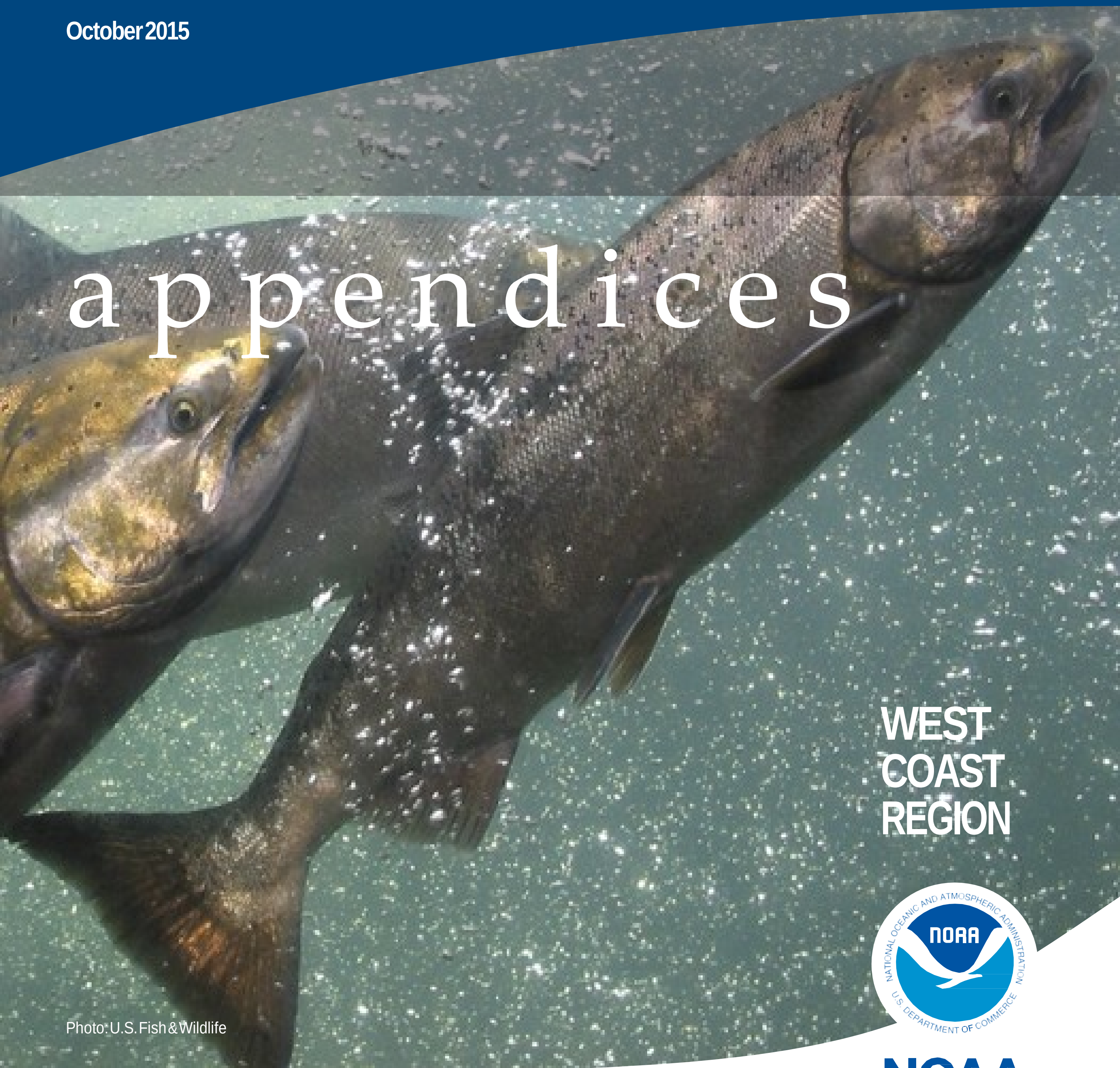
Appendices for: Proposed ESA Recovery Plan for Snake River Fall Chinook Salmon *(Oncorhynchus tshawytscha)*

October 2015



appendices

WEST COAST REGION

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Appendices for the

Snake River Fall Chinook Salmon
(*Oncorhynchus tshawytscha*)

ESA Recovery Plan

Prepared by
National Marine Fisheries Service
West Coast Region

October 2015

Appendix A: Current ESU Viability Assessment

Appendix B: Research, Monitoring & Evaluation for Adaptive Management

Appendix C: Temperature in the Lower Snake River during Fall Chinook Salmon Egg Incubation, Fry Emergence, Shoreline Rearing, and Early Seaward Migration

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Appendix A. Current ESU Viability Assessment[1]

Snake River fall Chinook salmon spawn predominately in the mainstem of the Snake River and some of its major tributaries. 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 sub-yearlings 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 Mainstem 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 Mainstem Snake River population.

The viability criteria for the Lower Mainstem Snake River fall Chinook salmon population are tailored to their specific life history characteristics following the same basic principles applied to the other Interior Basin listed Chinook salmon ESUs. The ICTRT described these principles in its report, Viability Criteria for Application to Interior Columbia Basin Salmonid ESUs (ICTRT 2007). NMFS' evaluation of the current status of the Lower Mainstem Snake River fall Chinook salmon population follows the framework recommended by the ICTRT for integrating information across 12 individual criteria using a matrix framework, as described in Section 3. The ICTRT criteria are first organized into two separate groupings: (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 provided one set of quantitative metrics for evaluating status vs. the individual viability criteria. It also provided examples of corresponding relative risk rating categories (very low, low, moderate and high). The ICTRT 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, NMFS initiated a 5-year status review for 32 species of salmon and steelhead, including Snake River Fall-Run Chinook salmon. To ensure that this Proposed Plan was based on best available information, we have included this Appendix, which incorporates material from the ongoing 5-year status review.
[2] The ICTRT (2005) update identified two historical populations above the current Hells Canyon dam site. Based on information summarized in Connor et al. 2015 and the basic distance/dispersal approach used by the ICTRT to define population boundaries, it is likely that the two relatively continuous spawning aggregations were part of a single population.

Snake River Fall Chinook ESU: Updated Information

In addition to extending the time series of basic population information to cover additional years, improved methods for estimating annual abundance from the data generated by annual sampling efforts have been implemented and new insights into the population structure of the extirpated component of the ESU that historically spawned above the current Hells Canyon Dam complex have been developed. The improved methodology for estimating abundance, age structure and hatchery/wild composition is described in the Abundance and Productivity section below. A brief summary of the updates to population structure above Hells Canyon and of the viability criteria adaptations included in the NOAA Snake River Fall Chinook Recovery Plan is included here.

Historically, natural production from this ESU was mainly from spawning in the mainstem of the Snake River upstream of the Hells Canyon Dam complex. The spawning and rearing habitat associated with the current extant population represents approximately 20% of the total historical habitat available to the ESU (Dauble 2000). Based on updated information (Connor et al. 2015), there was a single historical population (the Middle Snake population) above the current location of Hells Canyon Dam, consisting of two major spawning areas. The primary (largest and most productive) Middle Snake River subpopulation likely spawned within the area of direct aquifer influence described by Connor et al. (2015). The primary (largest and most productive) Middle Snake River subpopulation likely spawned within the area of direct aquifer influence described by Connor et al. (2015). Temperature conditions during spawning and incubation were strongly influenced by water inputs from the aquafer, allowing for earlier emergence timing and rapid growth especially in the reaches upstream of the current Swan Falls Dam site. A single population above Hells Canyon is a revision of the original determination of two populations above Hells Canyon Dam based on historical accounts of spawner distribution and spatial geomorphic considerations (ICTRT 2007). 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. 2015).

An adaptation of the ICTRT decision framework to assess the status of the ESU that specifically incorporates alternative ESU viability criteria scenarios is presented in Section 3 of the Snake River Fall Chinook Recovery Plan (Recovery Plan). Those alternative viability scenarios include both multiple-population and single-population versions. Given that at present there is only one extant population, this assessment evaluates current status vs. criteria for the single-population scenarios. However, the basic measures evaluated in this assessment would also apply the multiple population scenarios, which involve reintroduction of the ESU to areas above the Hells Canyon Complex.

A.1. Current Viability Rating

The following status assessment of the Lower Mainstem 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 Viability Scenario B (single population aggregate metrics), although we include brief summaries under specific VSP components of the findings or the additional information that would be required under variations that would be based on incorporating natural emphasis areas that include one or more major spawning areas.

A.1.1 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 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 Viability Criteria report (ICTRT 2007) also provided 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. The NOAA Snake River Fall Chinook Recovery Plan (Section 3) calls for exceeding the Very Low Risk viability curve by a margin corresponding to an 80% certainty.

Our abundance, trend and productivity estimates for the Lower Mainstem Snake River population are based on counts and sampling at Lower Granite Dam. Separate estimates of the numbers of adult (age 4 and older) and jack (age 3) 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. A portion of the fish sampled at the trap are 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 Section 7, Research, Monitoring and Evaluation and the RM&E appendix).

Sampling methods and statistical procedures used in generating the estimated escapements have improved substantially over the past 10-15 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, 2013). 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 Dept. of Fish and Wildlife Snake River laboratory (e.g. Milks et al. 2006). 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 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). Based on extrapolations from sampling at Ice Harbor Dam (1977-1990), the Lyons Ferry Hatchery (1987-present) and at Lower Granite Dam (1990-present), hatchery strays made up an increasing proportion of returns at the uppermost Snake River mainstem dam through the 1980s (Bugert et al. 1990; Bugert & Hopley 1989). Strays from out-planting Priest Rapids hatchery-origin fall Chinook salmon (and 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.

In recent years, naturally spawning fall Chinook salmon in the lower Snake River have included both 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 supplementation 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 the single population 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 will be archived in the Northwest Fisheries Science Center (NWFSC) Salmonid Population Summary (SPS) database following completion of the 2015 NWFSC Five Year Status Reviews. The data sets archived in SPS 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 abundance for the most recent 10 years of annual spawner escapement estimates (2004-2014) is 6,418, with a standard error of 0.19. Natural-origin spawner abundance has increased relative to the levels reported in the most recent NWFSC status review (Ford et al. 2011), driven largely by relatively high escapements in the most recent three years.

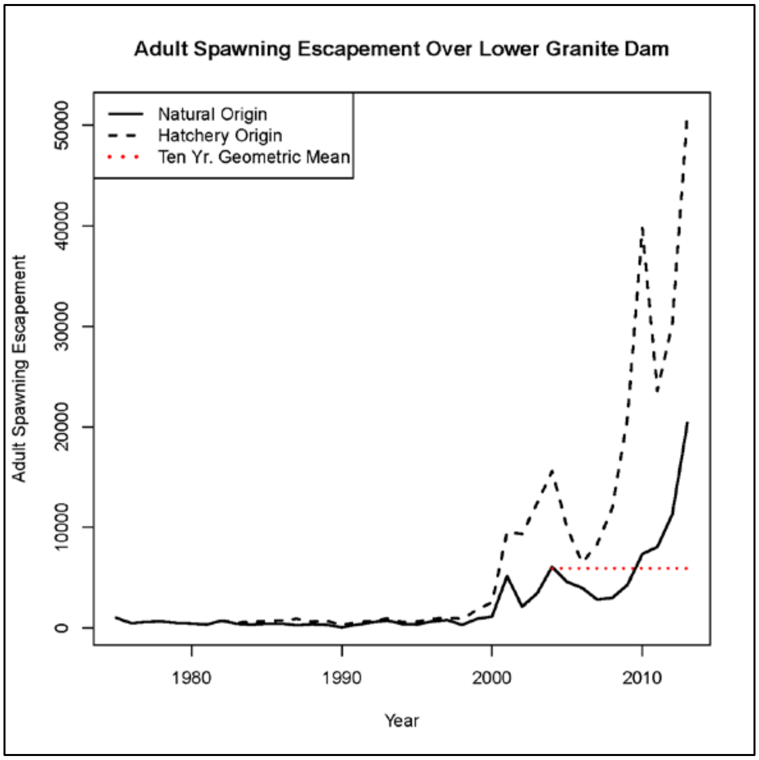

Figure A-1a. Spawner estimates for run years 1991 to 2013.

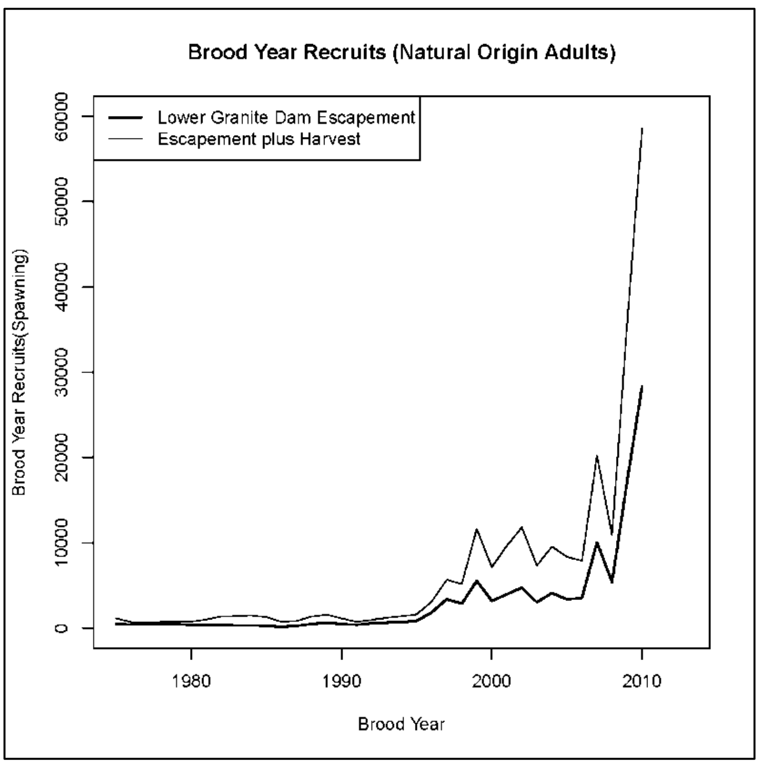

Figure A-1b. Brood year recruits measured as returns to natural spawning areas (dark line) and as spawners plus harvest (light gray line).

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 productivities 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 approach, 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 Viability report (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 have developed estimates of current productivity for this 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 simple 20-year R/S method, the current estimate of productivity for this population (1991-2010 brood years) is 1.5 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-2), 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 2010 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.

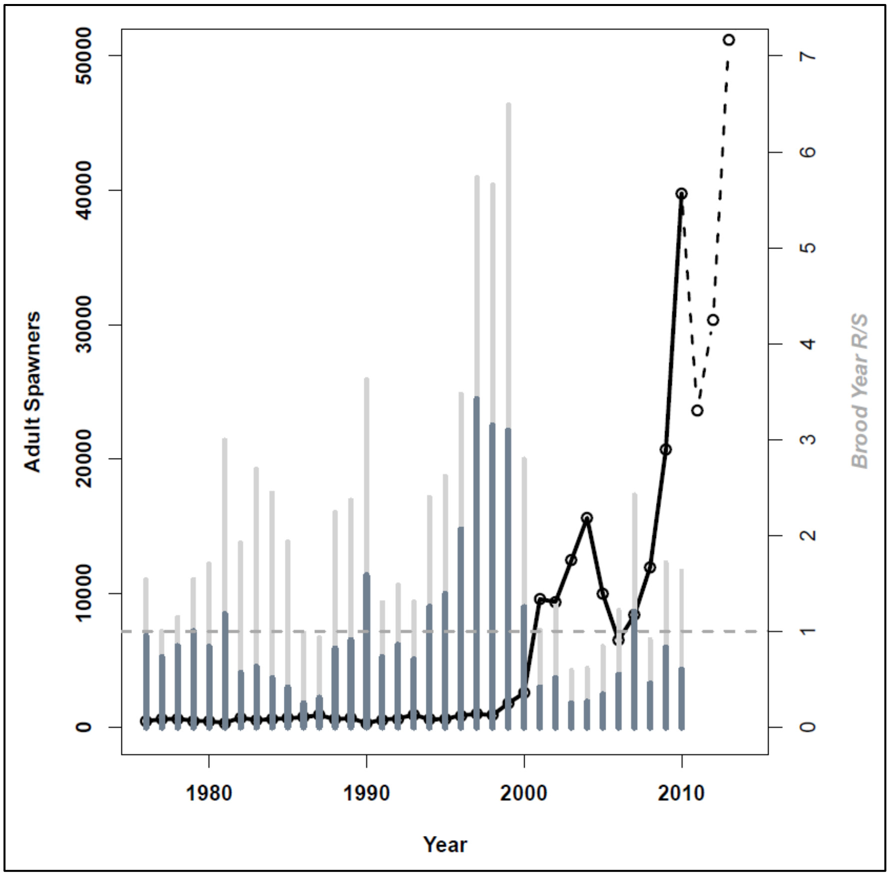

Figure A-2. Brood year parent spawning levels (right side axis, hatchery plus natural-origin adults) and brood year return per spawner estimates (left side axis, red squares) vs. parent brood year. Light bars: recruits are adult escapement plus ocean (adult equivalent) and in-river harvest. Dark bars: recruits are escapement over Lower Granite Dam. Parent brood year escapements with incomplete return ages depicted with dashed line.

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. 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, it 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 & 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).

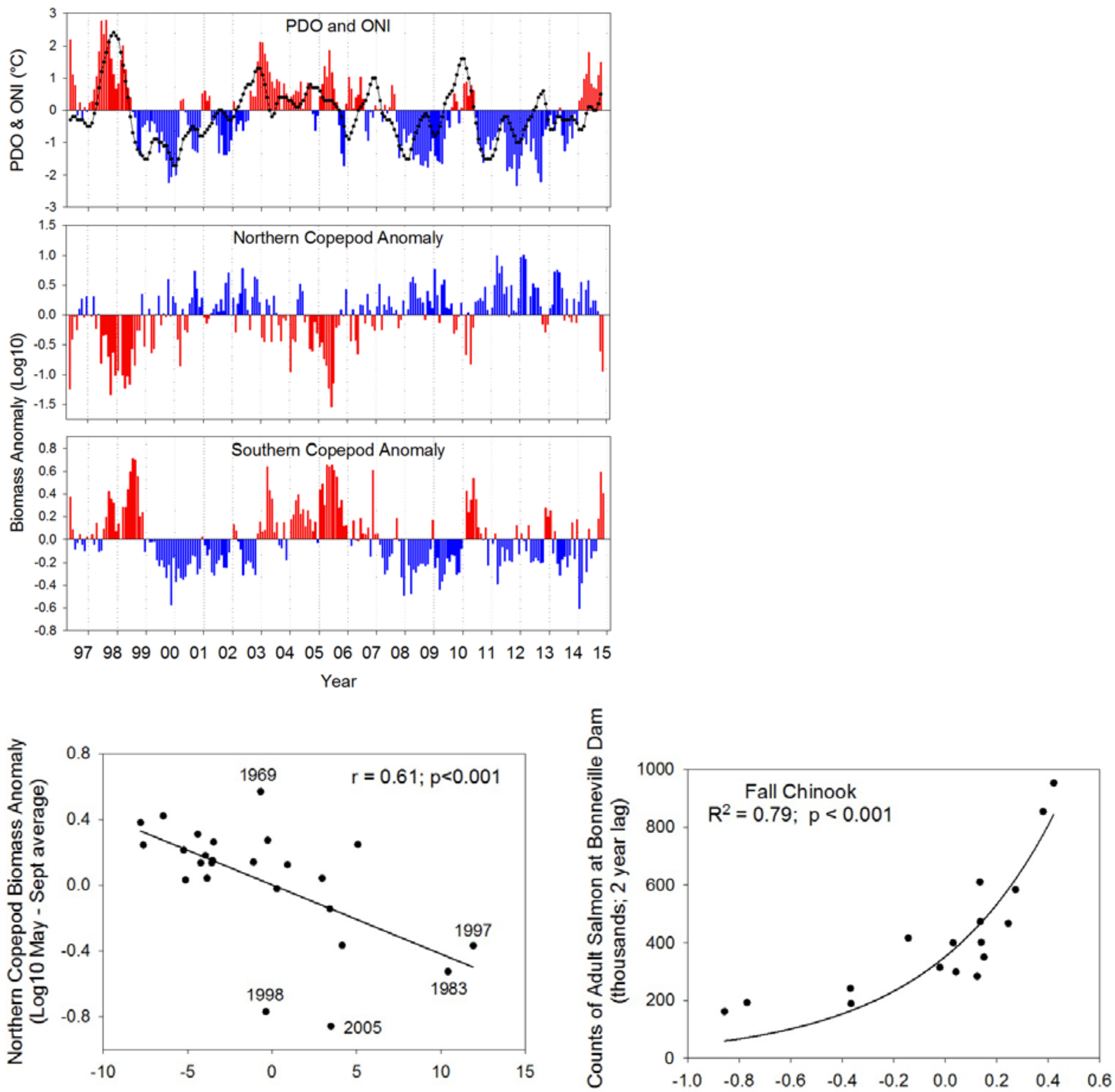

Figure A-3. Excerpts from Peterson et al. 2014. Top panel: Fig. NSC-01 - The Pacific Decadal Oscillation (upper), and northern copepod biomass anomalies (lower), from 1969 to present. Lower left panel: Fig. NSC-02 - Relationship of northern copepod anomalies and the PDO during the summer upwelling season (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.

