells Canyon MaSA, the Snake River mainstem reach extending upstream of the Salmon River to the current site of Hells Canyon

Dam, are currently the most similar to those associated with the historical Middle Snake River population (Connor et al. 2002) and data indicates that most smolts produced from this area migrate as subyearlings. Incubation and spring juvenile rearing temperatures in the Lower Hells Canyon MaSA, the Snake River mainstem reach downstream of the Salmon River confluence, and in the Clearwater River MaSA are relatively cold in comparison. As a result, subyearling Chinook salmon must rear later into the summer before reaching sufficient size to begin active migration, potentially exposing them to less favorable summer flow and temperatures in the lower Snake River. Out-migration timing from these reaches has likely shifted later relative to historical patterns.

In recent years, otolith analysis, age-specific run reconstructions, and scale samples have indicated that a proportion of both hatchery- and natural-origin returning adult Chinook salmon overwintered somewhere in the Columbia River system prior to entering the ocean (Marsh et al. 2007). This alternative life-history strategy may be a result of the flow and colder temperature conditions in the Clearwater River and, to a lesser extent, in the Snake River mainstem below the Salmon River confluence. These ultimately yearling migrants spend their first winter in one or more lower Snake River or Columbia River reservoirs and migrate to the ocean as yearlings the following spring or summer. Natural returns from both the subyearling and yearling migration types have demonstrated increases in return rates since the early 1990s. Sampling data indicate that the proportion of adult returns demonstrating a freshwater overwintering (yearling) life-history pattern peaked with the early 2000 broods, and has declined since then (Figure A-12).

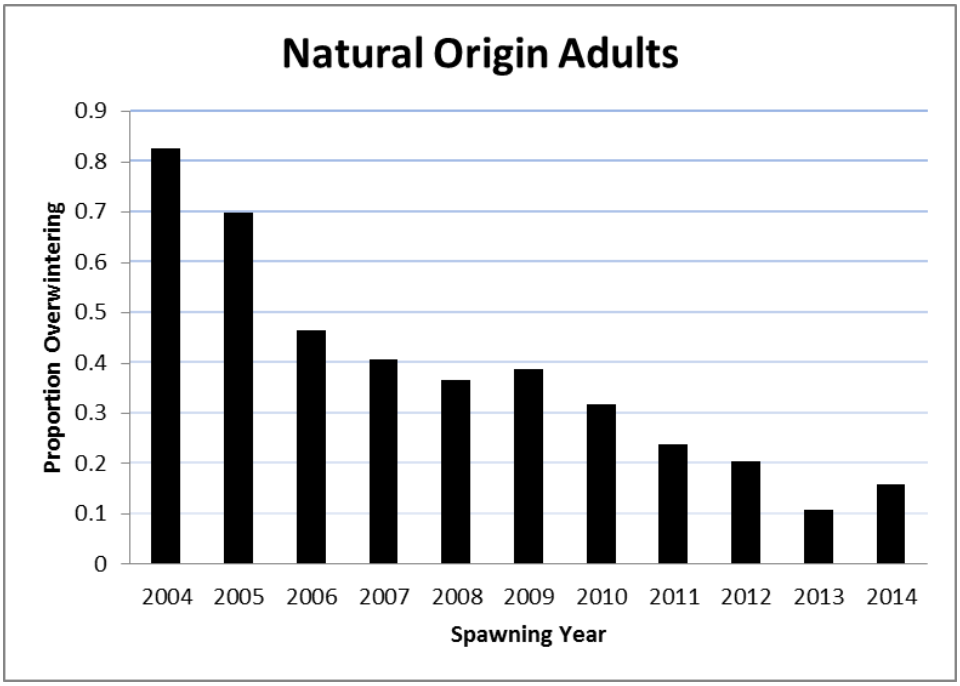


**Figure A-12**. Proportion of returning natural origin Snake River Fall Chinook adults sampled at the Lower Granite Dam trap identified as yearling outmigrants. Extrapolated from age specific estimates of unmarked returns adjusted for potential contributions of unmarked hatchery fish (see Bill Young et al. 2013 for description of run reconstruction methods).

It is likely that the expression of the two major life-history patterns in this ESU represents a combination of phenotypic plasticity and evolutionary adaptation (genetic change). A study is underway to gain a better understanding of the genetic basis for the patterns (R. Waples, pers. Comm.). The primary question being addressed in the study: "is the juvenile life history of an adult Snake River fall Chinook salmon (subyearling or yearling migrant) a good predictor of the juvenile life history of its offspring?" Currently, the data collection phase of the study is complete and analysis is underway. Preliminary analysis indicates modest support for higher juvenile growth rates for offspring from subyearling migrant parents and a positive correlation between higher growth rates and downstream migration rates. Unexpectedly, the study also found evidence for higher growth rates of juveniles from parents who were "forced" into a yearling rearing strategy in the hatchery program. This effect does not appear to have a genetic basis nor can it be explained by maternal effects such as egg size, it may represent a cross generational expression of environmental plasticity (R. Waples, pers. Comm.).

The expression of an alternative life-history strategy, or a change in the proportion of individuals within a population exhibiting a particular life-history strategy, may ultimately serve to reduce the overall extinction risk at both the population and ESU levels. The majority of returning naturally produced adults currently exhibits a subyearling life-history strategy. The analyses described above indicate that all historical major life history pathways are present and although there has likely been some change in patterns of variation, the current patterns likely represent adaptations to recent environmental conditions. Therefore, the current Lower Snake River fall Chinook salmon population is rated **low risk** for life history diversity based on recent patterns in subyearling and yearling natural production.

**Factor B.1.b: Phenotypic variation.**

Changes in the means or the variation in phenotypic traits away from levels that reflect natural adaption represent a potential risk to the long-term sustainability of a population. The ICTRT report on the viability criteria (ICTRT 2007) provided general criteria for assigning a risk rating based on current estimates of the mean and variability in key life-history traits. In those examples, the degree of risk is a function of the number of traits lost or substantially shifted vs. natural optimums. As with the other diversity criteria, a population would be assigned a very low risk rating for this factor if there were evidence supporting no loss, shift in means, or reduced variability for any trait. A substantial shift in the means or reduced variability for single trait translates to a low risk rating. Loss of a particular trait or a meaningful change in the pattern of variation for two or more traits results in a moderate risk rating. More extensive trait losses, or significant shifts or truncated variability, across multiple traits translates to a rating of high risk.

We reviewed current estimates of seven particular phenotypic traits for the Lower Snake River fall Chinook salmon population, each of which can be linked to natural selective forces at some life stage (Table A-4). Three of the traits reflect patterns in mature returning fish. The remaining four traits reflect characteristics of juvenile production. The ICTRT guidance for evaluating diversity noted that it was not appropriate to specify single point estimate "targets" for assessing

risk for specific diversity criteria component. Instead, assigning risk would require some judgment that considers whether the current mean and variation reflects an adaptation to current conditions and whether the range of variability in a particular trait encompasses what was likely the historical optimum. Information on specific phenotypic characteristics of naturally production from the Lower Snake River fall Chinook salmon population has been collected for recent years.

**Table A-4.** Summary of phenotypic traits and information sources.

| Phenotypic Characteristics | Information/sources |
|---|---|
| **Run Timing (mature returns)** | Daily counts at LGR Dam, PIT tag detections at mainstem dams (e.g. Young et al 2012) |
| **Age structure (mature returns)** | Trap sampling (Young et al. 2012, WDFW LSCMP annual reports, Young et al. 2013) |
| **Spawning timing** | Redd surveys (Mullins et al. 2014) |
| | |
| **Emergence timing** | Inferred from fry seining results etc. (Connor et al. 2014) |
| **Outmigration timing** | Bypass sampling and PIT tag detections at Lower Granite Dam. (Conner et al. 2014) |
| **Emigrant size distribution** | Parr seining surveys (Upper and Lower Snake River mainstem reaches and Clearwater River). (Connor et al. 2014) |
| **Subyearling migrant proportions** | Trap sampling, adult scale and otolith analyses, juvenile migrant timing patterns. (Young et al. 2012, Connor et al. 2014) |

Limited empirical data exists on the historical phenotypic patterns for production from the Lower Snake River population. Some insight into patterns that were prevalent historically can be gained through inference based on habitat conditions and comparisons with other populations of ocean-type, mainstem spawning fall Chinook salmon. Adult run timing can be estimated based on adult ladder counts and trap sampling at the lower Snake River dams. These data indicate that there has been a relatively small shift in the timing of peak counts passing over Ice Harbor Dam since 1962 (first year of counts). In summary, the seaward migration timing through the mainstem Snake and Columbia Rivers has likely been altered due to flow and temperature changes. Other key life-history traits (e.g. age at return, spawning and incubation timing) are consistent with

adaptations for the range of freshwater habitat conditions currently inhabited by the populations. The variation in these traits overlaps extrapolated historical patterns. Therefore, applying the ICTRT guidelines for assessing current phenotypic diversity, the Lower Snake River fall Chinook salmon population rates at **low risk** for phenotypic diversity**.**

**Factor B.1.c: Genetic variation.**
The ICTRT intended that this factor address changes in genetic variation for a population resulting from either (a) introgression from non-local hatchery spawners or (b) adverse genetic effects of small population size or changes in the level of differentiation within the population (ICTRT 2007). We evaluate current genetic variation of the population from both perspectives in order to assign a risk rating to this factor. The ICTRT guidelines for assessing the current status of a population with respect to genetic variation emphasize evaluating patterns in genetic variation from samples representative of the current population. Current and past genetic sampling data can be augmented with inferences from less direct information in assessing risk. The ICTRT status evaluation guidance provides a general framework for determining current status based on both direct and indirect information (ICTRT 2007).

<u>Outbreeding effects</u>
Outbreeding effects are the consequences of gene flow from one population into another. Altered patterns of gene flow among populations can result in increasing the level of genetic diversity in a receiving population or it can result in outbreeding depression ─ a reduction in fitness due to altered genetic frequencies (NMFS 2012a). One of the specific factors cited in the listing of Snake River fall Chinook salmon under ESA (57 FR 14653) was the potential for significant genetic introgression due to increased straying of outside stocks into natural spawning areas above Lower Granite Dam.

Recent sampling data indicates that (1) straying from the primary source ─ Umatilla River releases of Priest Rapids fall Chinook stock ─ has been reduced substantially; (2) broodstock protocols have eliminated identifiable out-of-ESU fish from the ongoing hatchery program; and (3) the overall genetic patterns have been consistent among hatchery- and natural-origin returns.

In addition to the potential effects of direct straying of out of basin stock into natural spawning areas within the population, inadvertent incorporation of out-of-basin strays into the broodstock collections for the Lyons Ferry Hatchery program also represented a risk to long-term diversity (e.g., Bugert et al. 1990). The effect of Umatilla River strays on Lyons Ferry broodstock (see metric B.2 for a description of strays and hatchery programs) was confirmed by genetic data where convergence of allele frequencies occurred in the late 1980s at loci differentiating the Snake River and upper Columbia River populations (Bugert et al. 1995). Starting in 1990, only fish of known Lyons Ferry-origin were used as breeders and these fish retained the genetic signature of the Snake River lineage. Because exogenous fall Chinook salmon could not be excluded from natural production in the Snake River, considerable concern arose that these wild fish may become an introgressed population of upper Columbia River and Snake River gene

pools (Bugert et al. 1995). This possibility was examined by genetically characterizing naturally produced juvenile progeny of fall Chinook salmon spawning upstream from Lyons Ferry between 1990 and 1994 (Marshall et al. 2000). That study concluded that distinctive patterns of allelic diversity persisted in naturally produced juveniles in the Snake River that: (1) were differentiated from upper Columbia River populations; and (2) supported earlier conclusions that the Snake River fall Chinook salmon ESU remained an important genetic resource.