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 PDO - Pacific Decadal Oscillation index (Figure A-3). 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.

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/pubs/TCCHINOOK(14)-1_V1.pdf) and are expressed in terms of adult equivalents (adjusted based on maturation rates derived from tagged Lyons Ferry sub-yearling releases). In-river harvest rates were obtained from annual WDFW/ODFW fall fishery status reports (e.g. WDFW 2014).

Four alternative stock-recruit models (Table A-1) were fit to the 1991-2010[3] brood year spawner and return data set for the Lower Mainstem Snake River fall Chinook salmon population: 1) Constant RS - a model that assumed a constant underlying R/S value that is invariant with respect to spawner density, 2) Beverton-Holt RS, 3) Ricker RS, and 4) the Shepard model RS (Shepard 1982), 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. The models were statistically compared using the AICc criteria (AICcmodavg package).

[3] Analyses and figures will be updated to include 2014 returns as part of the next round of reviews.

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-1. 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-1). 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.

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. Summary of results from fitting alternative stock-recruit functions to the Lower Snake fall Chinook salmon 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=Shapard "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-4). 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 development for Snake River Fall Chinook will allow for incorporating estimated changes in life stage survivals based on directed studies directly into assessment updates.

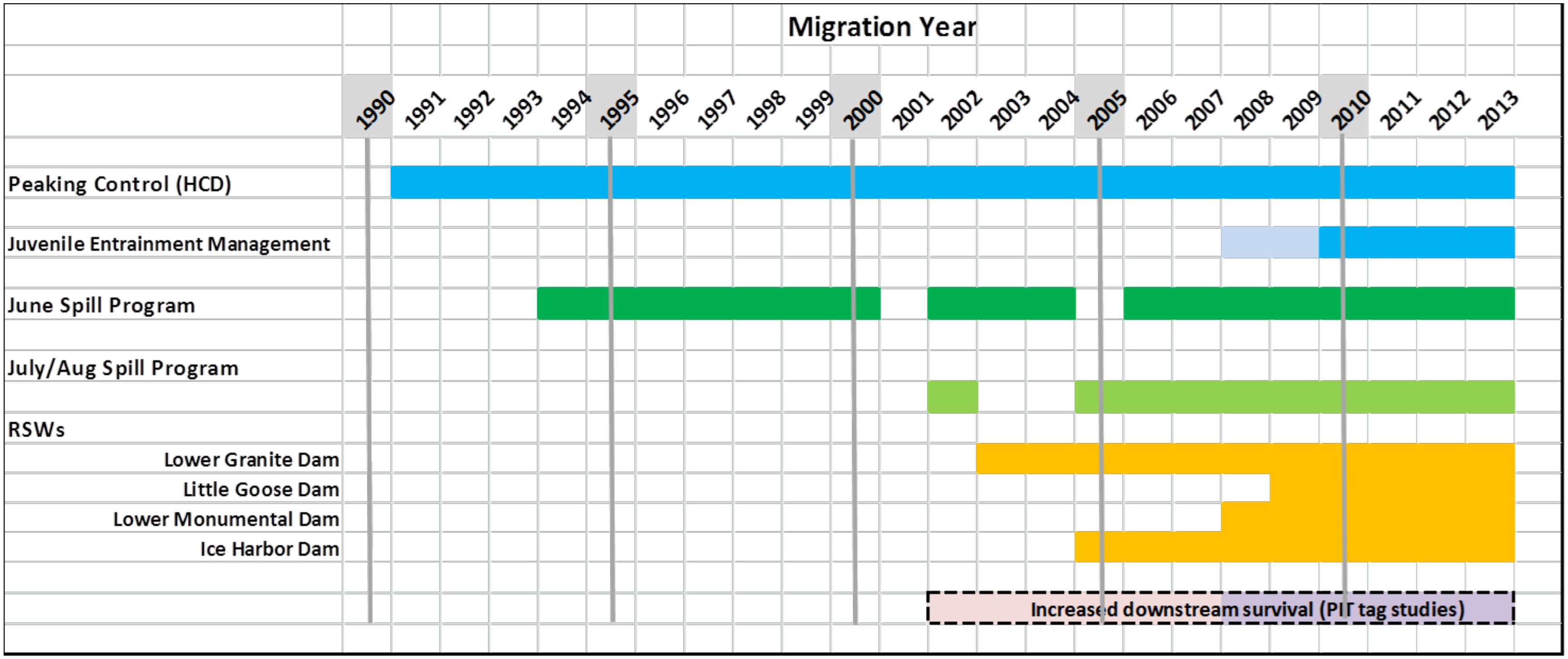

Figure A-4. Timing of recent actions with the potential to affect outmigration survival of juvenile Snake River Fall Chinook.

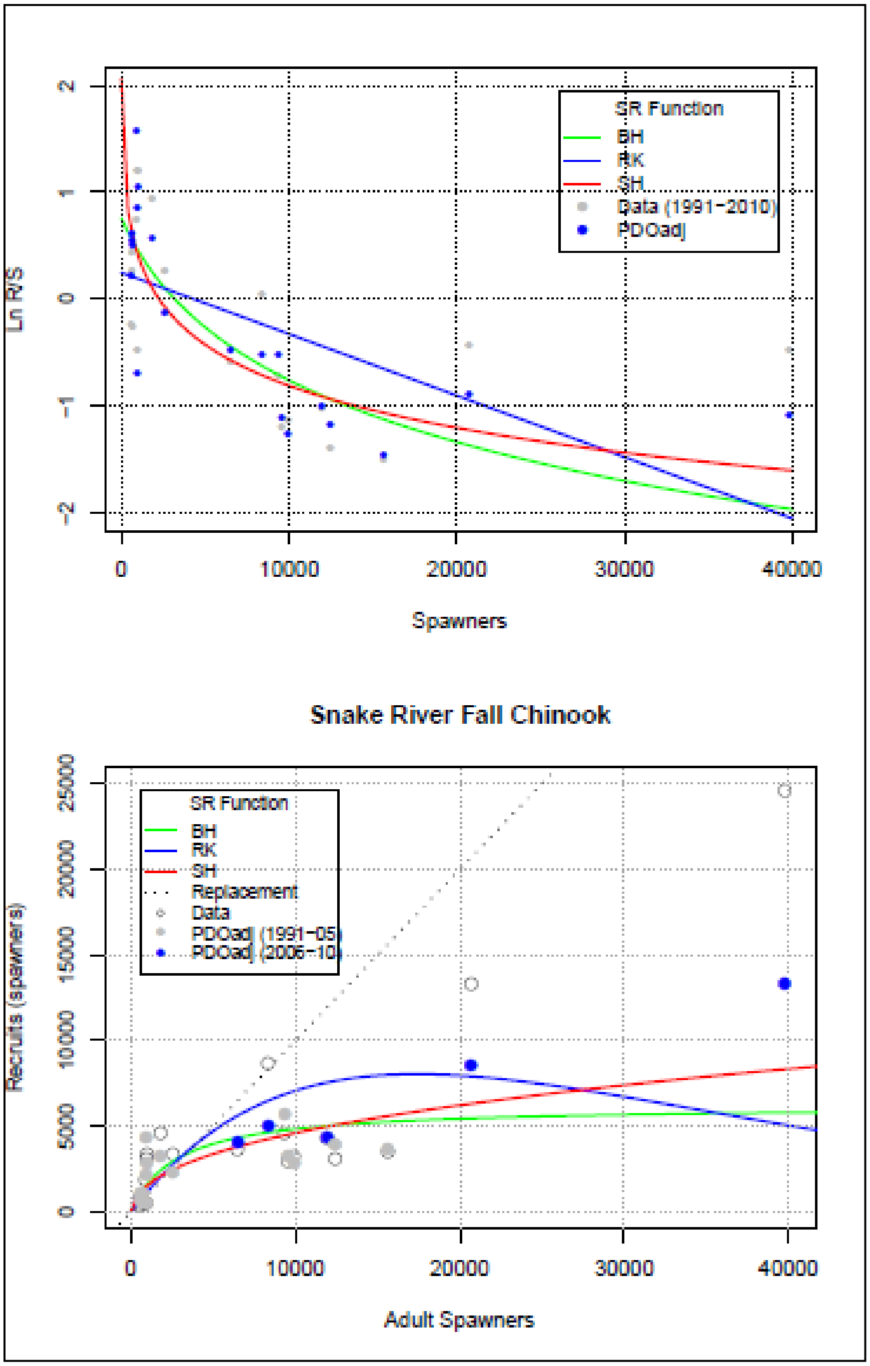

Figure A-5. Snake River Fall Chinook stock/recruitment function fits to 1991-2014 brood year adult return (to spawning grounds) vs. parent spawner estimates. Brood year 2014 recruits incomplete, expanded by average age 5 proportion (13.8%). Dark filled circles include adjustment for annual PDO. Top panel: 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).

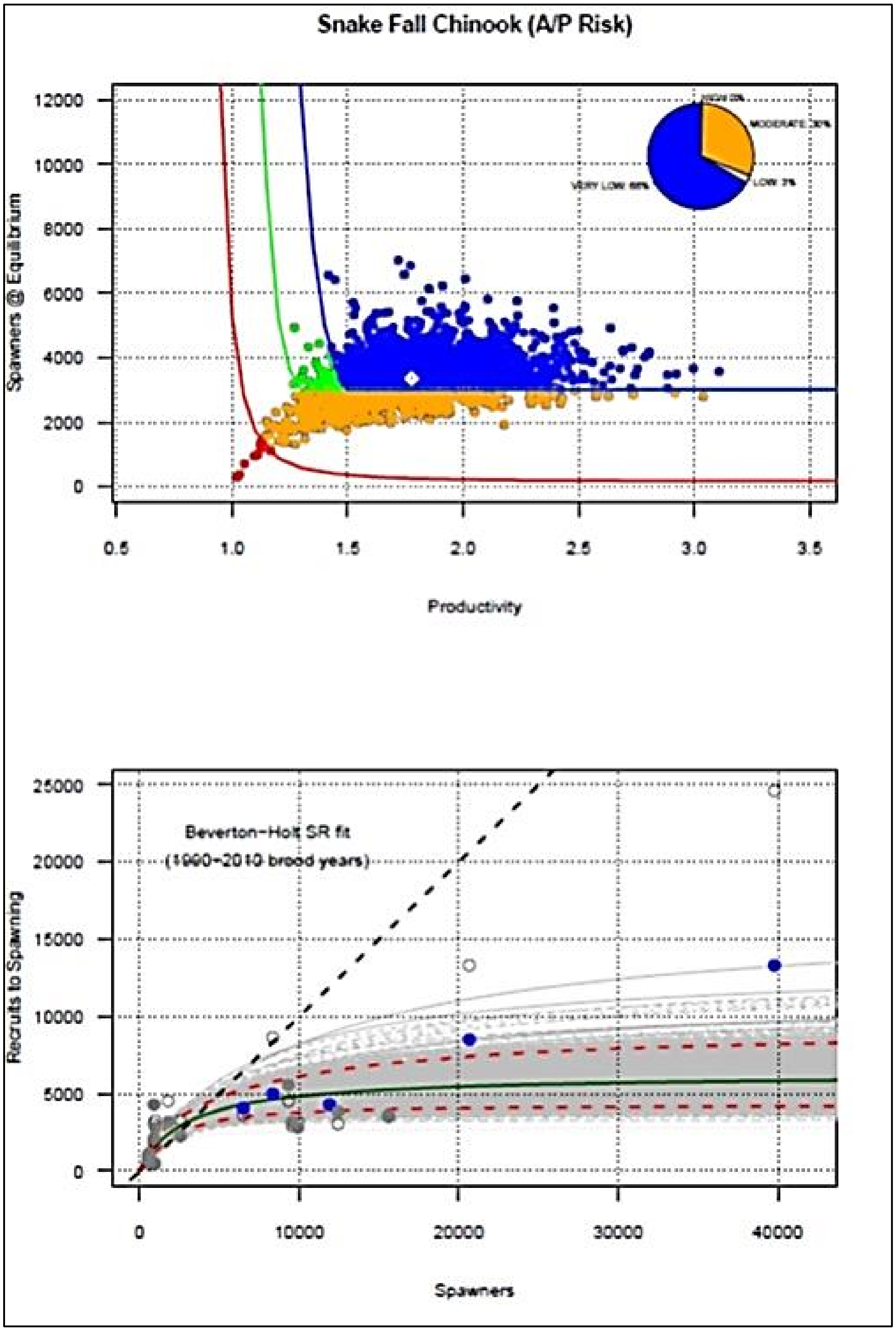

Figure A-6a & A-6b. Beverton Holt stock recruit relationship fitted to broodyears 1991-2010 Snake River Fall Chinook adult escapement estimates. Includes parameter uncertainty generated using the nlsBoot routine for the R statistical package. Top panel: Summary of bootstrap results (2,000 iterations) 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.

Efforts are underway to develop indices of downstream passage survival that could improve future stock-recruit analyses for Snake River Fall Chinook (see RM& E section). Initial estimates of subyearling outmigrant production relative to parent spawning escapements also indicate a strong density dependent component (Figure 3c from Connor et al. 2014). Efforts are underway to develop a multistage 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 RM& E section).

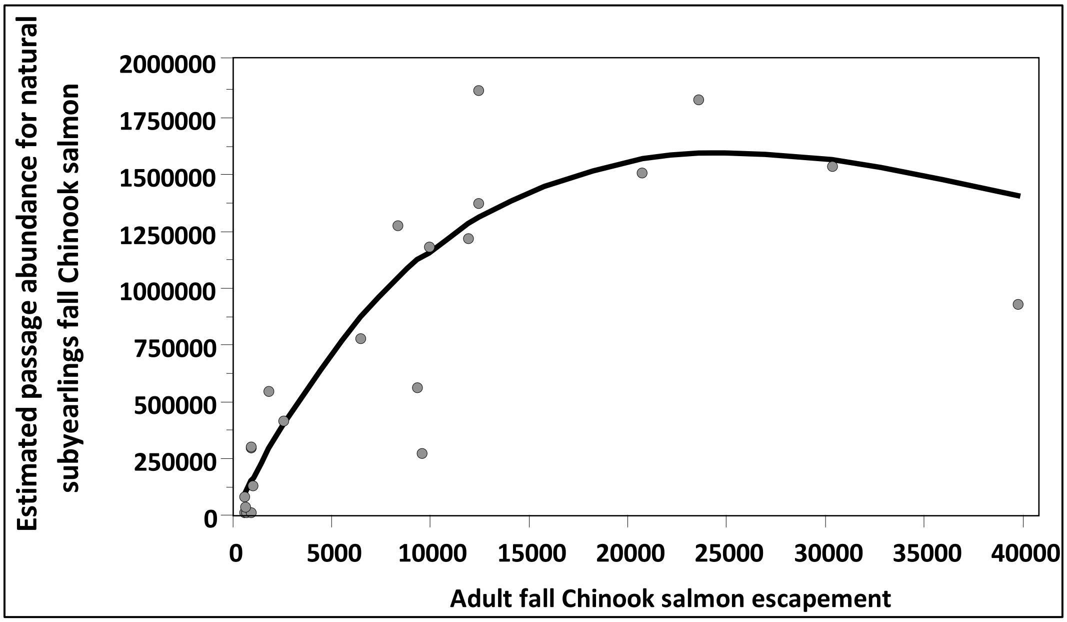

Figure A-7. The preliminary relation between adult stock (Table 1) and natural juvenile recruits (Table 3) for Snake River basin fall Chinook salmon subyearlings at Lower Granite Dam calendar years 1992 to 2013, brood years 1991 to 2012. Passage abundance was not estimated during the months of November through late March when the Smolt Monitoring Program was not in operation or in late March through April during the period of yearling passage.

A.1.2 Summary

Figures A-6a and A-8 illustrates that 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 under the single-population Viability Scenario B. 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.

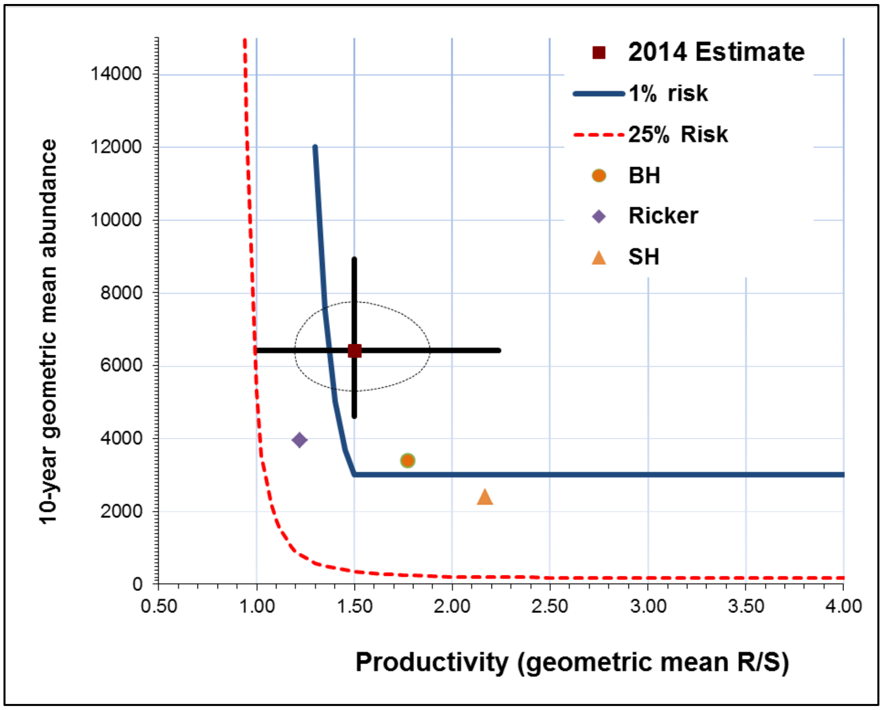

Figure A-8. Estimated equilibrium abundance vs. productivity for Lower Mainstem Snake River fall Chinook salmon population based on 1991 through 2013 data series (1991 to 2010 brood years). Oval represents 1 standard error assuming bivariate normal distribution. Lines represent 90% confidence limits. 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 meet the uncertainty-buffering requirement under the single-population viability scenario. Analyses of Viability Scenario B show the statistical uncertainty associated with the current paired estimates from either the simple empirical method or the fitted stock production functions and indicate that the buffer requirements are not met. As a result, the Lower Mainstem Snake River fall Chinook salmon population is rated at **Moderate Risk** for abundance and productivity.

The placeholder viability scenario for natural production emphasis areas recognizes that the unique spatial complexity of the Lower Mainstem Snake River fall Chinook salmon population provides an opportunity to meet recovery objectives if major spawning areas supporting the bulk of natural returns are operating consistent with long-term diversity objectives. The requirements under a natural production emphasis area scenario 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 with relatively low hatchery contributions to spawning. At present (escapements through 2013), 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 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 factors associated with each goal. Each of the factors has an associated set of metrics 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.

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 Mainstem 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, the 110-mile reach of the Clearwater River from the upper end of the Lower Granite Dam pool (near Lewiston, Idaho) to Selway Falls plus the lower reaches of major tributaries (e.g., the Grande Ronde and Imnaha Rivers) intrinsic potential for defining large areas of contiguous high potential spawning habitat within stream type Chinook salmon and steelhead populations. The resulting maps were used as a framework for evaluating spatial structure and diversity elements of viability. The basic method was adapted to apply to the mainstem habitats favored by Snake River fall Chinook salmon (ICTRT 2007).

The ICTRT identified five major spawning areas (MaSAs) for the Lower Mainstem Snake River fall Chinook salmon population (Figure A-9):

1. *Upper Mainstem Snake River reach* - Hells Canyon Dam downstream to the mouth of the Salmon River and including the lower mainstem of the Imnaha and Salmon Rivers;
2. *Lower Mainstem Snake River reach* - mouth of the Salmon River downstream to the upper end of Lower Granite Reservoir;
3. *Grande Ronde River*
4. *Clearwater River*
5. *Tucannon River (and contiguous mainstem Snake River habitat)*

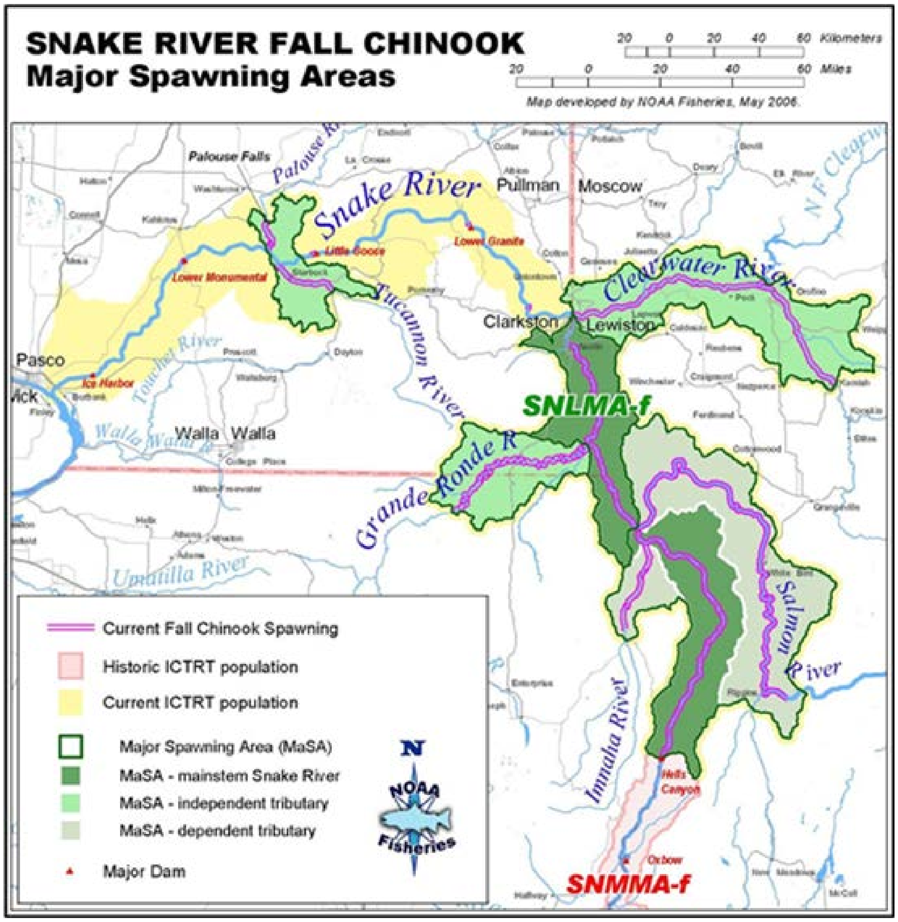

Figure A-9. Lower Mainstem Snake River fall Chinook salmon population: Major spawning areas (MaSAs) with core spawning habitats and associated dependent spawning areas deliniated.

The historic distribution of spawning was linear and included mainstem Snake River reaches from Hells Canyon downstream to the mouth of the Snake River along with the lower portions of three relatively large tributaries: the Clearwater, Grande Ronde and Tucannon Rivers (Connor et al. 2005). In addition, the lower mainstem reaches of the Salmon and Imnaha Rivers were likely minor spawning areas. There is some anecdotal information 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.

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.

Factor A.1.a: Number and spatial arrangement of spawning areas

Four of the five historical MaSAs currently are known to contain natural-origin spawners regularly. The fifth, the Tucannon River MaSA, also has fall Chinook salmon spawners, but recent year 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 productiive, 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 by the Lower Mainstem fall Chinook salmon population is shown in Figure A-10. Based on annual redd survey results, all five of the major spawning areas in this population exhibit spawning. It is very likely that recent spawning levels in, four out of five of the major spawning areas include natural-origin spawners and are considered occupied (the two free-flowing Snake River mainstem major spawning areas and lower portions of the Clearwater and Grande Ronde Rivers). Carcass sampling data from the manstem Clearwater MASA confirm the presence of natural origin spawners. Difficulties associated with 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. Efforts are underway to develop more specific estimates of the relative distribution of natural spawners among the major spawning areas (see RME section 7 in the Snake River Fall Chinook 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 spawners in that reach. Applying the ICTRT guidelines for a complex (trellis structured) population, the Lower Mainstem Snake River fall Chinook salmon population is rated at **low risk** for current spatial structure.

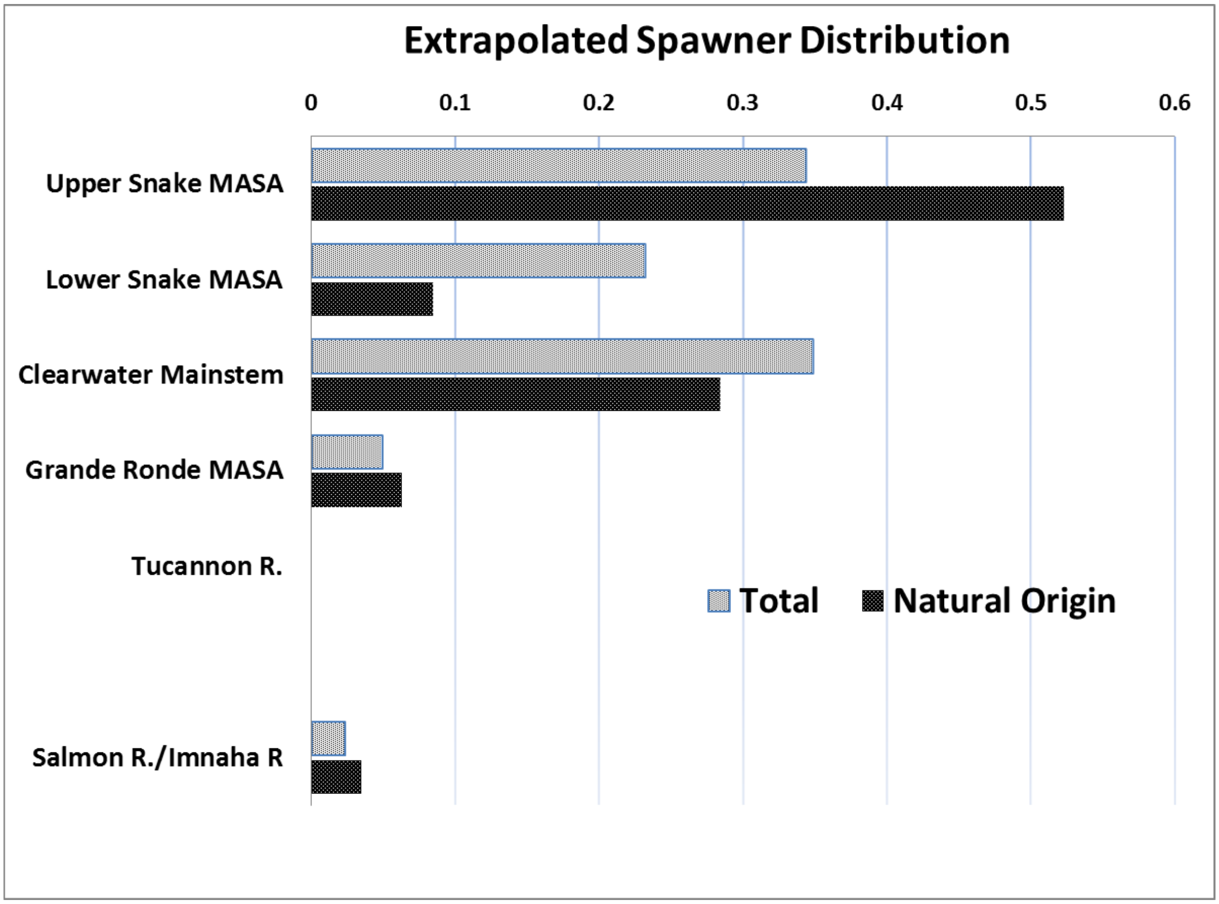

Figure A-10. Estimated average spawner distributions (2004-2014) across major and minor spawning areas. Total is average distribution of redds from annual multiple pass surveys, produced by combination of hatchery and natural origin spawners. Natural origin estimates extrapolated from regional total 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 Mainstem 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. While 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 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 Mainstem Snake River population were likely more diverse than those associated with the two extirpated upstream populations in the ESU. Conditions in 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 upstream populations (Connor et al. 2002) and data indicates that most smolts produced from this area migrate as sub-yearlings. Incubation and spring juvenile rearing temperatures in the Snake River mainstem below the Salmon River and in the lower Clearwater River mainstem are relatively cold in comparison. As a result, sub-yearling 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 adult returns of both hatchery- and natural-origin Chinook salmon overwintered somewhere in the Columbia River system prior to entering the ocean. 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/summer. Natural returns from both the sub-yearling 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 life history pattern peaked with the early 2000 broods, and has declined since then (Figure A-11).

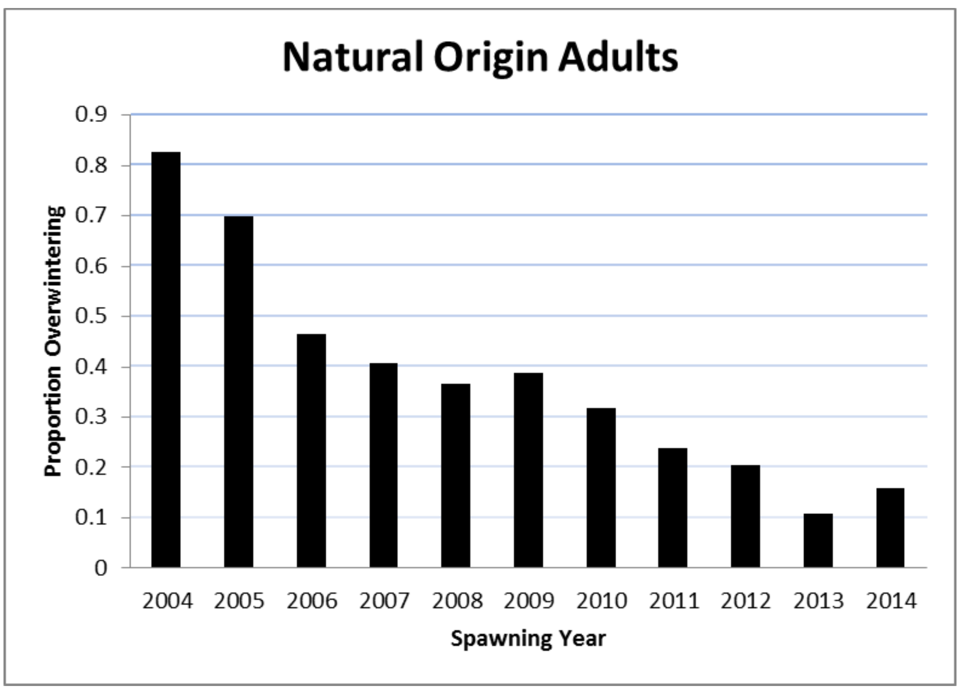

Figure A-11. Proportion of returning natural origin Snake River Fall Chinook adults sampled at the Lower Granite Dam trap identified as yearling outmigrants. Extrapolated from age specific estimates of unmarked returns adjusted for potential contributions of unmarked hatchery fish (see Bill Young et 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 an 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 sub-yearling life history pattern. 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 Mainstem Snake River fall Chinook salmon population is rated **low risk** for life history diversity based on recent patterns in sub-yearling 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 Viability Criteria Report (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 mean 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 Mainstem Snake River fall Chinook salmon population, each of which can be linked to natural selective forces at some life stage (Table A-3). 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 components, 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 Mainstem Snake River fall Chinook salmon population has been collected for recent years (Section 2.3).

Table A-3. 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 this particular population. Some insight into patterns that were prevalent historically can also 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. There has been a relatively small shift in 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 Mainstem 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 doe to altered genetic frequencies (NMFS 2012). One of the specific factors cited in the listing of Snake River fall Chinook salmon under ESA (NMFS 1991) was the potential for significant genetic introgression due to increased straying of outside stocks into natural spawning areas above Lower Granite Dam.

Recent year 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 brood stock (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, an indication that the actions taken to reduce the potential introgression of out-of-basin hatchery strays has been effective.

<u>Within-population diversity</u>
Given the diversity of habitats used across the major spawning areas within the Lower Mainstem Snake River population and evidence of relatively strong reach fidelity for acclimated supplementation releases, it is reasonable to assume some, albeit 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 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 the uppermost Snake River mainstem dam through the 1980s. Returns of hatchery-origin Snake River fall Chinook salmon from the Lyons Ferry hatchery program and strays from outplanting 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 1990.

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 (Figure 5.1.1–6). 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-12). 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**.

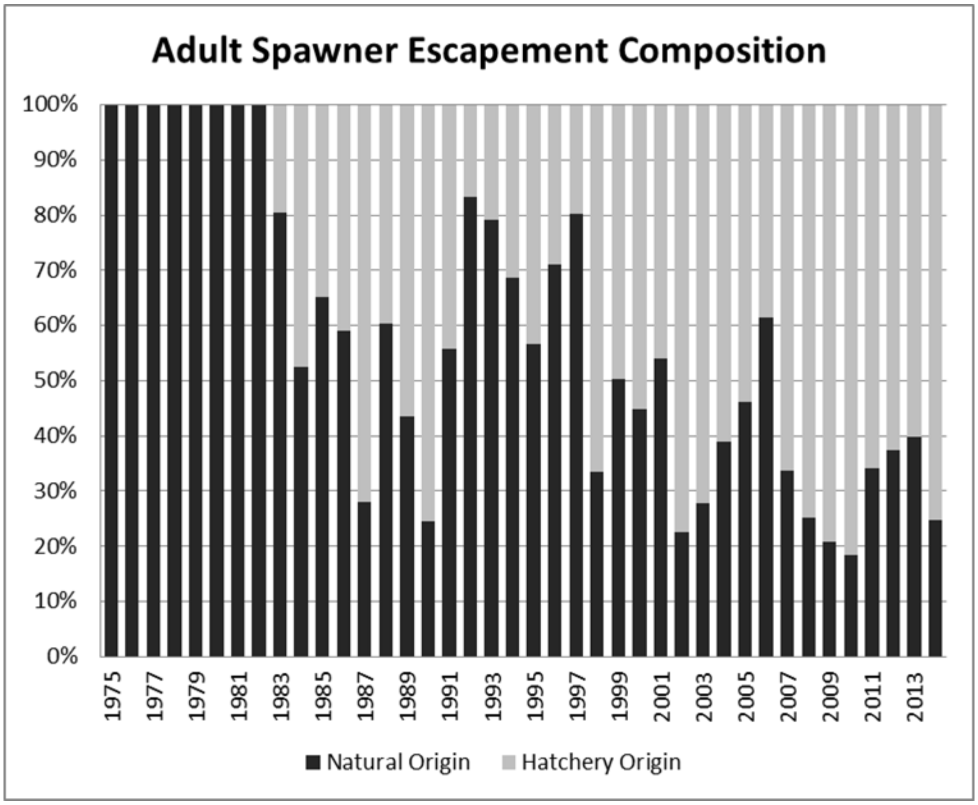

Figure A-12. Annual adult escapement proportions (natural origin (black) and hatchery origin (gray).

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 Mainstem 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 Mainstem Snake River population. Therefore, the extant Lower Mainstem 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.

Hydropower system

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 sub-yearling 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 risk rating of **moderate**. 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).

<u>Selection caused by non-random removals of fish for hatchery broodstock</u>
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**.

<u>Habitat</u>

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.

<u>Other</u>

Predation rates by both fish and birds on sub-yearling Chinook salmon have resulted in increased mortalities during the smolt outmigration. Northern pikeminnow, smallmouth bass and avian predators selectively target sub-yearling Chinook salmon relative to larger yearling migrants. However, size frequency comparisons of sub-yearlings consumed by predators with in-river sub-yearling 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 Mainstem Snake River fall Chinook salmon population. Applying the ICTRT guidelines assigning overall population risks associated with results in a **moderate risk** for selective effects.

Factor A.2.1: Spatial Structure and Diversity Summary

The Lower Mainstem 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-4). 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-4. Lower Mainstem 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.

Metric	Risk Assessment Scores				
	Metric	Factor	Mechanism	Goal	Population
Major Spawning Areas: NUMBER	VL (2)	VL (2)	Low Risk (Mean = 1.33)	Low Risk (Mean = 1.33)	**Moderate Risk (Highest of Goal Risks = 0)**
Major Spawning Areas OCCUPIED	L (1)	L (1)			
Major Spawning Areas: GAPS	L (1)	L (1)			
Major Life History Patterns	L (1)	L(1)	Moderate (Highest of metrics=0)	Moderate Risk (Avg. of Mechanisms = 0)	
Phenotypic Patterns	L (1)	L(1)			
Genetic Diversity	M (0)	M (0)			
Art. Prop. OUT of ESU	M (0)	High (-1)	High Highest of metrics=-1)		
Art. Prop OUT of MPG	N/A				
Art.Prop From MPG	N/A				
Art Prop. From POPULATION	H (-1)				
ECOREGION DISTRIBUTION	L (1)	L (1)	L (1)		
SELECTIVE IMPACTS	M (0)	M (0)	M (0)		

A.3 Overall Population Risk Rating

Overall population viability for the Lower Mainstem 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-13).

Abundance/ Productivity Risk	Spatial Structure/Diversity Risk: **Very Low**	**Low**	**Moderate**	**High**
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-13. Lower Mainstem 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 Mainstem Snake River fall Chinook salmon population is **Viable**. All of the potential delisting options described in Section 3 would require the population to meet or exceed minimum requirements for Highly Viable (green shaded combinations in Figure A-13). Single-population viability scenarios require an added uncertainty buffer, i.e. the population must be Highly Viable with high certainty. Under the Recovery 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 aggregate population spawning above Lower Granite Dam (e.g., the single-population viability scenario described in 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 (1990-2009 brood years) is 1.50. The combination of these two estimates do not exceed the ICTRT Very Low Risk (1% in 100 years) viability curve by a sufficient amount to meet the 80% confidence requirement called for in the Recovery Plan. Using the alternative approach of fitting stock-recruit functions to the 1991-2014 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 hatchery vs. natural spatial distributions, the population is currently not meeting the requirements for Highly Viable under the alternative single-population scenario natural emphasis area option. Under this variation on the single-population scenario, one or more major spawning areas would need to be producing the bulk of natural production with relatively low hatchery spawner proportions.

A.4 Gap between Current Status and Desired Status

Under the viability criteria in Section 3 for delisting with a single population, the extant population must achieve a viability rating of Highly Viable (Very Low risk) with a high degree of certainty before the ESU may be delisted. Achieving an overall population risk rating of Very Low 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.

Abundance/Productivity: 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 a natural production emphasis area scenario would depend on population-level pHOS and proportion of natural-origin broodstock (pNOB) at the time.

Given the information available through 2014, 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 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 Section 6 and Research, Monitoring and Evaluation Section 7 of this 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 the natural emphasis area variation of the single-population recovery scenario, 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.

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Appendix B. Research, Monitoring & Evaluation for Adaptive Management

B.1 Introduction

This appendix describes the research, monitoring, and evaluation (RM&E) plan and the role of RM&E in adaptive management for Snake River fall Chinook salmon. It discusses the RM&E recommended for assessing the status and trends in population viability, and for evaluating the success of management actions implemented to address threats and recovery of Snake River fall Chinook salmon. It also describes current efforts and additional RM&E needs. Although logistical and monetary limitations exist, the RM&E plan will focus on the common goal of assessing success in recovery.

This RM&E plan is based in part on principles and concepts laid out in the NMFS document *Guidance for Monitoring Recovery of Pacific Northwest Salmon and Steelhead Listed Under the Federal Endangered Species Act* (January 2011) and *Adaptive Management for ESA-Listed Salmon and Steelhead Recovery: Decision Framework and Monitoring Guidance* (May 1, 2007). These guidance documents provide a listing status decision framework, which is a series of decision-questions that address the status and change in status of a salmonid ESU, and the risks posed by threats to the ESU (Figure B-1). In addition, the RM&E plan borrows from other RM&E plans that were developed for other Columbia Basin regions and includes information from the Columbia Basin Anadromous Salmonid Monitoring Strategy (CBFWA 2010).