In summary, genetic samples from the aggregate population in recent years indicate that composite genetic diversity is being maintained and that the Snake River fall Chinook hatchery stock is similar to the natural component of the population. This indicates that the actions taken to reduce the potential introgression of out-of-basin hatchery strays have been effective.

Within-population diversity

Given the diversity of habitats used across the major spawning areas within the Lower Snake River population and evidence of relatively strong reach fidelity for acclimated supplementation releases, it is reasonable to assume some, albeit an unknown, level of within-population diversity existed historically. Given the widespread distribution of supplementation releases across major spawning areas within the population, the high proportion of hatchery fish in the aggregate run and evidence for homing fidelity of releases, it is likely that the maintenance or development of diversity among MaSAs has been impeded. Based on these considerations, the current genetic diversity of the population represents a change from historical conditions and, applying the ICTRT guidelines, the rating for this metric is **moderate risk**.

**Factor B.2: Spawner composition.**

Spawner composition (relative proportions of natural-origin and hatchery-origin fish on the spawning grounds) is a potential indicator of altered gene flows for a population. Other mechanisms (e.g. gaps in spawning or rearing habitat due to anthropogenic loss) are also possible and are addressed by other ICTRT criteria.

Prior to the early 1980s, returns of Snake River fall Chinook salmon were predominately of natural origin. As noted above, natural-origin return levels declined substantially following the completion of the Hells Canyon Complex (total block to major production areas above Hells Canyon) and the construction of the lower Snake River dams. Hatchery strays made up an increasing proportion of returns at Lower Granite Dam through the 1980s. Returns of hatchery-origin Snake River fall Chinook salmon from the Lyons Ferry hatchery program and strays from outplanted Priest Rapids Hatchery-origin fall Chinook salmon (out-of-ESU stock) were the dominant contributors. Natural-origin returns reached a low of less than 100 fish in 1978 and remained low through 1990, when only 78 natural-origin adult fall Chinook salmon returned to the Snake River (Lavoy and Mendel 1996).

Total returns of fall Chinook salmon over Lower Granite Dam increased steadily from the mid-1990s to the present. Natural-origin returns increased at roughly the same rate as hatchery-origin

returns through the 2000-run year. Since 2000, hatchery returns have increased faster than natural-origin returns (Table A-5; Figure A-13). The median proportion of natural-origin Snake River fall Chinook salmon has been approximately 32% over the past two brood cycles.

1. *Out-of-ESU spawners:* Over the past two brood cycles, the average proportion of out-of-ESU strays (based on trap sampling at Lower Granite Dam) has been reduced substantially from the levels observed in the 1990s and early 2000s. The most recent 5-year and 10-year average out-of-ESU contribution rates were both below 2%, meeting the ICTRT quantitative criteria for a low risk rating. The 15-year (three-brood cycle) average is currently 4.6%, corresponding to a moderate risk rating. The ICTRT guidelines recommend assigning the highest of the ratings for 1, 2, or 3 brood cycles, resulting in a **moderate risk** rating for this component of the metric. If the most recent pattern of low contributions continues, this rating will shift to low within five years.

2. *Out-of-MPG spawners from within the ESU:* There are no other MPGs within the Snake River fall Chinook salmon ESU. This metric is not applicable.

3. *Out-of-population spawners from within the MPG:* There are no other extant populations within the MPG and this metric is not applicable.

4. *Within-population hatchery spawners:* Returns of releases from the Snake River hatchery program (Lyons Ferry broodstock) along with a small component of out-of-ESU strays have accounted for an average of 68% of the escapement into natural spawning areas above Lower Granite Dam over the past 10 years (Figure A-14). Snake River hatchery fish above Lower Granite Dam include returns from supplementation releases in the mainstem Snake and Clearwater Rivers, as well as from releases at Lyons Ferry Hatchery. The relatively high proportion of within-population hatchery spawners results in a rating of **high risk**.

**Table A-5.** Five-year mean of fraction wild (sum of all estimates divided by the number of estimates).

| Population | 1990-1994 | 1995-1999 | 2000-2004 | 2005-2009 | 2010-2014 |
|---|---|---|---|---|---|
| Snake R. Low. Mainstem FR | 0.62 | 0.58 | 0.38 | 0.37 | 0.31 |

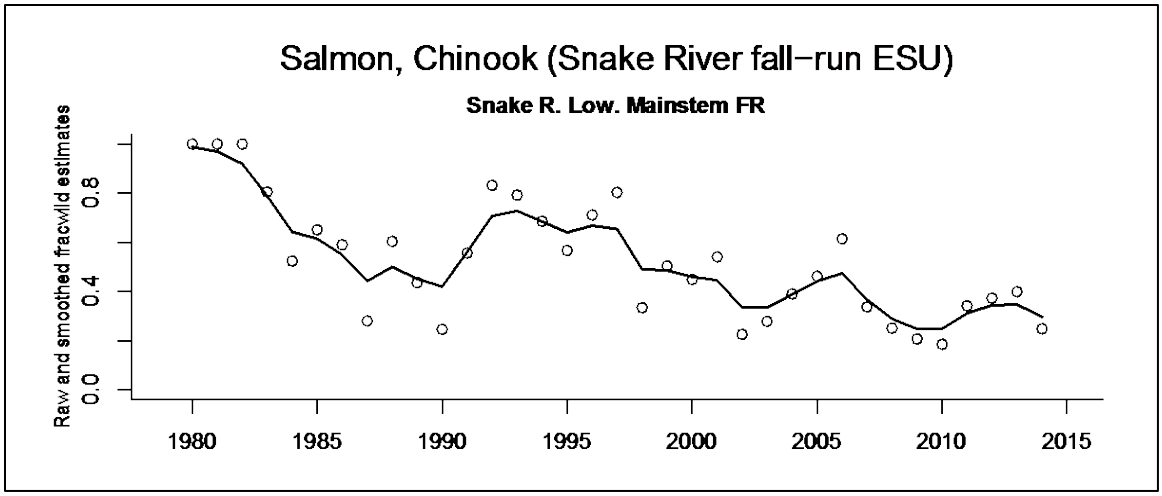


**Figure A-13.** Smoothed trend in the estimated fraction of the natural spawning population consisting of fish of natural origin. Points show the annual raw estimates.

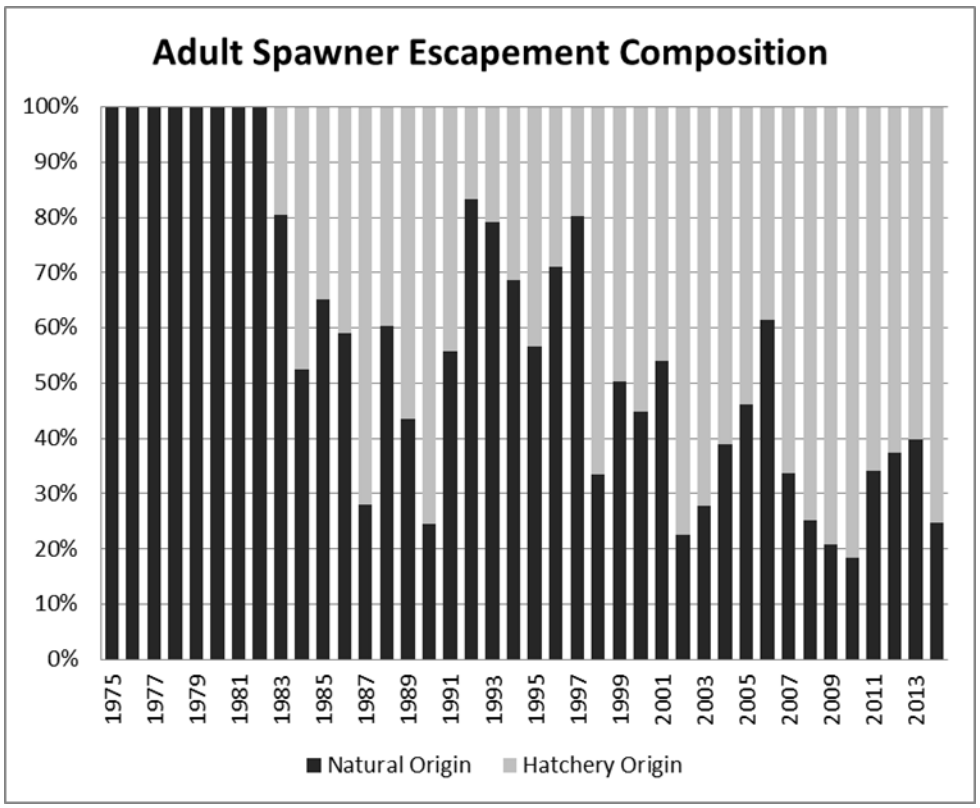


**Figure A-14.** Annual adult escapement proportions (natural origin (black) and hatchery origin (gray).

### Factor B.3: Distribution of population across habitat types.

The ICTRT recognized that maintaining spawner occupancy in a natural variety of habitat types would be another indirect means of supporting natural patterns of variation within a population. The ICTRT developed a simple risk index based on the proportional change in distribution

across major habitat types (using EPA level IV ecoregions) within a population. The ICTRT acknowledged that efforts are underway to develop more explicit indices of important variations in habitat conditions relative to natural fish production and that those approach could lead to improved indices in the future.

The Lower Snake River fall Chinook salmon population's spawning areas are distributed across five ecoregions. The Canyons and Dissected Uplands ecoregion contains the majority of spawning habitat for this population, followed by the Lower Clearwater Canyon. There has been some loss of spawning habitat due to inundation in the mainstem (Dissected Loess Uplands ecoregion); however, that ecoregion historically contained less than 5% of the total spawning habitat for the Lower Snake River population. Therefore, the extant Lower Snake River fall Chinook salmon population rates at **low risk** for distribution across habitat types.

**Factor B.4.a: Selective change in natural processes or selective impacts.**
Human activities at various life stages have the potential to result in substantial changes in phenotypes for populations. The magnitude of the longer-term response of a population to such change is determined by the heritability of the affected trait(s) and the strength or intensity of selection (see ICTRT 2007 for further discussion and relevant citations). Assessing the direct effects of selectivity on fitness within a population is very difficult, especially for "wild" populations. The ICTRT developed an index for evaluating the relative risks imposed by selectivity across life histories resulting from the combined impacts of harvest, hatchery, habitat and hydropower actions.

<u>Hydropower system</u>
Natural production of Snake River fall Chinook salmon from all four occupied major spawning areas pass eight mainstem dams as both juveniles on their downstream outmigration and as adults on their spawning return.

> *Juvenile migration timing:* It is likely that the system of hydroelectric dams and their operations imposed differentially higher mortalities on later migrating smolts in the in the years leading up to and immediately following listing. Actions have been taken to improve outmigration survivals, including elements targeting in-river conditions affecting a substantial portion of the later timed components. Ongoing studies of annual smolt migration timing and survivals indicated improvements in average survivals and a reduction in the potential for differential mortality across the run. Additional studies are underway or being analyzed that should further reduce uncertainties regarding differential impacts. Although results to date indicate that selective mortality on downstream migrants has been substantially reduced, there is still some uncertainty regarding the remaining effects. Heritability of this trait has not been assessed so we assume a moderate to low heritability. Therefore, the rated impact of the hydrosystem on this trait is **moderate risk.**

*Adult migration timing:* The relatively late Columbia River entry timing of fall Chinook salmon runs, including Snake River fall Chinook salmon, means they are subjected to relatively high temperatures and low flows in September and October. There are no direct indications that human actions have resulted in significant and consistent differential survival effects for a substantial component of the annual returns, resulting in a **low risk** rating for this trait.