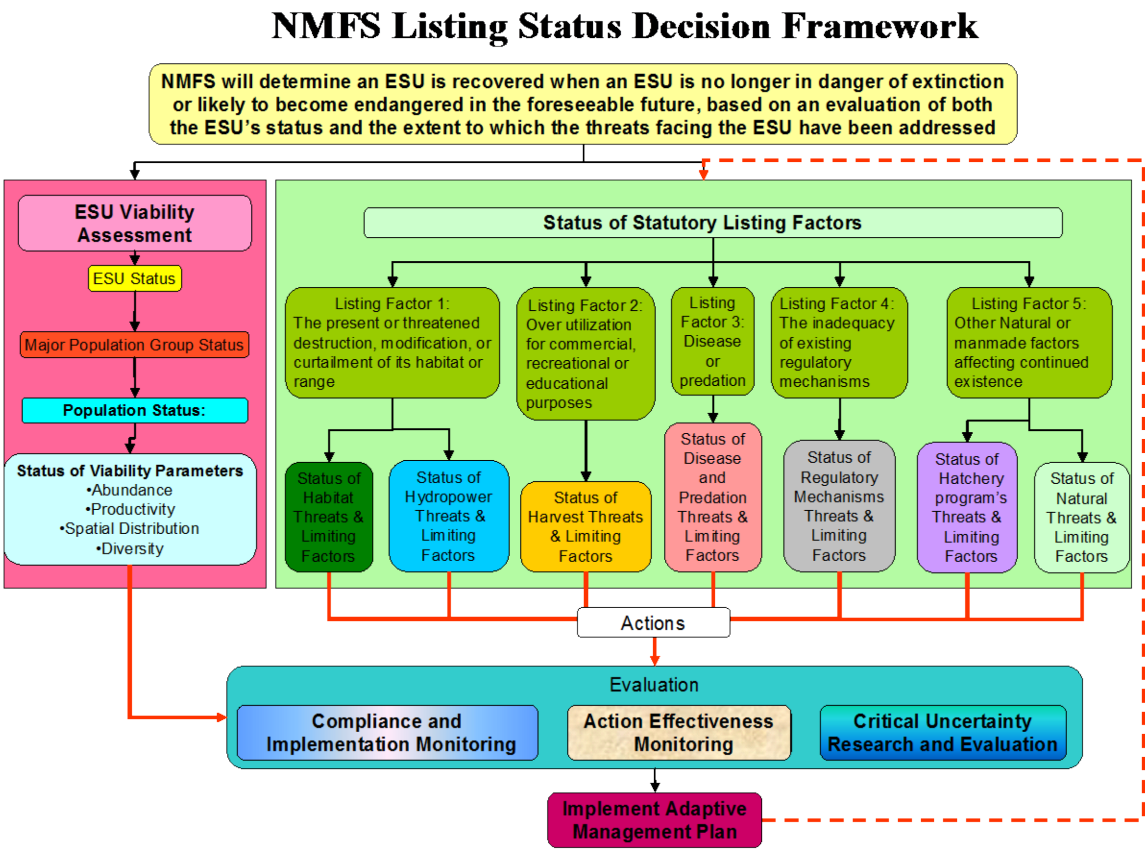

Figure B-1. Flow diagram outlining the decision framework used by NOAA Fisheries to assess the status of biological viability criteria and limiting factors criteria.

B.1.1 Types of Monitoring Efforts

Several types of monitoring are needed to support adaptive management and to allow managers to make sound decisions:

- **Status and Trend Monitoring.** Status monitoring describes the current state or condition of the population and their limiting factors at any given time. Trend monitoring tracks these conditions to provide a measure of the increasing, decreasing, or steady state of a status measure through time. Status and trend monitoring includes the collection of standardized information used to describe broad-scale trends over time. This information is the basis for evaluating the cumulative effects of actions on fish and their habitats.

- **Action Effectiveness Monitoring.** This type of monitoring addresses cause-and-effect. That is, action effectiveness monitoring is designed to determine whether a given action or suite of actions achieved the desired effect or goal. This type of monitoring is research oriented and therefore requires elements of experimental design (e.g., controls or reference conditions) that are not critical to other types of monitoring. Consequently, action effectiveness monitoring is usually designed on a case-by-case basis. Action effectiveness monitoring provides funding entities with information on benefit/cost ratios and resource managers with information on what actions or types of actions improved environmental and biological conditions.

- **Implementation and Compliance Monitoring**. Implementation and compliance monitoring determines if actions were carried out as planned and meet established benchmarks. This is generally carried out as an administrative review and does not require any parameter measurements. Information recorded under this type of monitoring includes the types of actions implemented, how many were implemented, where they were implemented, and how much area or stream length was affected by the action. Success is determined by comparing field notes with what was specified in the plans or proposals (detailed descriptions of engineering and design criteria). Implementation monitoring sets the stage for action effectiveness monitoring by demonstrating that the restoration actions were implemented correctly and followed the proposed design.

- **Critical Uncertainties Research**. Research of critical uncertainties includes scientific investigations of critical assumptions and unknowns that constrain effective recovery plan implementation. Uncertainties include unavailable pieces of information required for informed decision making, as well as studies to establish or verify cause-and-effect and identification and analysis of limiting factors.

B.1.2 Monitoring Framework and Objectives

The desired outcome of this recovery plan is the long-term persistence of naturally produced Snake River fall Chinook salmon. In order to determine if the desired outcome has been achieved, answers to two general questions are needed.

- Is the status of the ESU improving?
- Are the effects of the primary factors limiting the status of the ESU increasing, decreasing, or remaining stable?

Although these two general questions provide the basis for developing the RM&E plan, it is important to note that several specific objectives attend each of the two general questions. Below are listed the specific objectives.

1. Assess the status and trends in abundance and productivity of natural- and hatchery-origin fall Chinook salmon within the Lower Mainstem Snake River population.
2. Assess the status of the spatial structure of the Lower Mainstem Snake River fall Chinook salmon population based on current and historically used habitat.
3. Assess the status and trend in genetic and life history diversity of the Lower Mainstem Snake River fall Chinook salmon population.

4. Assess the status and trend of current and historically used adult holding, spawning, and juvenile rearing mainstem and tributary habitats used by Lower Mainstem Snake River fall Chinook salmon population.
5. Determine the effects of habitat limiting factors and associated management efforts in the major and minor spawning and rearing areas on the Lower Mainstem Snake River fall Chinook salmon population.
6. Determine the effects of federal hydropower operations and operational and structural improvements on the viability of Snake River fall Chinook salmon.
7. Determine the effects of ecological conditions in the estuary, plume, and near-shore ocean on the viability of Snake River fall Chinook salmon.
8. Determine the effects of physical and biological changes associated with climate change on the viability of Snake River fall Chinook salmon.
9. Determine the effects of harvest on the viability of Snake River fall Chinook salmon.
10. Determine the effect of disease, predation, prey base, competition, non-native species, and other ecological interactions on the viability of Snake River fall Chinook salmon.
11. Identify federal, state, tribal, and local regulatory mechanisms that conserve Snake River fall Chinook salmon and determine the adequacy of those regulatory mechanisms.
12. Determine the influence of hatchery supplementation programs on the viability of the natural population of Snake River fall Chinook salmon.
13. Develop life-cycle models to identify and assess potential factors that could limit the viability of Snake River fall Chinook salmon, including effects under current climate change projection scenarios.
14. Determine the influence of toxic contaminants on the viability of Snake River fall Chinook salmon.
15. Determine the feasibility of restoring passage to fall Chinook salmon populations in habitats upstream of the Hells Canyon Complex.

The following section addresses the needed RM&E for each of the monitoring objectives. The section provides background for each monitoring objective and identifies related monitoring questions. Discussions under each monitoring question describe why the questions are important and identify RM&E approaches (monitoring methods) and analyses needed to address them. They also discuss the current status of monitoring associated with the objective and identify gaps in monitoring. A gap is defined as any monitoring activity that is not funded and has not been implemented. Monitoring activities that have not yet been implemented but have funding and will occur in the future are not identified as gaps. These activities are described under status of monitoring.

The approaches and analyses described for each objective are not exhaustive, but are intended to represent those actions considered to have potential to be implemented while recognizing logistical and monetary constraints. In addition, for many of the monitoring needs, regional review (e.g., ISRP) and advances in monitoring techniques may suggest potentially different approaches and/or analyses. The intent of this RM&E plan is to highlight current RM&E and gaps that are important, and to help standardize approaches and analyses for monitoring and evaluation purposes.

B.2 Snake River Fall Chinook Salmon RM&E

As noted earlier, the overall goal of the RM&E Plan is to determine if the status of the ESU is improving and if the effects of the factors limiting the viability of the ESU are decreasing. This plan is designed to assess current monitoring efforts and test new strategies for the conservation of Snake River fall Chinook salmon. Several monitoring programs are already in place that measure the status of the population and several of its limiting factors. For example, current monitoring efforts include adult ladder counts, subsampling via adult trap, juvenile smolt indices and smolt condition, adult conversion rates, juvenile survival rates, assessments of avian predators, measurements of environmental parameters (e.g., project flow; spillway flow; forebay and tailrace total dissolved gas levels; forebay, tailrace, and scrollcase temperatures; and turbidity), juvenile dam passage performance evaluations, transportation evaluations, redd surveys, genetic sampling, tagging studies, fishery assessments, and there is an extensive plan to assess the supplementation program (Addendum to the Snake River Fall Chinook HGMPs, 2011). These monitoring programs, as they relate to each objective, are described below. Where there are gaps in monitoring, this plan intends to fill those gaps by building upon the existing monitoring efforts. Those additional efforts are also described below.

Objective 1: Assess the status and trends in abundance and productivity of natural- and hatchery-origin fall Chinook salmon within the Lower Mainstem Snake River population.

The viability status of a population is determined by estimating the VSP parameters shown in Figure A-1. The viability criteria are organized into two separate groupings: 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. Adult abundance is expressed as the most recent ten-year geometric mean natural-origin adult spawners. Natural return rates, or productivity, are estimated on a brood year basis as returns per spawner. Productivity is typically measured over a 20-year period. Estimating juvenile abundance at Lower Granite Dam will help to understand the influence of changes in density, environmental conditions, climate, harvest, supplementation, and other factors on productivity.

Monitoring Questions:

- What are the long-term status and trends in escapement of natural- and hatchery-origin adults to the spawning areas upstream of Lower Granite Dam?

- What are the long-term status and trends in abundance of natural- and hatchery-origin juveniles at Lower Granite Dam?
- What is the current estimate of intrinsic productivity for the Snake River Fall Chinook salmon population?

Below we describe the RM&E needed to address each monitoring question.

Monitoring Question (1a): What are the long-term status and trends in escapement of natural- and hatchery-origin adults to the spawning areas upstream of Lower Granite Dam?

This monitoring question focuses on generating annual estimates of natural- and hatchery-origin fall Chinook salmon that pass upstream of Lower Granite Dam to the spawning areas. Annual estimates of aggregate escapement into the spawning areas upstream from Lower Granite Dam are used to calculate standard metrics for recent average (geometric mean) adult escapement levels (total and natural origin), average hatchery proportions, and trends. Abundance is expressed as the most recent 5- and 10-year geometric mean natural-origin adult spawners. Trend in natural-origin spawners is calculated based on natural log transformed values. Standard metrics include the most recent 15-year trend and the trend since the time of listing. The inability to recover carcasses because of conditions prevalent in the large river spawning reaches used by Snake River fall Chinook salmon prevents direct estimation of area-specific hatchery and natural proportions.

> ***Approach (1a):*** Estimates of abundance are made from two data sources: (1) adult counts at Ice Harbor and Lower Granite Dams and (2) tag recoveries from broodstock trapping at the two dams. For the first source, adult counts at Ice Harbor are available from 1962 to present. Chinook salmon that pass Ice Harbor Dam from 12 August to 15 December are considered to be fall Chinook salmon. Adult counts at Lower Granite Dam are available from 1975 to present. Chinook salmon that pass that dam from 18 August to 15 December are considered to be fall Chinook salmon.
>
> Tag recoveries from broodstock trapped at the two dams provide the second source of data for estimating abundance. During the1976–1983 egg-bank program, coded wire tags (CWTs) were first implanted in smolts and recovered in returning adults collected at Ice Harbor Dam beginning in 1980 (Bugert et al. 1995). Collection of CWT data from egg-bank broodstock continued through 1984 when Lyons Ferry Hatchery became operational. Broodstock trapping was moved from Ice Harbor to Lower Granite Dam by the early 1990s. To provide the mark and tag recover data needed to break down the annual returns into natural-origin and hatchery-origin components, subsamples of fish are trapped daily and randomly throughout the run at a rate designed to meet hatchery broodstock needs based on the expected run size in a given year (Addendum to the Snake River Fall Chinook HGMPs, 2011). Minimizing effects on comingled returning Snake River steelhead listed under ESA is a constraint on trapping rates. The trapped fish are

transported back to Lyons Ferry Hatchery (since 1984) and Nez Perce Tribal Hatchery (since 2002). The fish are counted, measured, sexed, scale sampled (since 1998), and examined for tags (Young et al. 2012).

Analysis (1a): Before 1980, when hatchery adults began returning from the egg-bank releases of smolts, all of the adults counted at Ice Harbor and Lower Granite Dams were natural-origin fish. Mark recovery data on broodstock are used to allocate each daily ladder count by size, age, age-at-ocean entry, and parental origin (hatchery vs. natural parentage). Out-of-basin stray hatchery fish are also identified. Variations on this basic procedure have been used to reconstruct annual estimates of hatchery and natural returns to the Snake River since 1983. This procedure is known as "run reconstruction." Escapement of natural-origin adults upstream of the dam is calculated by subtracting the number of natural-origin fish taken back to the hatcheries for broodstock from the total number of natural-origin adults estimated to have arrived at the dam. The same calculation is made for hatchery-origin adults. The contributions to escapement upstream of Lower Granite Dam from direct releases at Lyons Ferry Hatchery and from out-of-basin sources are adjusted by applying a passive integrated transponder (PIT)-tag based annual fall back rate estimate.

Status (1a): Although the method for estimating annual spawning escapements is rigorous and standardized, the indirect method of estimating natural-origin returns based on subtraction does introduce uncertainty. Two approaches for independently evaluating aggregate run natural-origin return levels are possible: (1) Parental-Based Tagging (PBT) and (2) otolith microchemistry analysis (see Monitoring question 2b). Scale data for estimating age-at-ocean entry are available starting in 1998, but age-at-ocean entry has only been analyzed since 2005. Although the run reconstruction process is conceptually sound, the method generates indirect estimates of natural-origin returns and has varied over the years as it was developed. Applying the updated methodology to the 2000–2004 returns, a period of increasing contributions from off-station releases, has been identified as a priority. A standardized central data base of data used for run reconstruction during 1983–2013 will be developed. Run reconstruction is presently funded by the Bonneville Power Administration (BPA), Idaho Power Company, and the Lower Snake River Compensation Plan through the foreseeable future.

PBT marking of all Snake River hatchery program releases was initiated in 2012. Routinely employing PBT marking on an annual basis will allow for the independent assessment of contributions to adult returns for the predominant components of hatchery-origin fish. It will still be necessary to extrapolate to estimates of out-of-basin hatchery contributions based on CWT- or PIT-tag recoveries. A second method for validating the natural-origin vs. hatchery-origin proportions of each annual run arriving at Lower Granite Dam based on otolith microchemistry analysis is being tested in an ongoing short-term study described under Monitoring Question (1b).

Gaps (1a): There are no gaps for this monitoring question.

Monitoring Question (1b): What are the long-term status and trends in abundance of natural- and hatchery-origin juveniles at Lower Granite Dam?

Estimating juvenile abundance at Lower Granite Dam aids in understanding the influence of changes in density, environmental conditions, climate, harvest, supplementation, and other factors on productivity when coupled with results of Monitoring Question (1a) and used to answer Monitoring Question (1c).

Approach (1b): Answering this monitoring question requires data collection from the juvenile bypass at Lower Granite Dam. Such data have been collected since 1992. In concept, the approach for estimating juvenile abundance is similar to the approach for estimating adult abundance (Approach 1a). Randomly timed subsamples of river-run juveniles are routed into a sample tank by staff of the Smolt Monitoring Program from the juvenile bypass system at known rates. Age is subjectively determined, and tag and mark data are collected. Total counts of subyearlings are recorded daily. Genetic data for adjusting estimates of abundance for the presence of spring/summer Chinook salmon are made available through beach seining studies described under Objective 5. The Smolt Monitoring Program discontinues sampling fish from the bypass at the end of October. Water is not typically passed through the bypass of the dam from early December to late March. During those months, PIT-tagged fish cannot be detected and there are no fish sampled from the juvenile fish bypass system. Data for predicting passage for that time span were provided by a short-term radio-telemetry study conducted from October through December in 2010 and January through April in 2011 (Tiffan and Connor 2012).

Analysis (1b): Annual abundance of natural-origin fall Chinook salmon juveniles is estimated using a mark-recapture, expansion-subtraction method that will be submitted for publication. The mark-recovery data are used to estimate the daily number of hatchery-origin subyearlings collected by the Smolt Monitoring Program in the sample tank. Each of those daily estimates is subtracted from the total number of subyearlings collected on each corresponding day to estimate the daily number of natural-origin subyearlings collected in the sample tank. The estimated daily number of natural-origin subyearlings collected is multiplied by the percentage of natural-origin juveniles captured by beach seine in a given year that was determined to be fall-run lineage by genetic analyses. The resulting daily estimates of the number of natural- and hatchery-origin fall Chinook salmon in the sample tank are then expanded by corresponding daily sampling rates and estimated collection probabilities. Those two steps provide daily estimates of passage abundance for fish of each origin from March of year t through October of year t. Abundance of the remaining portion of late migrants is predicted separately by origin on a monthly time step (November of year t through April of year $t + 1$) using a regression model fitted from data collected by Tiffan and Connor (2012).

Status (1b): The process of estimating the abundance of natural- and hatchery-origin juveniles is continuing to be refined. Data collected at Lower Granite Dam when the juvenile bypass system is supplied with water and the Smolt Monitoring Program is operated are adequate to estimate abundance at the annual level as described above. BPA will provide funding for estimating abundance of natural-origin fall Chinook salmon subyearlings at Lower Granite Dam using the method outlined above from about 2016 to 2018 depending on when the next call for proposals is released. Tissue samples from juveniles collected during 2009–2014 have not been analyzed and no funding is presently slated. A simple method that uses body morphology independently of marks and tags (Tiffan and Connor 2011) is available for estimating juvenile origin at Lower Granite Dam and will be tested in 2014. In the absence of extended water up and smolt monitoring from early December through late March, it will be necessary to predict passage abundance during those months. The model for making those predictions was fitted with a single data set as described above. During 2006 and 2008 through 2012, the U.S. Army Corps of Engineers funded a study on transport and bypass when water was spilled at the Lower Snake River dams during summer (Marsh et al. 2007). An average of ≈ 270,000 hatchery fall Chinook salmon production subyearlings was tagged annually. The juvenile release portion of that study was completed in 2012 and given lack of full funding the number of hatchery fish tagged fell to ≈ 20,000.

Gaps (1b): Should the test for using body morphology prove successful in 2014, funding would be needed to use the approach in the future. Sample tank and PIT-tag data cannot be collected when the juvenile bypass system is routinely dewatered from early December through late March at Lower Granite Dam. Late passage could be largely accounted for if both the bypass was supplied with water and operation of the Smolt Monitoring Program was extended through December and was resumed the first of March. Funding for such an effort is lacking, and engineering and safety considerations might prohibit mid-to-late December operations. No funding is available for validating the model for predicting natural juvenile abundance when the bypass is dewatered. No funding is available to increase the number of hatchery subyearlings tagged annually, which influences the precision of the estimates of natural juvenile abundance.

Monitoring Question (1c): What is the current estimate of intrinsic productivity for the Snake River Fall Chinook salmon population?

This information is needed to assess the status of the population. The ICTRT approach pairs estimates of recent natural-origin abundance and productivity to compare population status against ICTRT viability criteria (ICTRT 2007). The ICTRT defines population-level intrinsic productivity as the average return per spawner at low to moderate spawning densities. The alternative viability criteria metrics described for Snake River Fall Chinook salmon in Section 4 of the Recovery Plan require estimates of productivity at either of two different spatial levels: (1) the aggregate population or (2) for a targeted set of one or more major spawning areas..

Approach (1c): Consistent with the alternative viability criteria metrics described for the species in Section 4 of the Recovery Plan, productivity (including a measure of statistical uncertainty) is estimated at the aggregate population level or for the one major spawning area. At the aggregate population level, intrinsic productivity is calculated based on ratios of estimated natural returns originating from the most recent 20-year series of total spawning escapements in the population of interest. Alternative methods for calculating aggregate population productivity include a standard simple approach and a model fitting approach. Both require a 20-year series of paired parent spawner and natural return estimates. In both cases the specific metrics called for in Section 4 of the Recovery Plan incorporate a measure of uncertainty in the estimate based on the year-to-year variability in the current 20-year data series. A similar set of metrics derived from the data series specific to targeted major spawning area is required to evaluate current status under the alternative single population criteria options described in Section 4. The inability to sample spawners in specific major spawning areas like the mainstem Snake River means that sub-area productivity estimates of annual abundance, hatchery/natural origin, and age structure must be extrapolated from other available data sets. Alternative methods of estimating intrinsic productivity may be appropriate or required in specific circumstances. For the Lower Snake River fall Chinook salmon population, answering this question requires the results produced by answering Monitoring Questions (1a) and (1c), data collected under Objectives 5 and 6, and other data that are available electronically.

Analysis (1c): Intrinsic productivity estimates at the aggregate population level or for a targeted major spawning area are derived from the corresponding most recent 20-year data series using basically the same procedures. For Snake River fall Chinook salmon , intrinsic productivity has been estimated using two procedures, the basic averaging method (ICTRT 2007) and by fitting stock-recruitment functions. Both methods generate point estimates and measures of statistical uncertainty in those estimates.

Under the simple averaging procedure, intrinsic productivity is calculated by taking the geometric mean of the brood year recruit to parent spawner ratios for those brood years in the most recent 20-year series where the parent escapement level fell below 75 percent of the minimum abundance threshold. The minimum abundance threshold for the Lower Snake River fall Chinook salmon population is 3,000 adult spawners; 75 percent of that level is 2,250. In addition to calculating the geometric mean, the standard error of that mean is also calculated. The alternative viability criteria metrics described in Section 4 in the Recovery Plan directly incorporate a probability of exceeding the target threshold level of 1 percent risk of quasi-extinction. The standard errors are estimating the relative probability that the current geometric mean intrinsic productivity exceeds a particular viability threshold.

For the Lower Snake River Fall Chinook salmon population, the low to moderate parent escapements in the most recent 20-year series are all from the earliest years. More recent year parent escapements consistently exceed the cut off level. Given the range of parent escapement levels in the data series, stock-recruitment curve fitting methods provide an alternative means of estimating intrinsic productivity using the information from the full data series. Estimates of intrinsic potential based on fitting stock recruit functions to the reconstructed return-per-spawner series are similar to the geometric mean results, but may also be subject to a high level of uncertainty given the lack of recent estimates at low to moderate parent abundance and uncertainties regarding the relative effects of the substantial number of hatchery-origin spawners.

Intrinsic productivity measures corresponding to the sub-area viability metric options could be estimated from a combination of aggregate and area specific data using the same mathematical procedures described below. Given the inability to sample carcasses to get direct information on age structure and hatchery/wild contribution rates for spawners in specific major spawning areas (e.g., the Hells Canyon Upper Mainstem major spawning area (MaSA)), indirect estimates of parent escapement and recruits would be based on area specific abundance (Monitoring Question 2a) and the aggregate population natural origin.

<u>Status (1c)</u>: Annual productivity estimates are derived from abundance, hatchery/wild composition, and natural-origin age structure estimates documented under Monitoring Questions 1a and 1b. Efforts are underway to develop a multi-life stage version of a stock recruitment model for Snake River fall Chinook salmon, incorporating additional information from annual monitoring programs aimed at juvenile life stages. The model under development may also incorporate results from analyses aimed at identifying common annual patterns in environmental and ocean conditions and their influences on Snake River fall Chinook salmon and other north migrating stocks (e.g., Hanford Reach and Deschutes River stocks). The development and testing of the multiple-stage life-cycle model will be funded by BPA through 2016–2018 depending on when the next call for proposals is released. Implementing the multi-stage assessment approach should reduce uncertainty associated with estimating productivity from adult-to-adult recruit data sets. However, the relatively high proportions of hatchery spawners contributing to recent brood years may still mask the actual potential natural intrinsic productivity of the population.

If future hatchery release strategies result in substantial reductions in one or more major spawning areas, it may be possible to generate estimates of intrinsic productivity for those areas that could be more representative of the underlying natural intrinsic potential of the population.

<u>Gaps (1c)</u>: Improvements in the available data sets on adult and juvenile abundance are outlined under the status section of Monitoring Question (1a) and gaps section of

Monitoring Question (1c). Development of a multi-stage life cycle model will provide a tool for estimating intrinsic productivity. It will also produce insights into potential density-dependent effects as a function of environmental conditions and provide a framework for evaluating the potential combined effects of management actions across life stages. Once fitted, the model will be used to assess "what if" scenarios. For example, changes in productivity resulting from changes in climate, harvest, and hatchery operations will be predicted. Staff availability for developing the model is limited, and would benefit greatly from collaboration through the Life Cycle Modeling initiative being carried out under the Adaptive Management Implementation Plan.

Objective 2: Assess the status of the spatial structure of the Lower Mainstem Snake River fall Chinook salmon population based on current and historically used habitat.

The major spawning areas of the Snake River basin fall Chinook salmon ESU identified by the TRT include the Hells Canyon Upper Mainstem reach (mainstem Snake River, Hells Canyon to Salmon River confluence), Lower Snake Lower Mainstem reach (Salmon River confluence to upper end of Lower Granite Reservoir), Lower Grande Ronde River, Lower Clearwater River, and the Lower Tucannon River. Based on redd counts, most spawners are associated with the Clearwater River and the upper and lower reaches of the Snake River mainstem. Attempts are also being made to restore the minor spawning aggregate in the lower Selway River, and to establish a minor spawning aggregate in the South Fork Clearwater River. Using estimated spawning escapement over Lower Granite Dam as a starting point, estimates of adult and/or juvenile abundance at other life stages (e.g., outmigrating smolts or returning adults at the Columbia River mouth, pre-harvest adult recruitment) can be derived using additional information on stage-specific survival rates. Specific approaches and analyses are not detailed for the Tucannon River under Objective 1 (or any other objective unless noted), but those described could be adapted for application to that spawning area.

Monitoring Questions:

- What are the long-term status and trends in estimates of spawning natural-origin adults in different spawning areas?
- How are estimates of the spawning distribution of natural-origin adults validated?

Monitoring Question (2a): What are the long-term status and trends in estimates of spawning natural-origin adults in different spawning areas?

It is highly unlikely that the proportion of hatchery-origin spawners is equal among the spawning areas as fidelity to the point of acclimation and release of hatchery adults and the numbers of hatchery smolts released varies among sites (Garcia et al. 2004; Connor 2014). Thus, the geographical distribution of redds does not accurately reflect the spatial distribution of natural-origin spawners. To fully inform managers of the status of the population relative to spatially explicit de-listing criteria, it will be necessary to estimate the spatial distribution of natural-origin spawners using an approach that accounts for the spatial distribution of hatchery-origin spawners. Below we describe two approaches that could be used to estimate the annual number of natural-origin adults that escaped to the individual spawning areas.

Approach (2a): The two approaches for answering this question require data collected under Monitoring Question (1a) coupled with data collected by cooperative redd surveys. Redd survey efforts were increased and became relatively standardized in 1993 (Groves et al. 2013). The redd surveys continue to be conducted. Radio-telemetry studies also have (Garcia et al. 2014) and are providing information on within-basin dispersal of returning hatchery-origin spawners.

Analysis (2a): The first method takes the run reconstruction estimates of the numbers of hatchery-origin females that returned from releases made into each spawning area (from Monitoring Question 1c), and adjusts them for within-basin dispersal. Assuming that sex ratio, pre-spawning mortality, and redd count accuracy are similar among spawning areas, and that each female constructed one redd, the number of hatchery-origin females estimated to have spawned in each area is subtracted from the observed redd count for that area. That difference represents the numbers of redds constructed by natural-origin females. To estimate the number of full-term (i.e., no jacks) adults that spawned in each area, the number of redds constructed by natural-origin females is multiplied by the ratio of full-term (i.e., no jacks) males to females for natural-origin adults from run reconstruction. The same calculation can be made to estimate the proportion of full-term hatchery adults that spawned in a given area.

The second method is more complicated, but it basically involves fitting a stock-recruitment model for each spawning area using redd counts in year t-4 as stock and redd counts in year t as recruits. Covariates including the number of hatchery juveniles released in year $t – 3$ are added to the model. Redd counts are predicted with each area-specific model using a value of 0 for the number of hatchery juveniles released. The number of redds predicted in each spawning area is divided by the total number of redds predicted basin-wide. Under the same assumptions of the first analytical method, those proportions are multiplied by the number of natural-origin females estimated to have passed upstream of Lower Granite Dam in a given year. Adjustments for sex ratios are made as previously described.

Status (2a): Both methods for evaluating the spawning distribution of natural-origin adults are under development and are planned to be applied to data collected during 1991–present. The first and second methods described will be funded by BPA through 2016–2018 depending on when the next call for proposals is released. Redd surveys are funded by the Idaho Power Company, and BPA directly, and through the Lower Snake River Compensation Plan until 2016 or the next call for proposals is made.

Gaps (2a): Development of the two methods needs to be completed.

Monitoring Question (2b): How are estimates of the spawning distribution of natural-origin adults validated?

The estimates of the spatial distribution of natural-origin spawners can be validated using otolith microchemistry (Hegg et al. 2013). Otolith microchemistry has the potential to become the primary process of tracking the spatial distribution of natural-origin spawners provided adequate samples of adults are trapped at Lower Granite Dam. It cannot be applied retrospectively.

Approach (2b): Attaining the empirical information that confirms origin, natal spawning area, overwintering location, and age-at-ocean entry of unmarked, untagged adults requires the collection of otoliths. Otoliths from returning adult fish have been collected from Lyons Ferry Hatchery since 2006 (N ~ 1400), and carcass collections in the Clearwater River in 2011 (N = 50). Otoliths have been collected from known natural-origin juveniles in the Snake River upper and lower reaches, and the lower Grande Ronde and Clearwater Rivers since 2010 (N = 96), PIT-tagged juveniles collected at Lower Granite Dam since 2007 (N ~ 100), and from unreleased hatchery mortalities at Lyons Ferry and Nez Perce Tribal Hatchery (N = 45). Otoliths are collected from all unmarked, untagged adults that are sampled and have the potential to be of either natural- or hatchery-origin. Chemical signatures unique to a given river reach are absorbed in the otolith as fish pass through that reach. Baseline water chemistry data are collected throughout the Snake River basin and portions of the Columbia River.

Analysis (2b): The otoliths are processed to reveal their sequential ring structure using abrasives. Chemical signatures are then recovered from the entire life of the fish (from the otolith core to its edge) using laser-ablation inductively coupled plasma mass spectrometry. Otolith microchemistry from each life stage is then analyzed using discriminant statistical models, which classify the otolith signature to the fish's likely location during that period. Discriminant classification models use baseline water samples to tie chemical signatures in otoliths to their geographical location within the basin. The accuracy of chemical signatures is validated using samples with known chemistry. Classification analyses are validated using known-origin juvenile fish.

Status (2b): The research on otolith microchemistry is a short-term effort with the potential for long-term application pending the outcome of ongoing research. Over the last three years, funding has been adequate to maximize the collection of unmarked, untagged broodstock trapped and transported to Lower Granite Dam and transported to Lyons Ferry Hatchery. The otolith study is funded by grants obtained from the University of Idaho, U.S. Army Corps of Engineers, and BPA through 2016–2018 depending on when BPA calls for proposals.

Gaps (2b): Results from the otolith microchemistry study could be applied to samples of unmarked, untagged adults collected for run reconstruction in future years to help refine and validate the run reconstruction approach. No funding is available for such a long-term effort.

Objective 3: Assess the status and trend in genetic and life history diversity of the Lower Mainstem Snake River fall Chinook salmon population.

Snake River fall Chinook salmon production may be influenced by local habitat conditions, releases of hatchery fish, hydropower operations, climate change, and many other natural and man-made factors. These influences may be expressed as changes in the pattern or overall level of diversity at both the genomic and life history levels. Therefore, monitoring diversity at both levels and understanding its implications for long-term population sustainability and productivity is critical. The hatchery programs have considerable potential to affect genetic and life history diversity, but can also affect the population in a variety of other ways. Thus, effects of the hatchery program are explicitly considered as a separate objective (Objective 11). However, there will obviously be considerable overlap between activities associated with this objective and those associated with Objective 11. Many genetic monitoring methods will be identical or nearly so to those used for status monitoring of many other populations, but some methods will be customized because of logistical constraints imposed by population biology or management. In addition, some measures may address concerns specific to this population. A case in point is monitoring diversity genetic diversity among MaSAs. Currently our ability to measure several important aspects of genetic change is very limited, but significant advances are expected within the next few years. Monitoring of life history diversity could be extended to other traits in the future as their importance becomes evident, but currently interest in life history diversity is limited to juvenile outmigration age. Understanding the relative contribution of environmental factors and genetic mechanisms to the relative proportions of juveniles exhibiting subyearling or yearling ocean entry is important for evaluating current diversity status as well as for determining how management operations or actions may affect the population. Smolt sampling indicates that most of the natural-origin juveniles from the Snake River drainage migrate seaward early and enter the ocean as subyearlings, whereas most of the natural-origin juveniles in the Clearwater River drainage migrate late and enter the ocean as yearlings.

Monitoring questions:

- What is the status of genetic diversity in the Lower Mainstem Snake River fall Chinook salmon population?
    - Status and trend of population effective size
    - Status and trend of overall diversity (heterozygosity, allelic richness, etc.)
    - Status and trend of genetic differentiation among MaSAs (e.g. F_{ST})
    - Status and trend of gene flow from other populations

  - o Status and trend of genomic indicators of important life-history traits

- What is the status and trend in the age-at-ocean entry of natural- and hatchery-origin adults that escape to the spawning grounds?
- What are the relative contributions of the subyearling and overwintering life history patterns to natural production?

Monitoring Question (3a): What is the status of genetic diversity in the Lower Mainstem Snake River fall Chinook salmon population?

Answering this monitoring question will help to determine if and how the genetic composition of the aggregate natural run is changing over time in terms of basic diversity metrics, initial level of differentiation among MaSAs and how it changes, and how the population may be changing genetically at key life history traits. The suite of measures thus allows for the standard whole genome assessment of diversity, but also allows for assessing life-history changes at the genetic level. It also addresses a key issue specific to recovery of this population, which is subpopulation structure. Note, however, that this objective does not include evaluation of all the genetic effects of the hatchery program. Specifically, it does not include the genetic impact to productivity through hatchery-influenced selection. That is covered under Objective 12.

> ***<u>Approach (3a)</u>:*** Systematic biological sampling of adult returns at the Lower Granite Dam trap and at the Lyons Ferry Hatchery trap is the basis for genetic monitoring of Snake River fall Chinook salmon production. Genetic samples from individual fish taken as potential broodstock at Lower Granite Dam, or from volitional entry into the Lyons Ferry Hatchery, are used to remove out-of-basin fish from the Snake River hatchery programs. Estimates of the potential proportions of out-of-basin stocks in annual spawning escapements into natural production areas is based on that same sampling data, after incorporating expansions for any associated unmarked fish from those release groups. Given the difficulty in obtaining samples from spawners in specific major spawning areas (e.g., the mainstems of the Snake, Clearwater, and Grand Ronde Rivers), efforts are underway to gain inferences from a combination of less direct information including radio tracking known origin returns, otolith micro-chemistry analysis (see Monitoring Question 2b), and PBT marking (Objective 2).
>
> ***<u>Analysis (3a)</u>:*** The overall genetic indicators can be estimated in a straightforward fashion from DNA samples, and trends can easily be tracked. Indicators related to differentiation among MaSAs cannot be done until MaSA of origin is known (through tracking or microchemistry), but if origin is known, calculation of metrics and tracking of trends is straightforward.
>
> Out-of-basin hatchery stock contribution estimates are made annually using the information generated by the run reconstruction procedures (see Objective 1). Out-of-basin stocks are assumed to "fall back" below Lower Granite Dam at the same annual

rates as returns from direct releases at the Lyons Ferry Hatchery (downstream of Lower Monumental Dam). The lack of reach-specific carcass recoveries has prevented direct analysis of within-population genetic structure for the population.

Trends in genomic indicators indicative of life history traits can in theory be done via quantitative trait loci (QTL) analysis once the QTLs are identified.

Status (3a): Overall genetic indicators have been and are being measured. Methods for development of reliable indicators of MaSA origin are underway. QTL methods are in development in several regional labs, but design of a monitoring plan awaits selection of traits and match up with appropriate QTLs.

Annual monitoring of out-of-basin stock contributions to annual escapements is a routine component of annual escapement estimation procedures. Approaches for evaluating genetic substructure of natural production are being explored. It may be possible to gain some insights into current genetic substructure through analysis of returns that can be assigned to large-scale production areas using the recently developed otolith technology (see Monitoring Question 2b). In addition, there is some potential for using genetic analyses of naturally produced juveniles from the Clearwater and Mainstem Snake Rivers to evaluate patterns over time.

An objective of the ongoing supplementation programs is to increase natural production from the Clearwater River drainage, including establishing natural production in reaches of the South Fork Clearwater River and the mainstem downstream of the Lochsa River (areas that likely supported an early timed spawning pattern historically). Current supplementation efforts in the Clearwater River are using the aggregate run broodstock collected at Lower Granite Dam. Conditions in the Lower Clearwater River are generally colder than in the mainstem Snake River, resulting in a prolonged incubation and early rearing life-history phase. Such conditions should favor earlier spawn timing compared to the Snake River mainstem. Ongoing monitoring of redd deposition timing and juvenile emergence and outmigration should allow for identifying local adaptations. If such patterns emerge, sampling of juveniles could verify a genetic basis.

Gaps (3a): Obtaining direct samples representative of natural production from specific subareas supporting the bulk of spawning and rearing within the population has not been possible to date. Efforts should continue to develop methods for identifying the level of genetic diversity among major spawning areas and tracking it over time. While direct sampling-based methods would be preferable, indirect methods taking advantage of otolith marking or other means of assigning fish sampled from the aggregate run to particular subareas should be explored.

Monitoring Question (3b): What is the status and trend in the age-at-ocean entry of natural- and hatchery-origin adults that escape to the spawning grounds?

Answering this question will provide information for evaluating the status and trend of the population relative to diversity criteria (e.g., the proportion of the natural population that enters the ocean at age-0 is stable or increasing).

> ***Approach (3b):*** Answering this question relies on data collected under Monitoring Question (1a) and relies on data collected from 1998 to present, the years when scale samples were taken from trapped adults.
>
> ***Analysis (3b):*** The numbers of natural- and hatchery-origin adults that arrive at the dam each year are estimated down to the levels of sex, total age, age-at-ocean entry, and release location in the case of hatchery fish (see Monitoring Question (1a) for more details). For earlier return years (1998 to 2004), scale pattern analysis was used to estimate age-at-ocean entry and origin for a subsample of adults collected at Lower Granite Dam (Connor et al. 2005), and the proportions of subyearling and yearling ocean entrants in those subsamples were expanded for the total runs. After 2005, scale pattern analysis continued to be used to estimate age-ocean-entry, but origin is determined by tag expansion and subtraction.
>
> ***Status (3b):*** The run reconstruction workgroup, which developed and applied updated methods to the 2005-to-present return years, plans to apply the updated escapement estimation framework to earlier years starting with the 2000 to 2004 series. As a result, estimates of hatchery and natural returns for each of those years, including the alternative estimates of natural-origin age proportions, may be updated. Applying that approach to 1998 and 1999 is less likely to result in changes in abundance or age structure estimates and therefore is currently a lower priority, but would nevertheless be useful.
>
> ***Gaps (3b):*** Routine validation or cross-checking using results of otolith microchemistry would be useful, but that method is under development and there are no plans for future implementation. Longer term monitoring and the associated analysis of production broken out by the two pathways may require additional funding.

Monitoring Question (3c): What are the relative contributions of the subyearling and overwintering life history patterns to natural production?

Understanding the relative contribution of environmental factors and genetic mechanisms to the relative proportions of juveniles exhibiting each of the basic life-history pathways is important for evaluating current diversity status as well as for determining how management operations or actions might affect the population. In addition to estimates of the contributions of the alternative pathways to adult returns, information on the production of subyearling and yearling outmigrants and their life stage survivals provides valuable insights. Estimating outmigrant smolt production by pathway and geographic area (e.g., Snake River upper and lower reaches versus lower Clearwater River) requires added monitoring and analysis. Smolt sampling indicates that most of the natural-origin juveniles from the Snake River drainage migrate seaward early and enter the ocean as subyearlings, whereas most of the natural-origin juveniles in the Clearwater River drainage migrate late and enter the ocean as yearlings.

Approach (3c): The data for answering this question are as follows. The numbers of natural- and hatchery-origin adults that spawn in the Snake and Clearwater River drainages are estimated under Monitoring Question (2a). The numbers of early and late migrating natural-origin juveniles at Lower Granite Dam are estimated under Monitoring Question (1c). Data are available for brood years 1991 to present.

Analysis (3c): The first step in this analysis is to break the annual estimates of natural-origin juvenile abundance provided by Monitoring Question (1c) into early and late migrants. A logistic regression model was fitted (Connor et al. 2015) from the known PIT-tag detection histories of the mixed-origin adults that predicted any fish that passed downstream in the lower Snake River reservoirs before 2 August had less than a 50 percent probability of becoming a yearling ocean entrant, whereas any fish that past thereafter had a 50 percent probability or higher of becoming a yearling ocean entrant. Summing the daily estimates of abundance produced under Monitoring Question (1c) from March through July separately by origin will provide annual estimates of abundance for early migrants presumed to enter the ocean as subyearlings. Summing the daily estimates of abundance from August of year t through April of year $t + 1$ by origin provides an annual estimate of abundance for late migrants assumed to enter the ocean as yearlings.