Harvest

Harvest has the potential to produce selective pressure on migration timing, maturation timing and size-at-age. Snake River fall Chinook salmon are harvested by both ocean and in-river fisheries. No direct estimates are available of the degree of selective pressure caused by ocean harvest impacts on natural-origin Snake River fall Chinook salmon. However, ocean exploitation rates based on coded wire tag results for subyearling releases of Lyons Ferry Hatchery fish are used as surrogates in fisheries management modeling (Chinook Technical Committee 2007).

Average annual ocean exploitation rates vary by age, increasing from relatively low levels on age-2 fish to approximately 25% on age-4 and age-5 fish (Peters et al. 1999). Based on the current timing and distribution of the fisheries with recoveries, ocean harvest of Snake River fall Chinook salmon is assumed to impact both maturing and immature fish (Chinook Technical Committee 2007). As a result, the cumulative impact of ocean harvest is higher on components of the run maturing at older ages. Snake River fall Chinook salmon are also harvested by in-river fisheries, largely in mainstem Columbia River fisheries on aggregate fall Chinook salmon runs including the highly productive Hanford Reach stock. Exploitation rates of in-river fisheries also increase with age-at-return. Annual in-river exploitation rates are reported in two categories: jacks (primarily age-2s, some smaller age-3s) and adults (dominated by age-4 and age-5 returns).

*Age-at-return:* The primary potential for selective impacts in harvest on natural-origin Snake River fall Chinook salmon would be on maturation timing, reflected in the relative age composition of fish arriving on the spawning grounds. Age composition data collected at Lower Granite Dam indicate that female Snake River fall Chinook salmon currently return primarily at age-4 and age-5. Male returns are skewed to younger ages, returning at age-2 through age-5. The immediate impact of differential harvest on the average age compositions can be calculated using the average harvest rates by age after accounting for both ocean and in-river fisheries. The immediate impact simply represents the changes in age composition to the spawning grounds caused by passing fish removed by harvest upstream to the spawning grounds. In the absence of harvest, the average age-at-return to the spawning grounds for females is predicted to be shifted upwards approximately 2% from 4.39 to 4.48 years. The largest shift in average age-at-return would be in male returns, which would be predicted to shift upwards approximately 8% from 3.30 to 3.58. The estimated shift in male age-at-return meets the ICTRT criteria for moderate selection intensity. Heritability of age-at-return is moderate, resulting in an age-at-return trait rating of **moderate risk**. It should be noted that the evolutionary response

to selective harvest is uncertain and is likely to be influenced by other selective forces (e.g., Hard et al. 2008; Riddle 1986).

Selection caused by non-random removals of fish for hatchery broodstock

Prior to 2003, the broodstock used for Snake River fall Chinook salmon hatchery programs were adult returns from previous program releases. The original broodstock was established in the 1980s and early 1990s through adult capture at lower Snake River dams (Burgert et al. 1995). Beginning with the 2003 return, natural-origin broodstock collected across the run by trapping at Lower Granite Dam have been included in the program (Milks et al. 2006). Given current removal levels and broodstocking protocols, selective intensity is assumed to be **negligible**.

Habitat

The primary changes in habitat conditions for this population are temperature and flow related. These changes have been assessed as impacts on production at the population aggregate or major spawning area level under the appropriate factors evaluated above (e.g., productivity, spatial structure, life history diversity, phenotypic diversity). The potential for selective mortality due to temperature and flow alternations associated with the management of the Hells Canyon Complex (mainstem Snake River) or Dworshak Dam (Clearwater River) was likely higher during the years leading up to and immediately following the ESA listing decision. Changes to operations, particularly for the Hells Canyon Complex, have generally stabilized conditions during spawning, incubation and rearing time windows. Therefore, actions impacting current spawning and rearing habitats of Snake River fall Chinook salmon are considered to have **negligible** selective effects.

Other

Predation rates by both fish and birds on subyearling Chinook salmon have resulted in increased mortalities during the smolt outmigration. Northern pikeminnow, smallmouth bass and avian predators selectively target subyearling Chinook salmon relative to larger yearling migrants. However, size frequency comparisons of subyearlings consumed by predators with in-river subyearling migrants support assuming **negligible** size selective mortality (Poe et al. 1991; Zimmerman 1999; Fritts and Pearsons 2006).

Selective pressures on two trait components were currently rated at moderate risk for the Lower Snake River fall Chinook salmon population. Applying the ICTRT guidelines assigning overall population risks associated with results in a **moderate risk** for selective effects.

#### A.2.2.1 Spatial Structure and Diversity Summary

The Lower Snake River fall Chinook salmon population was rated at low risk for Goal A (allowing natural rates and levels of spatially mediated processes) and moderate risk for Goal B (maintaining natural levels of variation) resulting in an overall spatial structure and diversity rating of **moderate risk** (Table A-6). The moderate risk rating was driven by changes in major life history patterns, shifts in phenotypic traits, and high levels of genetic homogeneity in

samples from natural-origin returns. In addition, risk associated with indirect factors, specifically the high levels of hatchery spawners in natural spawning areas and the potential for selective pressure imposed by current hydropower operations and cumulative harvest impacts contribute to the current rating level.

**Table A-6**. Lower Snake River fall Chinook salmon population spatial structure and diversity risk ratings. Overall rating determined as the highest risk among (1) spatial mechanism, (2) direct diversity mechanism, and (3) average across direct and indirect diversity mechanisms.