The remainder of this analysis will follow the analysis described under Monitoring Question (1c) with the following exceptions. Two stock-recruitment analyses will be conducted. The first analysis will use the number of natural- and hatchery-origin adults estimated to have spawned in the Snake River drainage as “stock” in the stock-recruitment analysis and the number of early migrating juveniles estimated to have passed Lower Granite Dam as “recruits.” The second analysis will use the number of natural- and hatchery-origin adults estimated to have spawned in the Clearwater River as “stock” and the number of late migrating juveniles estimated to have passed the dam as “recruits.”

Status (3c): The status of issues pertaining to this monitoring question is the same as the status of Monitoring Question (1c) with one exception. Completing the population-level analysis under Monitoring Question (1c) is the present priority. Developing the estimated production and survival estimates by subyearling overwintering life history patterns is currently being carried out as part of the development of a two-stage life cycle model.

Gaps (3c): See Monitoring Question (1c). Completing the analyses on the two population aggregates may not be complete if BPA funding is not provided beyond 2016.

Objective 4: Assess the status and trend of current and historically used adult holding, spawning, and juvenile rearing mainstem and tributary habitats used by Lower Mainstem Snake River fall Chinook salmon population.

Each of the spawning areas (see Objective 2) functions as a holding and rearing area. In addition, Lower Granite Reservoir is likely a holding area for returning adults prior to spawning, and fry and parr rear along the reservoir shorelines. Every juvenile spends some time feeding and growing within the reservoir before migrating seaward. An important part of this objective is to determine whether cool-water releases from Dworshak Dam maintain adequate migration conditions for adults destined for spawning areas upstream of Lower Granite Dam. Pursuing that question would also be compatible with proposals to alleviate both elevated temperatures and low stream flows in affected streams such as the Tucannon River during autumn by increasing shade through riparian restoration and managing water withdrawals to maintain as high a flow as possible. Assessment of spawning and rearing carrying capacity is also an important component of this objective.

Monitoring Questions:

- What is the current understanding of adult fall Chinook salmon holding habitat quantity and quality within major and minor spawning areas?
- What is the status and trend in fall Chinook salmon spawning and incubation habitat quantity and quality within major and minor spawning areas?
- What is the status and trend in fall Chinook salmon rearing habitat quantity and quality within major and minor spawning areas?

Monitoring Question (4a): What is the current understanding of adult fall Chinook salmon holding habitat quantity and quality within major and minor spawning areas?

The answer to this monitoring question would establish if cool-water releases from Dworshak Dam maintain adequate migration conditions for adults destined for spawning areas upstream of Lower Granite Dam. Pursuing that answer would also be compatible with proposals to alleviate both elevated temperatures and low stream flows in affected streams such as the Tucannon River during autumn by increasing shade through riparian restoration and managing water withdrawals to maintain as high a flow as possible. Activities associated with this monitoring question would include the evaluation of potential restorative actions identified early in the Recovery Plan including: (1) changes in structures or operations at Lower Granite Dam to address adult passage blockages caused by warm surface waters entering the fish ladders and (2) other actions to reduce September water temperatures for adult migration and passage at Lower Granite Dam.

Approach (4a): Established flow gaging stations provide the flow data required to evaluate flow-related changes in holding habitat of all adults destined for all of the spawning areas. The most important variable affecting holding habitat quantity and quality is likely temperature, because immigration begins in late summer. Temperature is measured throughout the year in every priority spawning area through a combination of thermographs and gaging stations. Temperature data have been and are also being collected by deploying strings of vertically spaced thermographs throughout Lower Granite Reservoir to evaluate thermal stratification throughout the summer. The U.S. Army Corps of Engineers measures reservoir flow, temperature, water transparency, and dissolved gas levels at Lower Granite Dam.

Analysis (4a): Cook et al. (2006) used flow data, water quality monitoring station data, and vertical temperature measurements to calibrate a 3-D temperature model that could be used to simulate the availability of temperature refuge from the confluence of the Clearwater River to Lower Granite Dam during adult holding in August and September.

Status (4a): Adequate temperature and flow data will be collected through the foreseeable future.

Gaps (4a): The availability of cool-water refuge in the Tucannon River and all areas upstream of the Clearwater River confluence, and upstream of the North Fork Clearwater River, is poorly understood. There is currently no funding to assess the availability of cool-water refugia or to determine its current importance or level of use by adults.

Monitoring Question (4b): What is the status and trend in fall Chinook salmon spawning and incubation habitat quantity and quality within major and minor spawning areas?

Answering this question would provide information on the carrying capacity of spawning habitat. It would also address key information needs including: (1) whether the Hells Canyon Complex could be operated to further benefit fall Chinook salmon egg incubation, (2) whether spawning and rearing conditions and survival could be improved by increasing water quantity and quality while reducing sediment delivery in the lower Grande Ronde River, and (3) what are the high priority opportunities to restore adaptive spawn timing patterns in the lower reaches of the Selway, and South Fork Clearwater Rivers.

Approach (4b): See Monitoring Question (4a) for details on the collection of flow and temperature data. There are also detailed stage-discharge and river bathymetry data sets available for a subset of spawning and rearing sites along the Snake River upper and lower reaches (Connor et al. 2001), and the lower Clearwater River (Arnsberg et al. 1992). Detailed data focusing on sediment processes that affect spawning and rearing habitat quantity and quality are being collected along the Snake River upper reach. Limited data on spawning and rearing habitat availability have been collected in the Grande Ronde, Selway, South Fork Clearwater, and Tucannon Rivers (B. D. Arnsberg, unpublished data). Substrate composition, temperature, and dissolved oxygen levels have been measured at known spawning sites along the Snake River upper and lower reaches and the lower Clearwater River (Arnsberg et al. 1992; Bennett et al. 2003; Geist et al. 2006).

Analysis (4b): Spawning habitat data collected in the Snake River upper and lower reaches and in the lower Clearwater River have been analyzed using the Instream Flow Incremental Methodology (IFIM), 2-D hydrodynamic habitat/flow models, and GIS. Substrate composition, temperature, and dissolved oxygen levels were related to egg-to-fry survival either by direct observation or laboratory study (see above references).

Status (4b): To date, spatially explicit estimates of spawning habitat, as they relate to flow, have been made at select sites along the Snake River upper and lower reaches and the lower Clearwater River. Discharge at Hells Canyon Dam is held stable during the spawning period, and a flow level to protect the shallowest redd is determined annually. Flows do not drop below this level during the incubation period. Upon issuance of a FERC license for the Hells Canyon Complex, the Idaho Power Company will continue this monitoring in both reaches of the Snake River at approximate 5-year intervals to assess egg-to-fry survival and quantity and quality of spawning habitats. Data collected on sediment processes that affect spawning habitat quantity in the Snake River upper reach will be analyzed to quantify changes in the quantity of both spawning and rearing habitat. BPA, the Idaho Power Company, and the U. S. Army Corps of Engineers funded the studies that produced estimates of the spawning habitat area in the primary areas. Those studies are complete. Funding of stream gaging and the collection of water quality data will depend on Federal, State, and private sources, but complete flow, temperature, and dissolved gas monitoring are expected at a minimum. The Idaho Power Company began collecting and analyzing data focusing on sediment processes that affect spawning and rearing habitat quantity and quality in 2008, and that effort will continue through the life of the next FERC license associated with the Hells Canyon Complex.

Gaps (4b): The methods for estimating spawning habitat area were not standardized between the Snake and Clearwater Rivers. Analyses of spawning habitat data collected along the Grande Ronde, Selway, and South Fork Clearwater Rivers are incomplete. Habitat area in the Tucannon River has not been measured. No information on egg-to-fry survival as it relates to substrate quality is available for the Selway, South Fork, or Tucannon Rivers. No information on the effects of ice formation and associated scouring on egg-to-fry survival is available for spawning areas that freeze and thaw or are subject to prolonged exposure of eggs and fry to very cold temperatures during the spawning and incubation periods including the Grande Ronde, Selway, and South Fork Rivers. Overall, a common data collection (or mining) program has not been coupled with a standard modeling framework (e.g., GIS) to either establish present habitat status or monitor long-term trends across the spawning areas of interest. Funding for such an effort is not currently available.

Monitoring Question (4c): What is the status and trend in fall Chinook salmon rearing habitat quantity and quality within major and minor spawning areas?

Answering this question will provide a standardized assessment of rearing habitat in the major and minor spawning areas that is currently lacking especially in the Grande Ronde, Selway, South Fork Clearwater, and Tucannon Rivers. Such a program could be coupled with a standard modeling framework to establish the present status of habitat threats and limiting factors (Figure B-1).

> ***Approach (4c):*** The relevant data collection procedures for answering this question have already been covered previously under Objective 4 and noting that the environmental status reflected in those data sets are of equal importance across the life stages. Here, additional data collection is described that spans the progression of life stages in some cases. Data for fitting a 1-D hydrodynamic flow model with complete channel bathymetry and stage-discharge data for the upper Snake River reach were collected by the Idaho Power Company. The 1-D flow model also extends through the lower Snake River reach, but the associated bathymetry is limited. Monitoring of entrapment pools are conducted weekly from 15 March through the completion of rearing in the upper Snake River reach. Temperature is monitored in the high use entrapment pools. The data on channel morphology, vegetation, substrate, velocity, and temperature needed to estimate rearing habitat quantity in Lower Granite Reservoir have been collected through various studies funded by the U. S. Army Corps of Engineers. Water surface elevation that influences rearing habitat availability in Lower Granite Reservoir is measured daily.
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> The relationship between total dissolved gas and spill levels at Hells Canyon Dam has been developed by the Idaho Power Company. Upon issuance of a FERC license for the Hells Canyon Complex, flow deflectors will be installed at spill gates, and a Total Dissolved Gas monitoring plan will be developed. Total dissolved gas levels are monitored daily in the Snake River lower reach at the Anatone Gage, in the North Fork Clearwater River (tributary to the lower Clearwater River) at Dworshak Dam, and at Lewiston, Idaho. Sediment samples are collected about every five years in the Selway and South Fork Clearwater Rivers. Temperature and dissolved oxygen are measured at the Hells Canyon Dam penstocks at 10-minute intervals by the Idaho Power Company. In addition, water quality trend monitoring is occurring at the Hells Canyon Dam boat launch. Measurements occur at two-week intervals and include Nitrate, Ammonia, Total Kjeldahl Nitrogen, Ortho Phosphate, Total Phosphate, Total Organic Carbon, Dissolved Organic Carbon, Chlorophyll A, Total Suspended Solids, Volatile Suspended Solids, Temperature, Dissolved Oxygen, pH, conductivity, and turbidity.
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> Temperature, pH, fecal coliform bacteria, dissolved oxygen, and nutrient and sediment loads along the Snake River lower reach and the lower Tucannon River are measured monthly. Temperature, dissolved oxygen (percent saturation and concentration),

biochemical oxygen demand, pH, total solids, ammonia and nitrate nitrogen, total phosphorus, and bacteria are measured every other month in the Grande Ronde River, but sediment data are lacking. The Nez Perce Tribe Water Resources Department conducts water quality sampling in the Lower Clearwater including Potlatch Mill's effluent that extends into the lower Snake River. Temperature, total dissolved gas levels, and sechi-disk transparency are measured daily in Lower Granite Dam forebay. Sediment samples and measurements of dissolved oxygen have been collected on an "as needed basis" in Lower Granite Reservoir.

Analysis (4c): The 1-D hydrodynamic flow model is used during the monitoring of entrapment pools by the Idaho Power Company during the rearing period to assess the timing and distribution of flows relative to changes in flow at Hell Canyon Dam. Discharge data from Hells Canyon Dam were also related empirically to the channel elevations of juvenile entrapment and stranding areas within rearing habitats in the upper Snake River and is monitored daily during the rearing period to reduce potential effects to juveniles entrapped in pools that are separated from the main channel during periods of load following at Hells Canyon Dam. Operational protocols at Hells Canyon Dam have been established to reconnect entrapment pools daily. A short-term IFIM study conducted along the Clearwater River related rearing habitat to flow and temperature (Arnsberg et al. 1992).

Status (4c): Data collected on the quantity of rearing habitat in the Snake River upper and lower reaches and Lower Granite Reservoir have been entered into a GIS database by the Idaho Power Company. All of the ongoing work on rearing habitat quantity (and quality with the exception of water quality sampling outside of the Snake River upper reach) is funded by the Idaho Power Company, and those efforts will continue through the life of the next FERC license associated with the Hells Canyon Complex. Much of the ongoing work on rearing habitat in the lower Clearwater River and Lower Granite Reservoir was funded by BPA and the U.S. Corps of Engineers. Those short-term studies have been completed. Water quality sampling in Lower Granite Reservoir will likely take place when reservoir dredging is being planned or implemented.

Gaps (4c): Only limited habitat quantity and quality data have been collected in the Tucannon River. The methods for estimating rearing habitat area were not standardized between the Snake (mostly upper reach) and lower Clearwater Rivers. Limited data on rearing habitat quantity and quality have been collected in the Grande Ronde, Selway, and South Fork Clearwater Rivers by the Nez Perce Tribe Department of Fisheries Resources Management. Rearing habitat quantity and quality in the Tucannon River have not been measured. Sampling of mercury is inadequate to assess the status of the riverine portions of all spawning areas except for the Snake River upper reach. As is the case with spawning and incubation habitat, no attempt has been made to determine how the information summarized here could be supplemented (i.e., crucial gaps identified and filled) and then used in a standardized fashion across the primary areas to depict the present status of the habitats. As such, a common data collection (or mining) program has not been coupled with a standard modeling framework to either establish present rearing habitat status or monitor long-term trends across the rearing areas. Funding for such an effort is not presently available.

Objective 5: Determine the effects of habitat limiting factors and associated management efforts in the major and minor spawning and rearing areas on the Lower Mainstem Snake River fall Chinook salmon population.

The abundance, survival, and productivity of Snake River fall Chinook salmon are affected by the quantity and quality of spawning and rearing habitat. As described in Section 5 of the Recovery Plan, spawning and rearing habitat is currently affected by reduced outflow and water quality, low dissolved oxygen levels in late summer and fall, elevated total dissolved gas (TDG) levels in winter and spring, and altered thermal regime. As a result, there could be lower survival for fall Chinook salmon due to delayed emergence and higher mortality for rearing juveniles and gas bubble disease. Also, altered flows (on a seasonal, daily, and hourly basis) result in altered migration patterns, and juvenile fish stranding and entrapment. Interruption of geomorphological processes (entrapment of sediment) results in potential reductions in spawning gravels and reduced turbidity that increases predation. Lower Granite Dam forebay and ladder temperatures may influence ladder ascension and fall back rates of migrating adult salmon. An important priority under this objective will be the documentation of historical and current mean levels and annual variation in pre-spawning survival and egg viability. That information will dictate how much effort is needed to evaluate the factors affecting pre-spawning mortality. In addition, a full evaluation of spawner-to-pre-smolt survival will inform restorative actions such as gravel monitoring and management in the Hells Canyon reach of the Snake River and the identification and evaluation of potential measures to increase juvenile survival in the mainstem Snake River major spawning areas.

Monitoring Questions:

- How do environmental and behavioral factors influence pre-spawning survival and egg viability?
- What is the current understanding of factors limiting spawner-to-pre-smolt productivity?
- How do environmental and behavioral factors during rearing and early seaward migration influence growth, emigration size, survival, emigration, and age-at-seaward entry?
- Have management actions directed at mainstem and tributary habitat conditions improved adult-to-pre-smolt productivity of Snake River Fall Chinook salmon?

Monitoring Question (5a): How do environmental and behavioral factors influence pre-spawning survival and egg viability?

Current thermal regimes in Lower Granite Reservoir and some spawning areas may be reducing pre-spawning survival and egg viability. Evaluations of structures or operations at Lower Granite Dam are needed to address adult passage blockages caused by warm surface waters entering the fish ladders. In addition evaluation of actions to reduce September water temperatures for adult migration and passage at Lower Granite Dam and actions to improve the quality of water discharged (dissolved oxygen) from the Hells Canyon Complex as called for in NMFS recommendations for the Hells Canyon FERC Relicensing are needed (NMFS 2006). Thus, the first priorities under this monitoring question will be the documentation of historical and current mean levels and annual variation in pre-spawning survival and egg viability. That information will dictate how much effort is needed to evaluate the factors affecting pre-spawning mortality. If warranted, a full evaluation of whether current September and October temperatures significantly affect pre-spawning survival rates and gamete viability would provide information on existing protective actions including cool-water releases at Dworshak Dam, as well as the effectiveness of the actions described above.

Approach (5a): Published radio-telemetry studies can be reviewed to evaluate movement behavior of adults and pre-spawning survival (Garcia et al. 2004; Connor and Garcia 2006). Carcasses that are recovered annually on the spawning grounds of the lower Clearwater and Tucannon Rivers (Nez Perce Tribe Department of Fisheries Resources Management; Washington Department of Fish and Wildlife) provide additional information on pre-spawning mortality. Studies are available on egg-to-fry survival as affected by temperature, oxygen, and sediment levels (Arnsberg et al. 1992; Bennett et al. 2003; Geist et al. 2006). Environmental data are also collected as described under Objective 4 if future field studies are conducted.

Analysis (5a): Pre-spawning survival could be crudely assessed by calculating the percentage of the adults (mostly hatchery) that had been radio tagged but were never detected entering a spawning area after release; however, the resulting numbers could be biased by tag loss and non-functional tags. Pre-spawning mortality could also be assessed based on the percentage of eggs retained in carcasses of females recovered along the lower Clearwater and Tucannon Rivers. Field and lab studies could be reviewed to document survival of eggs from fertilization as influenced by temperature, oxygen, and sediment levels.

Status (5a): To date, no direct observation or analysis has demonstrated excessively low levels of pre-spawning survival or reductions in egg viability associated with environmental or movement behaviors. However, neither of the radio-telemetry studies conducted was designed to evaluate pre-spawning mortality. Evaluating egg retention in carcasses collected in the Clearwater and Tucannon Rivers as an index of pre-spawning mortality has not been completed, but it would not provide any information on females and males that died prior to arriving on the spawning grounds, or on pre-spawning mortality in the other spawning areas where fish have to swim longer distances under warmer conditions. Gametes for field and lab studies conducted to evaluate egg-to-fry survival did not fully experience ambient environmental conditions in the river because they were collected from adults held in cool water at hatcheries before spawning.

Gaps (5a): The fine-scale information that can be obtained using modern radio-telemetry technology that records physiological status, mortality, and environmental experiences over time and space is not available. Information on gamete viability as affected by immigration experience of adults is also lacking. Presently there is no funding available for more detailed studies.

Monitoring Question (5b): What is the current understanding of factors limiting spawner to pre-smolt productivity?

A full evaluation of spawner-to-pre-smolt survival would inform restorative actions including a gravel monitoring and management plan in the Hells Canyon reach of the Snake River (FERC 2007) and the identification and evaluation of potential measures to increase juvenile survival in the mainstem Snake River major spawning areas.

Approach (5b): After adults reach spawning areas, potential factors limiting spawner-to-pre-smolt productivity (offspring per female) include redd superimposition (one or more redds are constructed on top of others), egg consumption by predators, and predation after fry emergence. Different methods are being used to evaluate spawner-to-pre-smolt productivity. First, redd surveys are conducted annually in all of the primary areas. In addition, UAS (Unmanned Aircraft Systems) equipped with high resolution cameras are being tested as a supplemental redd survey method on the Snake River upper and lower reaches and the Clearwater River. Together with traditional aerial surveys, deep-water camera surveys, and on-the-ground surveys, video recordings taken from the UAS provide data for assessing redd-superimposition. One short-term study on predation has been completed (Nelle 1999), and another short-term study on predation by smallmouth bass is ongoing (BPA project 199102900). Estimates of spawner abundance in the Snake River upper and lower reaches made under Monitoring Question (2a) and apparent abundance under Monitoring Question (5c) provide information for evaluating spawner-to-pre-smolt productivity.

Analysis (5b): The density-dependent nature of the relationship between pre-smolt production and parent spawner abundance can be evaluated by fitting functional relationships to annual estimates of the two parameters, paired on a brood-year basis. Both the completed and ongoing short-term studies estimate abundance of smallmouth bass along the Snake River upper and lower reaches, diet composition, and loss of subyearling Chinook salmon to predation.

Status (5b): Information on redd superimposition as a potential factor limiting spawner-to-pre-smolt survival is evolving but is not fully adequate. Analyses conducted to establish the relationship between spawner escapement and pre-smolt abundance are underway. Funding for the redd and juvenile surveys in the major and minor spawning areas, except for the Tucannon River, is presently provided by the Idaho Power Company and BPA. Funding from the Idaho Power Company is expected to continue through the term of the next FERC license for the Hells Canyon Complex and funding from BPA for the period 2016 to 2018 depends on when the next call for proposals is released. The UAS project is funded entirely by the Idaho Power Company. There is potential to modify existing BPA projects to obtain additional funding. Data collection in the Tucannon River is provided by the Lower Snake River Compensation Plan through the foreseeable future. The predation and stock-recruitment analyses are funded by BPA through 2016–2018 depending on when the next call for proposals is made. The completed short-term study on predation suggested that predation was not a factor limiting spawner-to-pre-smolt survival under low prey densities (Nelle 1999), whereas the ongoing study conducted under high prey densities is continuing to be developed.

Gaps (5b): Analyses conducted to establish the relationship between spawner escapement and pre-smolt abundance are lacking in all spawning areas except for the Snake River upper and lower reaches. Field studies on egg loss because of superimposition in recent years as spawner density has increased have not been conducted in any spawning area. The spatial and temporal coverage of the smallmouth bass predation studies are limited largely due to logistics and funding level. Predation on eggs by sturgeon in the Snake River upper and lower reaches has been observed, but the understanding of such predation as a factor affecting spawner-to-pre-smolt productivity is lacking.

Monitoring Question (5c): How do environmental and behavioral factors during rearing and early seaward migration influence growth, emigration size, survival, emigration, and age-at-seaward entry?

Answering this question will inform Limiting Factor 5 under the NMFS Listing Status Decision Framework (Figure B-1) by helping to determine how hatchery supplementation and natural environmental variability influence important phenotypic traits of the population. In turn, annual measures of those traits will be useful as covariates when developing life cycle models under Objective 12. The information generated along with the life cycle modeling assessments will provide important insights into how survivals during this life stage have changed relative to those prevalent at the time of listing.

Approach (5c): Various types of information on density, food availability, and environmental conditions as potential limiting factors on juvenile growth, emigration size, emigration timing, and survival are available in the major and minor spawning and rearing areas in the Snake River drainage downstream of Hells Canyon Dam. Environmental data are collected as described under Objective 4. Ongoing beach seining and PIT-tagging efforts along the Snake River upper and lower reaches by the U. S. Fish and Wildlife Service and U.S. Geological Survey under BPA projects 199102900 and 200203200 have produced information on all aspects of this monitoring question since 1992 (Connor et al. 1998, 2002, 2003a, 2003b, 2005, 2012, 2013; Connor and Burge 2003; Venditti et al. 2000; Tiffan et al. 2003, 2009a, 2009b, 2012, 2014). A companion beach seining and PIT-tagging study has been conducted along the lower Clearwater River by the Nez Perce Tribe Department of Fisheries Resources Management. Smolt traps are operated on the lower Grande Ronde and Tucannon Rivers and juveniles are counted, measured, and PIT tagged by the Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife. Data are collected on PIT-tagged and river-run juveniles passing through the bypass at Lower Granite Dam when the bypass is supplied with water from late March through late fall (PTAGIS 2014). Advances have also been made in an otolith-based approach to understand the factors affecting age-at-seaward entry (see Monitoring Question 1b).

Analysis (5c): The data collected under the beach seining and PIT-tagging study of the Snake River upper and lower reaches has and can be analyzed to evaluate the influence of apparent density, flow, and temperature on parr growth, size at dispersal from riverine to impounded habitat, parr-to-smolt growth (intermittently), and emigration timing at Lower Granite Dam. The influence of temperature, flow, and growth on survival of PIT-tagged, natural-origin Snake River juveniles to the tailrace of Lower Granite Dam has and can be statistically tested.

Radio-telemetry studies have documented the relation between downstream rate of movement and velocity in free-flowing and impounded reaches along the Snake River lower reach and Lower Granite Dam, and behavioral thermoregulation in Lower Granite Reservoir. Diets of fish in the Snake River lower reach and Lower Granite Reservoir have been compared. Growth and migration behavior in the reservoir have been documented in the short-term. Winter passage of juveniles at the Lower Snake River dams has also been confirmed. See the references listed under Approach (5c) for details.

Data collected by beach seining along the lower Clearwater River is analyzed primarily to document emigration timing at Lower Granite Dam, noting that an unknown portion of passage is not represented when the bypass is dewatered before the end of December.

The smolt traps on the lower Grande Ronde and Tucannon Rivers provide some information on migrant size and time of dispersal from the rivers to points downstream and passage timing at dams.

Otoliths collected from adults are being sectioned to count growth rings and are being chemically analyzed to describe time of fish presence at specific locations between fry emergence and ocean entry. Stage-structured life history modeling will be used to understand how location-specific growth was affected by location-specific temperature, and how the temperatures experienced by the fish during incubation, rearing, and seaward migration varied between subyearling and yearling ocean entrants (Hegg and Kennedy 2013).

Status (5c): Information collected during the long-term beach seining and PIT-tagging study conducted under BPA project 199102900 along the Snake River upper and lower reaches provides adequate information for evaluating the long-term status and trends of juvenile growth, emigration size, emigration timing, and survival as affected by the potential limiting factors density, food availability, flow, and temperature. That study is funded by BPA through 2016 to 2018 depending on when the next call for proposals is released.

Adequate information was provided by radio-telemetry studies on the relation between downstream rate of movement and velocity in free-flowing and impounded reaches along the Snake River lower reach and Lower Granite Dam, and behavioral thermoregulation in Lower Granite Reservoir.

Data collected during the long-term beach seining and PIT-tagging study conducted along the lower Clearwater River by the Nez Perce Tribe Department of Fisheries Resources Management is affected by difficult sampling logistics, but those data do provide the existing information on natural fall Chinook salmon in the lower Clearwater River that could be analyzed in more detail. The long-term study of the lower Clearwater River is also funded by BPA through 2016 to 2018 depending on when the next call for proposals is released.

Juvenile sampling efforts in the Grande Ronde, Selway, South Fork Clearwater, and Tucannon Rivers are challenged by difficult logistics, and by low juvenile abundances at present levels of use in two Clearwater River tributaries. Should the decision be made to increase sampling effort in those areas, funding is not presently available.

A short-term beach seining and PIT-tagging study conducted in Lower Granite Reservoir (Tiffan and Connor 2012) provided similar information to that provided by the long-term study in the Snake River upper and lower reaches. However, beach seining and PIT tagging in the reservoir was only funded for one year and there is no present discussion of renewing that study.

The status of the otolith study is covered under Monitoring Question 1b.

Gaps (5c): No information on juveniles is collected in the Selway and South Fork Clearwater Rivers. Long-term information on aspects of juvenile life history, growth, and survival in Lower Granite Reservoir is lacking. Passage of PIT-tagged fish when the juvenile fish bypass system is dewatered and over the spillways cannot currently be monitored.

Monitoring Question (5d): Have management actions directed at mainstem and tributary habitat conditions improved adult to pre-smolt productivity of Snake River Fall Chinook salmon?

Current activities identified in Section 6 of the Recovery Plan include reservoir management operations targeting mainstem flow and temperatures and Hells Canyon operations to stabilize flow conditions during spawning, prevent redd dewatering losses, and to avoid juvenile entrapment.

Approach (5d): The Fish Passage Advisory Committee makes technical recommendations on federal water management activities (e.g., spring refill, summer drafts to augment flows and reduce temperatures) in the Snake River basin after considering technical information (e.g., flows, temperatures, fish passage distribution, etc.) from spring through mid-September. The recommendations are, if adopted, implemented by the U.S. Army Corps of Engineers and the U. S. Bureau of Reclamation. The Idaho Power Company participates by refilling reservoirs in the spring and augmenting flows during the summer consistent with agreements associated with the licensing of the Hells Canyon Complex. Studies have been conducted to evaluate the efficacy of summer flow augmentation on adults and juveniles. The Idaho Power Company stabilizes flows from Hells Canyon Complex during spawning and manages them thereafter to prevent redd dewatering and extended periods of juvenile entrapment. Short-term studies have been conducted to evaluate egg-to-fry survival as influenced by temperature, dissolved oxygen, and sediment, and the influence of stranding and entrapment conditions on juvenile survival, both of which affect spawner-to-pre-smolt productivity.

Analysis (5d): The Fish Passage Center writes annual reports that compare recommended and realized operations to manage flow and temperature in Lower Granite Reservoir. The effectiveness of managing flows and temperatures in Lower Granite Reservoir on juveniles has frequently been assessed using data collected on Snake River juveniles that largely represent the earliest seaward migrants including a portion of the fish from the Grande Ronde River. Short-term studies documented the influence of environmental conditions on egg-to-fry survival (but see Status 5a and Gaps 5a) and juvenile stranding and entrapment. The Idaho Power Company monitors flows from Hells Canyon Complex to prevent redd dewatering and limit the effects of juvenile entrapment that would otherwise decrease spawner-to-pre-smolt productivity in the Snake River upper and lower reaches.

Status (5d): Compliance monitoring of flow and temperature management programs in the Snake River drainage are adequate. Compliance programs are funded by BPA and the Idaho Power Company, and funding will likely continue. The effectiveness of flow monitoring to prevent redd dewatering and juvenile stranding and entrapment is adequate in the Snake River upper and lower reaches. Such flow monitoring is expected to be funded by the Idaho Power Company through the term of the next FERC license for the Hells Canyon Complex.

Gaps (5d): A process of monitoring the effectiveness of managing flow and temperature with the intent to assess pre-spawning mortality is contingent of the answer to Monitoring Question 5a. Currently, such a process is not in place. Although it has been well established that juvenile fall Chinook salmon are present and moving downstream in the Lower Snake River reservoirs during late fall, winter, and early spring when the juvenile fish bypass systems are dewatered (Tiffan et al. 2012), there are no water management or compliance programs for such late migrants because an estimate of their abundance is presently lacking (but see Monitoring Question 1c).

Objective 6: Determine the effects of federal hydropower operations and operational and structural improvements on the viability of Snake River fall Chinook salmon.

Spawning and rearing habitat for both extant and historic populations of Snake River fall Chinook salmon lies upstream of mainstem Columbia River and Snake River hydroelectric projects. As a result, emigrating juveniles and returning adults must migrate past up to eight mainstem dams. Migrants are affected by mainstem dams both directly (e.g., injuries or mortalities occurring at a particular dam and reservoir) and indirectly (e.g., altered flows or water quality parameters that are also strongly influenced by upstream water storage project operations and agricultural, municipal, and industrial water management activities). Monitoring is essential for assessing the effect of management actions at the mainstem dams (or at upstream water storage projects) on passage conditions, and the migration timing and survival of migrating juvenile and adult fall Chinook salmon.

Monitoring Questions:

- What is the timing and duration of juvenile and adult fall Chinook salmon passage through the mainstem hydropower projects?
- What is the effect of hydropower operations (including transportation) on naturally produced Snake River fall Chinook salmon emigrants using subyearling and freshwater overwintering migration pathways?
- What is the effect of Columbia River hydropower operations on returning adult Snake River Fall Chinook salmon as they migrate upstream to natal spawning reaches?
- What are the effects of Columbia River hydropower operations on flow, temperature, total dissolved gas levels, and turbidity in the Snake and Columbia River mainstems?

Monitoring Question (6a): What is the timing and duration of juvenile and adult fall Chinook salmon passage through the mainstem hydropower projects?

Answering this question will provide information on the effect of management actions at the mainstem dams (or at upstream water storage projects) on the migration timing of migrating juvenile and adult fall Chinook salmon and thereby inform managers about the efficacy of management actions taken to date and the "current" status of hydropower threats and limiting factors (Figure B-1).

> ***Approach (6a):*** Smolt monitoring indices, adult ladder counts, and juvenile and adult PIT-tag detections in the Columbia and Snake Rivers provide managers with high quality information regarding the timing and duration of juvenile and adult fall Chinook salmon passage through the eight mainstem Columbia and Snake River hydropower dams.
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> ***Analysis (6a):*** Smolt monitoring indices, adult ladder counts and ladder counts, and PIT-tag detections are updated each day throughout the primary migration seasons of juvenile and adult fall Chinook salmon. This information is summarized annually and can be used to assess if substantial changes in migration timing or duration are changing over time. PIT-tag information also provides migration rate information for individual fish between dams with detection systems.
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> ***Status (6a):*** With one exception identified under Gaps (6a), current monitoring activities (e.g., smolt monitoring, adult ladder counts, and PIT-tag detection evaluations) are expected to continue indefinitely. Monitoring of the migration timing and duration of juvenile and adult fall Chinook salmon passage is currently sufficient to assess significant changes in these parameters in the future, should they occur.
>
> ***Gaps (6a):*** Turbine intake screens are removed at the mainstem dams for maintenance and to prevent ice from damaging the juvenile bypass systems. Before 2006, the screens were typically removed at the end of October and reinstalled at the end of March depending on the dam. Screen removals were delayed starting in 2006 until about mid-December and that schedule greatly increased coverage of the juvenile fall Chinook salmon migration from the Clearwater River (an average of 37.0% ± 7.0% of the Clearwater River juveniles that passed Lower Granite Dam during 2006–2012 passed during extended bypass operations; Connor et al. 2014). In 2011-2012 (2010 brood year), 6.0 percent of natural-origin fall Chinook salmon juveniles passed Lower Granite Dam in November and December, and 2.4 percent passed in January through March (Connor 2014). Juvenile salmon that survive over the summer and migrate in the fall or winter have relatively high smolt-to-adult returns (SARs) and contribute substantially and consistently to adult returns (20 to 40 percent of all returning adults (2008 to 2012

returns[1]) were yearling ocean entrants), especially those from the Clearwater River spawning aggregate (Connor 2014). Delaying the removal of turbine intake screens until as late as possible in December and reinstalling them as early as possible in March, combined with continued collection of PIT-tag and smolt passage data would reduce turbine passage of migrants from the ESU and increase data for RM&E. However, safety and the risk of equipment failure during the normal bypass season are important considerations, as screen or juvenile bypass system failures could negatively impact not only juvenile fall Chinook salmon, but the other ESA-listed Snake River species as well.

Monitoring Question (6b): What is the effect of hydropower operations (including transportation) on naturally produced Snake River fall Chinook salmon emigrants using subyearling and freshwater overwintering migration pathways?

Since the early 1990's, there have been a series of changes to hydropower operations aimed at improving the survival of out-migrating fall Chinook salmon. Identifying survival rates associated with current hydropower operations and contrasting those with rates that were prevalent at the time of listing is a high priority. Answering this question will help to evaluate the efficacy of recent structural and operational improvements, and the "current" status of hydropower threats and limiting factors (Figure B-1). Additionally, since 2010, between 30 percent and 56 percent of "hatchery" and 41 percent and 61 percent of "wild" subyearling Chinook salmon smolts were collected at Snake River dams and transported via barge or by truck to below Bonneville Dam (FPC 2013, Annual Report, Appendix G, Table G.9). Assessing the seasonal efficacy of transportation will provide managers with substantially better information on which to base future transport decisions. The information gained from this effort should also provide insights on the potential for additional survival improvements.

Approach (6b): Juvenile survival and ongoing transportation studies provide managers with sufficient information to assess the effect of hydropower operations from April through mid-November (when juvenile bypass systems are operating) and transportation from late April to mid-November (when transportation is occurring at the three Snake River collector and transport dams).

Analysis (6b): Juvenile Dam Performance Standard evaluations use run-of-river fish and are generally sufficient to assess passage and survival at individual dams. Smolt indices and PIT-tag detections are used to estimate survival rates of juvenile fall Chinook salmon (primarily of hatchery-produced fish used as surrogates) migrating through longer reaches (primarily Lower Granite to McNary Dams) of the impounded Snake and Columbia Rivers.

[1] The years 2008-2012 best represent "recent" hydropower operations that would have affected the 2005 and subsequent outmigrations.

<u>Status (6b)</u>: Juvenile Dam Passage Standard performance evaluations are expected to be completed by 2018 at all eight mainstem dams. Smolt indices have been generated for over 20 years and are expected to continue indefinitely at key locations. Similarly, hatchery fish and naturally produced juveniles seined at rearing areas in the Snake and Clearwater rivers have been PIT tagged since the late 1990s and these efforts are expected to continue into the foreseeable future. This information should continue to provide limited survival and passage behavior information.

<u>Gaps (6b)</u>: Relatively few naturally produced juveniles are PIT tagged annually, substantially limiting the ability of managers to estimate survival rates through longer reaches of the mainstem Columbia and Snake Rivers. Increasing tagging or increasing downstream detection rates would substantially improve the ability of managers to assess the effects of the hydropower projects on naturally produced juveniles (as opposed to hatchery surrogates, which have primarily been used for this purpose to date).

Little information is available regarding the effect of hydropower operations on juvenile fall Chinook salmon that choose to overwinter in the Snake River reservoirs. Information on mortality due to turbine passage during the late fall and winter months (many studies have been conducted during the spring and early summer) would be informative and provide a baseline of comparison for assessing survival improvements resulting from scheduled replacement of existing turbine units with newly developed units designed to minimize impacts to juvenile salmon and steelhead.

Monitoring Question (6c): What is the effect of Columbia River hydropower operations on returning adult Snake River Fall Chinook salmon as they migrate upstream to natal spawning reaches?

Answering this question will provide estimates of adult mortality associated with hydropower operations and support an assessment of the status of hydropower threats and limiting factors (Figure B-1).

<u>Approach (6c)</u>: Adult ladder counts and PIT-tag detections provide sufficient information to assess passage survival through the mainstem Columbia and Snake River dams.

<u>Analysis (6c)</u>: Both adult ladder counts and PIT-tag detections from within the adult ladders are used by managers to estimate passage timing and survival rates between dams or through longer reaches of the impounded Columbia and Snake Rivers. The use of ladder counts is generally more limited than for PIT tag because (1) ladder counts are unable to differentiate fish stocks (e.g., Upper Columbia summer/fall Chinook salmon from Snake River fall Chinook salmon, from Deschutes River fall Chinook salmon), (2) ladder counts only differentiate between mini-jacks, jacks, and adults whereas PIT tags indicate the overall ages of fish, and (3) ladder counts are estimates expanded from human counters whereas PIT tags in the ladders operate 24 hours each day throughout the migration period and detect nearly 100 percent of the tagged adults using the ladder systems.

Status (6c): Ladder counts have occurred at each of the mainstem dams since they were constructed (1938 for Bonneville Dam to 1975 for Lower Granite Dam) and are expected to continue unless regional managers no longer support collecting this information at specific dams. PIT-tag detection systems continue to be installed in the mainstem fish ladders. At this time, only John Day Dam does not have adult detection systems. PIT-tag detectors at Little Goose, Lower Monumental, and The Dalles Dams are considered to be temporary systems at this time. However, these systems are proving to be relatively inexpensive, surprisingly durable, and extremely valuable to fish managers so it is likely that these systems will continue to operate for many years into the future as configured or installed permanently.

Gaps (6c): In addition to adult losses caused by the hydropower system or from natural mortalities, adult fall Chinook salmon are harvested at substantial rates in the Columbia and Snake Rivers in accordance with ESA-permitted tribal and recreational fisheries. Historically, these fisheries have relied heavily on dam counts and estimated fish landings to assess harvest effects on individual stocks of fall Chinook salmon. Increasingly, PIT tags are being used to more finely assess hydropower-related losses in these reaches. Substantially increasing the number of PIT-tag detections from harvested fish (either from tribal, recreational, or downstream commercial fisheries) would allow improvements and refinements to reach survival estimates based on PIT tags and would improve assessments of hydropower effects.

Monitoring Question (6d): What are the effects of Columbia River hydropower operations on flow, temperature, total dissolved gas levels, and turbidity in the Snake and Columbia River mainstems?

Answering this question will provide the data to populate models, inform project operations on an hourly, daily, or seasonal basis, and assess whether operations and structures are achieving management goals, including those established directly for fish and water quality standards.

Approach (6d): Flow and water quality information is collected in the forebays and tailraces of each of the mainstem dams through either automated systems (e.g., flow, temperature, total dissolved gas) or human observation (e.g., turbine scrollcase temperatures, turbidity).

Analysis (6d): The Corps of Engineers has developed temperature and total dissolved gas models to assess alternative operations and comply with water quality permits (i.e. total dissolved gas waivers issued by the states of Idaho, Oregon, and Washington); meet broader management goals (i.e., maintain temperatures in the Snake River at 20°C or less for adult migrants using cool-water releases at Dworshak Dam); or operational requirements (i.e., power generation and spill volumes or rates for juvenile fish passage).

Status (6d): Flow and water quality information has been collected for decades and is expected to continue for the foreseeable future.

Gaps (6d): There are no monitoring gaps for this monitoring question.

Objective 7: Determine the effects of ecological conditions in the estuary, plume, and near-shore ocean on the viability of Snake River fall Chinook salmon.