<table>
<tr><th rowspan="2">Metric</th><th colspan="5">Risk Assessment Scores</th></tr>
<tr><th>Metric[d]</th><th>Factor[c]</th><th>Mechanism[b]</th><th>Goal[a]</th><th>Population</th></tr>
<tr><td>Major Spawning Areas: NUMBER</td><td>VL (2)</td><td>VL (2)</td><td rowspan="3">Low Risk<br>(Mean = 1.33)</td><td rowspan="3">Low Risk<br>(Mean = 1.33)</td><td rowspan="14">Moderate Risk<br>(Highest of Goal Risks = 0)</td></tr>
<tr><td>Major Spawning Areas OCCUPIED</td><td>L (1)</td><td>L (1)</td></tr>
<tr><td>Major Spawning Areas: GAPS</td><td>L (1)</td><td>L (1)</td></tr>
<tr><td>Major Life-History Strategies</td><td>L (1)</td><td>L(1)</td><td rowspan="3">Moderate Risk<br>(Highest of metrics=0)</td><td rowspan="11">Moderate Risk<br>(Avg. of Mechanisms = 0)</td></tr>
<tr><td>Phenotypic Patterns</td><td>L (1)</td><td>L(1)</td></tr>
<tr><td>Genetic Diversity</td><td>M (0)</td><td>M (0)</td></tr>
<tr><td>Art. Prop. OUT of ESU</td><td>M (0)</td><td rowspan="4">High<br>(-1)</td><td rowspan="4">High Risk<br>Highest of metrics=-1)</td></tr>
<tr><td>Art. Prop OUT of MPG</td><td>N/A</td></tr>
<tr><td>Art.Prop From MPG</td><td>N/A</td></tr>
<tr><td>Art Prop. From POPULATION</td><td>H (-1)</td></tr>
<tr><td>ECOREGION DISTRIBUTION</td><td>L (1)</td><td>L (1)</td><td>Low Risk (1)</td></tr>
<tr><td>SELECTIVE IMPACTS</td><td>M (0)</td><td>M (0)</td><td>Moderate Risk (0)</td></tr>
</table>

[a] *Goals* are the biological or ecological objectives that spatial structure and diversity criteria are intended to achieve.

[b] *Mechanisms* are biological or ecological processes that contribute to achieving those goals (e.g., gene flow patterns affect the distribution of genotypic and phenotypic variation in a population).

[c] *Factors* are characteristics of a population or its environment that influence mechanisms (e.g., gaps in spawning distribution affect patterns of gene flow, which then affect patterns of genotypic and phenotypic variation).

[d] *Metrics* are measured and assessed at regular intervals to determine whether a population has achieved goals, or to evaluate its current risk level. Each factor has one or more metrics associated with it.

### A.2.3 Overall Population Risk Rating

Overall population viability for the Lower Snake River fall Chinook salmon population is determined based on the combination of ratings for current abundance and productivity and combined spatial structure diversity (Figure A-15).

| | | Spatial Structure/Diversity Risk | | | |
|---|---|---|---|---|---|
| | | **Very Low** | **Low** | **Moderate** | **High** |
| **Abundance/ Productivity Risk** | **Very Low** (<1%) | **HV** | **HV** | **V** | **M** |
| | **Low** (1-5%) | **V** | **V** | **V** **Lower Main. Snake** | **M** |
| | **Moderate** (6 – 25%) | **M** | **M** | **M** | **HR** |
| | **High** (>25%) | **HR** | **HR** | **HR** | **HR** |

**Figure A-15.** Lower Snake River fall Chinook salmon population risk ratings integrated across the four viable salmonid population (VSP) metrics. *Viability Key: HV – Highly Viable; V – Viable; M – Maintained; HR – High Risk; Green shaded cells – meets criteria for Highly Viable; Gray shaded cells – does not meet viability criteria (darkest cells are at greatest risk).*

The overall current risk rating for the Lower Snake River fall Chinook salmon population is **viable**. All of the potential ESA recovery scenarios described in Chapter 3 would require the population to meet or exceed minimum requirements for highly viable (green-shaded combinations in Figure A-15). The single-population viability scenarios (Scenarios B and C) require an added uncertainty buffer, i.e., the population must be highly viable with a high degree of certainty. Achieving the desired rating of highly viable will require at least an 80% certainty that the combination of abundance and productivity exceeds the 1% viability curve and that spatial structure/diversity is rated at low risk.

The current rating described above is based on evaluating current status against the criteria for the single Lower Snake River population, measured in the aggregate (e.g., Scenario B, described in Chapter 3 of the recovery plan). The current (2015) overall risk rating is based on a **low risk** rating for abundance/productivity and a **moderate risk** rating for spatial structure/diversity. For abundance/productivity, the rating reflects ongoing uncertainty that recent increases in abundance can be sustained over the long run. The geometric mean natural abundance for the most recent 10 years of annual spawner escapement estimates (2005-2014) is 6,418 fish. Using the ICTRT simple 20-year R/S method, the current point estimate of productivity for this population (1991-2010 brood years) is 1.53. The combination of these two estimates do not exceed the ICTRT's very low risk (1% in 100 years) viability curve by a sufficient amount to meet the 80% confidence requirement called for in Scenario B. Using the alternative approach of

fitting stock-recruit functions to the 1991-2010 brood-year data series results in the same conclusion: the Beverton-Holt model including a PDO parameter was statistically the "best fit." Although the parameter estimates differed from the simple averages, the probability that the true underlying relationship exceeded the very low risk viability curve was similar and therefore did not meet the 80% probability requirement.

For spatial structure/diversity, the moderate risk rating was driven by changes in major life history patterns, shifts in phenotypic traits, and high levels of genetic homogeneity in samples from natural-origin returns. In particular, the rating reflects the relatively high proportion of within-population hatchery spawners and the lingering effects of previous high levels of out-of-ESU strays. In addition, the potential for selective pressure imposed by the combined current hydropower operations and cumulative harvest impacts contribute to the current rating level.

Because of the widespread distribution of hatchery returns across the major spawning areas within the population, and the lack specific information supporting differential spatial distribution of hatchery- versus natural-origin spawners, the population is currently not meeting the requirements for highly viable under Scenario C, the single-population with Natural Production Emphasis Areas scenario. Under Scenario C, one or more major spawning areas would need to be producing the bulk of natural production with relatively low hatchery spawner proportions.

## A.3 Gap between Current Status and Desired Status

Under the viability criteria for the single-population recovery scenarios described in the Plan, Chapter 3, the extant Lower Snake River population must achieve a viability rating of highly viable (very low risk) with a high degree of certainty. Achieving an overall population rating of very low risk will require that the population demonstrate a very low risk rating for combined abundance and productivity along with at least a low risk rating for spatial structure and diversity.

<u>Abundance/Productivity</u>: To achieve highly viable status with a high degree of certainty requires a combination of recent geometric mean natural-origin spawner abundance and intrinsic productivity exceeding the 1% viability curve by a buffer reflecting the statistical uncertainty in the current estimates (uncertainty buffer). Viability Scenario B would require the combination of natural-origin abundance and productivity to exhibit an 80% or higher probability of exceeding the viability curve for a 1% risk of extinction over 100 years. Potential abundance and productivity metrics for Scenario C, the Natural Production Emphasis Areas scenario, would depend on population-level pHOS and proportion of natural-origin broodstock (pNOB) at the time.

Given the information available through 2015, an increase in estimated productivity (or a decrease in the year-to-year variability associated with the estimate) would be required,

assuming that natural-origin abundance of the single extant Snake River fall Chinook salmon population remains relatively high. An increase in productivity could occur with a further reduction in mortalities across life stages. Such an increase could be generated by actions such as a reduction in harvest impacts (particularly when natural-origin spawner return levels are below the minimum abundance threshold) and/or further improvements in juvenile survivals during downstream migration. It is also possible that actions in recent years (e.g., more consistent flow-related conditions affecting spawning and rearing and increased passage survivals resulting from expanded spill programs) have increased productivity, but that the increase is effectively masked as a result of the relatively high spawning levels in recent years. A third general possibility is that productivity levels may be decreasing over time as a result of negative impacts of chronically high hatchery proportions across natural spawning areas. Such a decrease would also be largely masked by the high annual spawning levels. Given the possibility of such an effect, it is possible that substantial reductions in the hatchery fractions in one or more major spawning areas could lead to increased natural productivity. The recovery strategy in Chapter 6 and the research, monitoring and evaluation in Chapter 7 of the recovery plan include provisions for further addressing these uncertainties.

Spatial Structure/Diversity: To achieve highly viable status with a high degree of certainty for Scenario B, the spatial structure/diversity rating needs to be low risk. This status assessment used the ICTRT framework for evaluating population-level status in terms of spatial structure and diversity organized around two major goals: maintaining natural patterns for spatially mediated processes and maintaining natural levels of variation (ICTRT 2007). Based on our evaluation of an explicit series of factors associated with each goal, the current rating for spatial structure/diversity is **moderate risk** for the extant Lower Snake River population.

Under Scenario C, achieving low risk for spatial structure/diversity would require that one or more major spawning areas produce a significant level of natural-origin spawners with low influence by hatchery-origin spawners relative to the other major spawning areas. At present (escapements through 2013), given the widespread distribution of hatchery releases and hatchery-origin returns across the major spawning areas within the population, and the lack of direct sampling of reach-specific spawner compositions, there is no indication of a strong differential distribution of hatchery returns among major spawning areas.

## A.4 Literature Cited

Arnsberg, B., P. Groves, F. Mullins, D. Milks, and M. Allen. 2014. 2013 Snake River fall Chinook salmon spawning summary, February, 2014, 5 pp.

Bugert, R. and B. Hopley. 1989. The Snake River fall Chinook salmon egg bank program: The final chapter. 7 p. Washington Department of Fisheries, Olympia, Washington.

Bugert, R., P. LaRiviere, D. Marcach, S. Martin, L. Ross, and D. Geist. 1990. Lower Snake River compensation plan salmon hatchery evaluation program. 1989 Annual Report. Washington Department of Fisheries, Olympia, Washington, to U. S. Fish and Wildlife Service, Lower Snake River Compensation Plan Office, Boise, Idaho (Cooperative Agreement 14-16-0001-89525).

Bugert, R. M., C. W. Hopley, C. A. Busack, and G. W. Mendel. 1995. Maintenance of stock integrity in Snake River fall Chinook salmon. American Fisheries Society Symposium. 15:267-276.

Chinook Technical Committee (Pacific Salmon Commission Joint Chinook Technical Committee). 2007. Annual report on catch, escapement, exploitation rate analysis and model calibration of Chinook salmon under Pacific salmon commission jurisdiction, 2006, 1/30/2007.

Connor, W. P., A. P. Garcia, A. H. Connor, E. O. Garton, P. A. Groves, and J. A. Chandler. 2001. Estimating the carrying capacity of the Snake River for fall Chinook salmon redds. Northwest Science. 75(4): 363-371.

Connor, W. P., H. L. Burge, R. Waitt, and T. C. Bjornn. 2002. Juvenile life history of wild fall Chinook salmon in the Snake and Clearwater rivers. North American Journal of Fisheries 22:703-712.

Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, and D. Ross. 2005. Two alternative juvenile life histories for fall Chinook salmon in the Snake River basin. Transactions of the American Fisheries 134:291-304.

Connor, W. P., F. Mullins, K. F. Tiffan, R. W. Perry, J. M. Erhardt, S. J. St. John, B. Bickford, and T. Rhodes. 2014. Research, monitoring, and evaluation of emerging issues and measures to recover the Snake River fall Chinook salmon ESU, 1/1/2012 – 12/31/2013: Annual report, 1991-029-00.

Connor, W. P., B. D. Arnsberg, J. A. Chandler, T. D. Cooney, P. A. Groves, J. A. Hesse, G. W. Mendel, D. J. Milks, D. W. Rondorf, S. J. Rosenberger, M. L. Schuck, K. F. Tiffan, R. S. Waples, and W. Young. 2016. A Retrospective (circa 1800–2015) on the Abundance, Spatial Distribution, and Management of Snake River Basin Fall Chinook salmon.

Dauble, D. D., T. P. Hanrahan, D. R. Geist, et al. 2003. Impacts of the Columbia River hydroelectric system on main-stem habitats of fall Chinook salmon. North American Journal of Fisheries Management. 23:641–659, 1/1/2003.

Ford, M. J., A. Albaugh, K. Barnas, T. Cooney, J. Cowen, J. J. Hard, R. G. Kope, M. M. McCLure, P. McElhany, J. M. Myers, N. J. Sands, D. Tell, and L. A. Weitkamp. 2011. Status Review Update for Pacific Salmon and Steelhead Listed under the Endangered Species Act: Pacific Northwest. November 2011. NOAA Technical Memorandum NMFS-NWFSC-113. Northwest Fisheries Science Center, U.S. Department of Commerce, NMFS, Seattle, Washington.

Fritts, A. L. and T. N. Pearsons. 2006. Effects of predation by nonnative smallmouth bass on native salmonid prey: the role of predator and prey size. Transactions of the American Fisheries Society 135:853-860.

Garcia, A., S. Bradbury, B. Arnsberg, S. Rocklage, and P. Groves. 2004. "Fall Chinook Salmon Spawning Ground Surveys in the Snake River Basin upriver of Lower Granite Dam", 2002-2003 Annual Report, Project No. 199801003, 60 electronic pages, (BPA Report DOE/BP-00004700-3). 8/1/2004.

Groves, P. A. and J. A. Chandler. 1999. Spawning habitat used by fall Chinook salmon in the Snake River. No. Amer. J. Fisheries Management. 19:912-922.

Hard, J. J., M. R. Gross, M. Heino, R. Hilborn, R. G. Kope, R. Law, and J. D. Reynolds. 2008. Evolutionary consequences of fishing and their implications for salmon. Evolutionary Applications.

Hillborn, R. and C. J. Ealters (Eds). 1992. Quantitative Fisheries Stock Assessment, Choice, Dynamics and Uncertainty.

ICTRT (Interior Columbia Basin Technical Recovery Team). 2005. Viability criteria for application to interior Columbia basin salmonid ESUs. Northwest Fisheries Science Center, Seattle, Washington, July 2005.

ICTRT (Interior Columbia Basin Technical Recovery Team). 2007. Viability criteria for application to interior Columbia basin salmonid ESUs. Review draft, 3/1/2007.

Marshall, A. R., H. L. Blankenship, and W. P. Connor. 2000. Genetic Characterization of Naturally Spawned Snake River Fall-Run Chinook salmon. Transactions of the American Fisheries Society. Vol. 129, Iss. 3, 2000.

Milks, D., M. Varney, J. Jording, and M. Schuck. 2006. Lyons Ferry Hatchery evaluation fall Chinook salmon salmon annual report: 2003 and 2004. Washington Dept. of Fish and Wildlife Fish Program Science Div. Report FPA 06-97. 128 p.

NMFS (National Marine Fisheries Service). 1991. Policy on applying the definition of species under the Endangered Species Act to Pacific salmon. Federal Register 56(224):58612-58618, 11/20/1991.

NMFS (National Marine Fisheries Service). 2012. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Manguson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation: Snake River Fall Chinook Salmon Hatchery Programs, ESA section 10(a)(1)(A) permits, numbers 16607 and 16615.October 9, 2012. NMFS Northwest Region.

Peters, C. N, D. R. Marmorek, and I. Parnell, editors. 1999. Plan for analyzing and testing hypotheses (PATH): decision analysis report for Snake River fall chinook. ESSA Technologies Ltd., Vancouver, B.C.

Peterson , W. T., C. A. Morgan, J. O. Peterson, J. L. Fisher, B. J. Burke, and K. Fresh. 2014. Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. 12/1/2014.

Poe, T. P., H. C. Hansel, S. Vigg, D. E. Palmer, and L. A. Prendergast. 1991. Feeding of predaceous fishes on out-migrating juvenile salmonids in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. 120: 405–420.

Riddle, B. E. 1986. Assessment of selective fishing on age at maturity in Atlantic salmon (Salmo salar): a genetic perspective. In D. J. Meerburg ed. Salmonid age at maturity. p102–109. Canadian Special Publication in Fisheries and Aquatic Sciences 89, Ottawa, ON.

Shepard, J. G. 1982. A versatile new stock-recruitment relationship for fisheries, and the construction of sustainable yield curves. ICES J Mar Sci (1982) 40 (1): 67-75. DOI: https://doi.org/10.1093/icesjms/40.1.67. Published: 01 February 1982.

Waples, R. S. 1991. Pacific salmon, Onchorhynchus spp., and the definition of species under the Endangered Species Act. Mar. Fish. Rev. 53(3):11-22.

Waples, R. 2015. Personal Communication between Tom Cooney (NWFSC) and Robin Waples (NWFSC) regarding juvenile life history of Snake River fall Chinook.

WDFW (Washington Department of Fish and Wildlife). 2017. Lower Snake River Compensation Plan Annual Operation Reports. https://www.fws.gov/lsnakecomplan/Reports/WDFWreports.html. Accessed July 21, 2017.

WDFW (Washington Department of Fish and Wildlife) and ODFW (Oregon Department of Fish and Wildlife). 2014. 2014 Joint Staff Report: Stock Status and Fisheries for Fall Chinook Salmon, Coho Salmon, Chum Salmon, Summer Steelhead, and White Sturgeon. Published July 14, 2014.

Young, W., D. Milks, M. Schuck, and B. Arnsberg. 2012. Snake River Fall Chinook salmon Age and Size at Return: Then and Now. Produced for Fish and Wildlife Service.

Young, W. P., D. Milks, S. Rosenberger, B. Sandford, and S. Ellis. 2013. Snake River Fall Chinook Salmon Run Reconstruction. Lower Snake River Compensation Project, Fall Chinook Salmon Review. Clarkston, WA.

Zimmerman, M. P. 1999. Food habits of smallmouth bass, walleyes, and northern pikeminnow in the lower Columbia River basin during outmigration of juvenile anadromous salmonids. Transactions of the American Fisheries Society 128:1036-1054, 1/1/1999.