Regardless of the age at ocean entry, Snake River fall Chinook salmon will use the estuary, plume, and near-shore ocean environments for rearing and migration. Thus, factors that affect these environments will also have some effect on the viability of fall Chinook salmon. For example, diking and other structural alterations, combined with flow management, have reduced access to juvenile rearing habitat for fall Chinook salmon in the estuary, and led to reduced macrodetritus production (the base of the food web) and prey availability. Large releases of hatchery fish may compete with natural-origin fish for food and space in the estuary when they overlap in space and time. In addition, fall Chinook salmon are lost to fish, bird, and marine mammal predators in the estuary. Finally, climate variability may affect growth and survival within the estuary, plume, and near-shore ocean environments. Thus, it is important to monitor these conditions to understand their effects on the status of the species.

Monitoring Questions:

- What are the effects of habitat conditions in the estuary on the growth, condition, and survival of juvenile Snake River fall Chinook salmon?
- What are the effects of habitat conditions in the plume on the growth, condition, and survival of juvenile Snake River fall Chinook salmon?
- When taking into account all the hatchery and wild fish in the estuary, plume, and near-shore ocean, is density dependence influencing the survival of Snake River fall Chinook salmon?

Monitoring Question (7a): What are the effects of habitat conditions in the estuary on the growth and survival of juvenile Snake River fall Chinook salmon?

Subyearling Snake River fall Chinook salmon use shallow-water habitats downstream of Bonneville Dam (Roegner et al. 2013) and derive direct benefits from these areas (e.g., food and water quality adequate for growth and the physiological transition to salt water; refuge from predators). Less is known about yearling fall Chinook salmon. Based on preliminary data for spring/summer Chinook salmon, these larger juveniles also may forage in or near wetlands or consume insects and amphipods transported from shallow water habitats to the main channel.

Additional data on feeding and prey selection, combined with information on the migration timing and residency of juvenile and adult Snake River fall Chinook salmon passing through the lower Columbia River and associated near-shore habitats, will help NMFS determine how habitat restoration actions downstream from Bonneville Dam contribute to the recovery of the ESU.

Approach (7a): Here the approach is to monitor juvenile (subyearling and yearling) Snake River fall Chinook salmon habitat use and consumption of invertebrate prey in selected mainstem and off-channel habitats. Use PIT-tag detection stations at selected off-channel sites in the upper estuary (Lewis River confluence to the tailrace of Bonneville Dam)[2] to monitor the presence of Snake River fall Chinook salmon in these areas. Use otoliths from adults returning to the Snake River basin to reconstruct juvenile size and time of estuary entry, duration of estuary residence, and growth.

Analysis (7a): Analyze the stomach contents and the presence of trophically transmitted parasites[3] in juvenile Snake River fall Chinook salmon collected at both shallow water beach seine and deep water purse seine sites below Bonneville Dam. Count and identify invertebrate taxa from benthic and terrestrial samples to identify habitat sources of these prey items. Analyze the strontium isotopic signatures of otoliths collected from adult Snake River fall Chinook salmon to quantify periods of juvenile rearing and growth in the tidal freshwater estuary.

Status (7a): Teel et al. (2014) described the temporal and spatial patterns of Chinook salmon stock distribution throughout the estuary based on bimonthly beach seine catches during 2010 through 2012. They observed small numbers of Snake River fall Chinook salmon at shallow water sites in the upper estuary, particularly during late summer. Finer scale surveys initiated during 2012 found Snake River fall Chinook salmon in Multnomah Channel as well as the mainstem river (Roegner et al. 2013).[4] In addition, (Roegner et al. 2013) identified a diversity of ESA-listed Interior ESUs, including Snake River fall Chinook salmon, entering vegetated wetland channels in the mid- and upper estuary (downstream of Longview and near the south end of Sauvie Island) when they operated a series of PIT-tag detection stations in 2011 through 2013. The number of stocks they identified increased as they added more PIT-tag monitoring stations. Finally, examination of otoliths collected from adult fall Chinook salmon returning to selected Columbia River subbasins has indicated differences in the size and time of estuarine

[2] During 2010-2012 surveys, Teel et al. (2014) captured higher proportions of Snake River fall Chinook, identified through genetics testing, in the upper estuary (Reaches E-H) than further downstream (Reaches A-D).
[3] Trophically transmitted parasites persist in the guts and abdominal cavities of the juvenile salmonid host for months to years, so provide a longer history of the individual's feeding habitats that stomach contents. Yearling Chinook captured in the lower estuary that contain marine obligate parasites of this type have consumed prey in the lower estuarine reaches, providing evidence of the value of lower river habitat to their growth and condition.
[4] Comprehensive sampling in the upper estuary was discontinued after 2013. Additional Chinook salmon tissue samples were collected in 2013 and 2014 for genetic stock identification, but these have not yet been analyzed.

entry among a diversity of upriver Chinook salmon stocks (Roegner et al. 2013), but the researchers have not analyzed any otoliths from adult Snake River fall Chinook salmon.

Gaps (7a): Previous surveys are too coarse to distinguish the finer details of Snake River fall Chinook salmon life history and habitat use in the estuary. Neither gut contents, prey resources, nor trophically transmitted parasites have been sampled systematically enough to identify the food resources that support subyearling or yearling Snake River fall Chinook salmon downstream from Bonneville Dam. Distinct strontium isotopic signatures of water samples collected above and below the Willamette River confluence hold promise as an otolith marker for the timing of juvenile fish entry into the tidal-fresh estuary. However, further sampling of water and fish will be required to develop and validate the method for Snake River fall Chinook salmon. If successful, the otolith technique would provide a tool to understand the estuary's contribution to returning adults. The stomach, trophically transmitted parasites, and prey availability results, in turn, will identify the biological resources and habitats within the estuary that support Snake River fall Chinook salmon.

Monitoring Question (7b): What are the effects of habitat conditions in the plume on survival of juvenile Snake River fall Chinook salmon?

The timing and magnitude of mainstem flows during June and July, when juvenile Snake River fall Chinook move from interior spawning areas to the ocean, have been drastically altered by management of flows in the Columbia River basin for flood control and power production (Figure 5.1-2 in NMFS 2008a). There are close physical connections between the river, estuary, and ocean that can affect biological processes, but these relationships can be complex. Two sets of relationships that appear to affect juvenile survival and thus merit further investigation are: (1) connections between river flow and the distribution and abundance of forage fishes in the estuary and plume (bottom up processes), and (2) bird and fish predation on juvenile salmonids (top down control). With respect to the latter, several studies (Pearcy 1992; Rechisky et al. 2009; Tomaro et al. 2012; Miller et al. 2013; Brosnan et al. 2014; Zamon, unpublished data) suggest that there is significant mortality in the estuary and along the coast of the Long Beach Peninsula, Washington, and that predation, especially by birds, might be a major factor in these areas.

Approach (7b): The prey field available to Chinook salmon in near-surface waters of the plume is studied with towed plankton nets. Collections begin in May, when yearling Chinook (including some from the Snake River fall Chinook ESU) and some subyearlings (mostly hatchery-origin fish) enter the plume. They are repeated in June, when a mixture of yearlings and subyearlings are caught, and then in September when only subyearlings are present (Peterson et al. 2014a, Teel et al. 2015). Thus far, there has been little work on predation outside the mouth of the Columbia, but this factor could be studied with visual observations and gut contents in the case of seabirds, and trawls, hook-and-line fishing, and acoustics in the case of piscivorous fish. Researchers collect basic chemical and physical oceanographic data at each station including depth, temperature, salinity, density, dissolved oxygen, chlorophyll, and nutrients. These data are used to describe the currents and water masses affecting the distribution of juvenile salmonids, their predators, and prey. Juvenile salmon may be less vulnerable to predation when the biomass of other small forage fishes (e.g., anchovies, sardines, and smelts) increases. Hypothetically, the biomass of all forage fishes is higher during cold ocean conditions when their zooplankton prey are abundant, but researchers have not studied these interactions.

Analysis (7b): Analyses of juvenile fall Chinook salmon include basic morphometric measurements and observations of hatchery marks or tags, blood for growth hormone levels, otoliths for growth rates, and gut contents for prey. The plankton sampled from the prey field are identified to the lowest possible taxon, and for each, estimates are made of the density per cubic meter of water sampled.

Status (7b): Juvenile Snake River fall Chinook salmon are generally captured in nearshore waters during May through September. As described above, some differences are observed in the timing of capture between yearlings and subyearlings and between hatchery and natural-origin fish.[5] There are indications that year-class strength is set during their first summer in the ocean—years when plankton such as euphausiids and crab larvae are eaten correlate well to adult returns two years later at Bonneville Dam (Peterson et al. 2014b, Dale et al. 2015).

Gaps (7b): Our understanding of the factors that affect the survival of Snake River fall Chinook salmon during early ocean residency would be improved by more information on fish and avian predators:

- Very few data exist on predation levels by fish or birds outside the mouth of the river, how these rates vary through space and time, and the role of alternative prey (such as anchovy) in predation rates on salmonids. Size and condition of salmon caught in coastal surveys suggest that there usually is enough food to prevent starvation (although reduced growth rates could play a role through size-dependent vulnerability to predators). This suggests that mortality during early ocean residence is predation-based.
- What oceanographic factors influence the presence of fish and avian predators and alternative prey fields during June through September when juvenile Snake River fall Chinook are in nearshore waters and to what degree does this affect year class strength and adult returns?

[5] Initial data from purse seine collections in the lower estuary also show that hatchery-origin subyearlings leave the river a month earlier than their natural-origin counterparts, corresponding with the information obtained from the nearshore trawl stations (Weitkamp et al. 2015).

Monitoring Question (7c): When taking into account all the hatchery and wild fish in the estuary, plume, and near-shore ocean, is density dependence influencing the survival of Snake River fall Chinook salmon?

The estuary has undergone significant changes—where historically there were marshes, wetlands, and side channels along the river that provided salmon with food and refuge, most of these shallow water habitats have been diked and filled for agricultural, industrial, and other uses (NMFS 2011b). Little is known about the potential for density dependence in the estuary between natural-origin salmonids and hatchery releases in this modified system (Bottom et al. 2011). The ISAB (2015) said that this information gap was critical because a key goal for habitat restoration is to reduce density dependent limitations by increasing capacity and productivity.

The overlap of hatchery- and natural-origin Chinook once these fish reach coastal waters has the potential to reduce early marine survival during unfavorable conditions. Jacobson et al. (2013) noted that the quantity of prey is generally lowest during July, when most subyearlings migrate to sea, suggesting the potential for competition.

Objectives:

- Assess the degree of spatial, temporal, and ecological overlap between natural- and hatchery-origin Chinook salmon throughout the estuarine and marine life history phases.
- Is there evidence for density-dependent mortality or limits to growth, production, and life history diversity due to this type of overlap?

<u>Approach (7c)</u>: Conduct large-scale controlled experiments by varying hatchery production to test hypotheses concerning interactions between natural- and hatchery-origin Chinook salmon including responses to changes in spatial, temporal, and ecological overlap; growth rates; and survival under variable estuarine and ocean conditions.

<u>Analysis (7c)</u>: Analyses that would address these questions include: (1) surveys for presence and indices of abundance and life history diversity of juvenile Chinook salmon in the lower Columbia River, the plume, and the nearshore ocean; (2) quantitative surveys of prey availability; (3) food web structure across different river conditions and oceanographic regimes; and (4) changes in these parameters under different levels of hatchery production. However, it could be difficult to detect changes in resource partitioning, if they occur, given natural variability and background changes in estuarine and marine ecology including those associated with climate change. This would increase the duration of the experiment (number of years) needed in order to detect a change in niche or life history diversity. In addition, there are likely to be practical and legal constraints on reducing the numbers of juvenile Chinook released from Columbia basin hatcheries for this type of experiment. Zabel (2014) estimated that Columbia River hatcheries released about 57 million juvenile Chinook in 2014[6] with about 50 million reaching the mouth of the Columbia River. Many of these programs support tribal, commercial, and recreational fisheries in the Pacific Northwest and commercial fisheries in the marine waters of Southeast Alaska and British Columbia. All of these stakeholders would have to be willing to forego some level of fishing opportunity to support this type of large-scale experiment. In addition, the operation of hatcheries that function to reduce the short-term risk of extinction while conserving the genetic legacy of threatened and endangered salmonids would be affected.

Status (7c): Recent survey data for the Columbia River estuary are summarized in Bottom et al. (2011), Roegner et al. (2013), and Sagar et al. (2015). Chinook salmon stocks and life histories sampled by beach seine exhibit broad seasonal and spatial patterns that are consistent between years. Small subyearlings dominate Chinook salmon catches in shallow nearshore habitats and larger Chinook salmon from Interior Columbia River stocks constitute a higher proportion of the catch upstream of the Lewis River. However, when PIT-tag detectors were deployed in secondary channels on Russian Island in Cathlamet Bay, larger subyearling and yearling Chinook salmon, including hatchery-origin fish, were also shown to use shallow water wetlands in the lower estuary (Roegner et al. 2013, McNatt 2015).

Bottom et al. (2011) commented that, compared with the protracted period of estuary use described in surveys conducted a hundred years ago (1914-1916), fewer juvenile migrants now enter or remain in the estuary from summer to fall. They ascribed this difference primarily to hatchery practices. [7] In Sagar et al. (2015), marked Chinook mostly were present from May through July, while unmarked juveniles were found throughout the year except during late summer and fall.

Sagar et al. (2015) found that juvenile Chinook salmon showed positive selection for dipterans and amphipods (i.e., consumed at a rate higher than expected given their abundance in the habitats sampled). Although juvenile salmon displayed flexibility in their diets, they exhibited strong preferences for certain taxa. Seasonal patterns of stock composition in the lower Columbia River estuary generally reflected the broad spatial structure of some major population groups.

Correlative studies of density-dependent growth and survival form the basis for much of what we know regarding competition involving salmon in ocean habitats. Miller et al. (2013) investigated the hypothesis that variation in size, growth, and condition of subyearling summer-fall Chinook salmon from the (unlisted) Upper Columbia River ESU was correlated with the density of conspecifics, but found no evidence of an effect of fish

[6] Depending on degree of overlap in time and space, hatchery origin coho salmon could also exert density dependent effects on Snake River fall Chinook salmon.

[7] Scale patterns from juveniles collected during a survey in 1914-1916 defined at least six juvenile life history types in the Columbia River estuary, five of which were subyearling migrant types (Bottom et al. 2011).

per km^2 on the size, growth, or condition of subyearling Chinook in the coastal ocean. However, Daly et al. (2012) found high dietary and spatial overlap well as similar growth rates between hatchery- and natural-origin yearling Chinook salmon during early marine life. The observed overlaps in diet and spatial occurrence, size, condition, and growth appeared to change at the same time, suggesting that yearlings were responding synchronously to changes in environmental conditions regardless of origin. The Snake River fall Chinook ESU produces both yearling and subyearling life history forms.

The quantity of prey available to juvenile salmonids varies seasonally. Prey species richness is highest in May when most yearling Chinook enter the ocean, but the community is dominated by the juveniles of benthic species that will soon settle to deeper habitat (Jacobson et al. 2013). The quantity of prey is generally lowest and numbers of adult forage fishes, piscivorous fishes, and carnivorous jellyfish are highest in July when most subyearling Chinook migrate to sea, indicating competition for resources and a higher risk of predation during this time. Morgan et al. (2014) suggested that in years of poor (typically warmer) ocean conditions, larger smolts forage more successfully than smaller smolts.

Gaps (7c): As described under “Status,” above, we are learning a lot about the degree of spatial, temporal, and ecological overlap between natural- and hatchery-origin Chinook salmon during their estuarine and marine life history phases. This work is ongoing through RM&E for the FCRPS biological opinion and other research programs. However, the detection of density dependence due to niche overlap with hatchery fish would require a large scale experiment that has not been authorized for the Columbia basin, and could require review under the National Environmental Policy Act, the Endangered Species Act, and other federal and state statutes.

Objective 8: Determine the effects of physical and biological changes associated with climate change on the viability of Snake River fall Chinook salmon.

Likely changes[8] in temperature, precipitation, wind patterns, and sea-level height due to climate change could have profound implications for survival and viability of Snake River fall Chinook salmon. All other threats and conditions remaining equal, changes in air temperature, river temperature, water quality, and river flows due to climate change could cause changes in fall

[8] As discussed in the NOAA Fisheries Climate Science Strategy (Link et al. 2015), natural variability in the earth’s climate systems occurs on short time scales as weather and annual to decadal climate variability. Climate change occurs on a multi-decadal scale. The climate we experience is a combination of natural variability and long-term change. Climate change is not detectable day-to-day or year-to-year. It is detectable in the long-term trends in daily and annual temperatures. In addition to affecting the average climate, these long-term trends may also change the frequency and magnitude of the processes responsible for natural variability, such as El Niño events. Monitoring the impacts of both climate variability and change on listed species is very important to developing effective management approaches across multiple time scales and the RM&E measures in this section are intended to address both.

Chinook salmon distribution, behavior, growth, timing, and survival. The magnitude and timing of these changes — and their effects on Snake River fall Chinook salmon viability — remain unclear. It is possible that the Snake River subyearling life history strategy will allow Snake River fall Chinook salmon to adapt to climate change effects on mainstem and tributary habitats.

The effects of climate change will largely depend on how Snake River fall Chinook salmon migration, spawning timing, emergence, and dispersal are affected by increased water temperatures. In the lower mainstem Columbia and Snake Rivers, increased water temperatures (August through October) could cause adult Snake River fall Chinook salmon to delay passage, leading to increased mortality or reduced spawning success due to lethal temperatures, delay, fallback at the dams, depleted energy reserves, or increased susceptibility to disease. Increased water temperatures in the lower Snake River above Lower Granite Dam during September and October may also reduce spawning success or egg viability.

A delay in spawn timing could then trigger a delay in fry emergence; however, warm water temperatures could also increase incubation rates, so that fry emerge at a similar date as they do today, or even earlier. A change in fry emergence would likely also shift the timing of dispersal to nearshore areas and, later, downstream. Such a change could be either beneficial or detrimental depending on location, size and prey availability. Climate change could also increase water temperatures in the lower Snake River and Lower Granite Reservoir to levels that cannot be suitably reduced by releases from Dworshak Reservoir, resulting in a loss or reduction in Snake River fall Chinook salmon yearlings, or reservoir-types; considered an important alternative life history strategy for the species.

Currently, the degree to which phenotypic or genetic adaptations by Snake River fall Chinook salmon may partially offset these potential effects is being studied but is poorly understood. A better understanding of the mechanisms by which climatic changes influence population productivity and diversity will be essential to avoid undesirable outcomes. Monitoring is critical to track and evaluate the effects of habitat alterations on abundance, productivity, distribution, and genetic and life history characteristics of the natural-origin population. Life cycle modeling will help assess habitat metrics (e.g. flow and temperature) across a diversity of ecological regimes and habitat types to evaluate responses to climate change.

The monitoring questions below address potential biological responses of Snake River fall Chinook salmon to climate change. This plan assumes that physical environmental variables associated with projected climate change will continue to be monitored and summarized to explore correlations with the biological factors described below. In some cases, there may be gaps in monitoring that require some additional effort and these are described under the following biological questions. For example, water temperatures throughout the mainstem migration corridor are currently monitored, but an expansion of temporal coverage may be necessary in some locations to track potential effects on yearlings that overwinter in reservoirs. Similarly, some expansion may be needed to ensure adequate temperature monitoring at the mouths of tributaries that function as cold-water refugia during the adult migration. A variety of physical and biological factors are monitored in the estuary and ocean, but in some cases continuation of these monitoring programs may be uncertain.

Monitoring Questions:

- Is the phenotypic and genotypic diversity of the natural-origin population changing over time? Are the changes consistent or not with expectations regarding climate change?
- Are relative contributions of the subyearling and overwintering life history patterns to natural production changing over time? Are the changes consistent or not with expectations regarding climate change?
- How are environmental and behavioral factors influencing emergence, growth, emigration size, emigration, and age-at-seaward entry? Are the changes consistent or not with expectations regarding climate change?
- How are environmental and behavioral factors influencing pre-spawning survival and egg viability? Are the changes consistent or not with expectations regarding climate change?
- How is ocean productivity of Snake River fall Chinook salmon changing? Are the changes consistent or not with expectations regarding climate change?

Monitoring Question (8a): Is the phenotypic and genotypic diversity of the natural-origin population changing over time? Are the changes consistent or not with expectations regarding climate change?

This question refers to a population's degree of adaptation to the existing diversity of environments it occupies, and its capacity to evolve and adapt to future environmental change due to climate change. Monitoring evaluates measurable key life history traits such as run timing, age structure, and behavior. It also monitors and evaluates differentiation among major spawning areas and how it changes.

Approach (8a): Monitoring key life history traits (run timing, spawn timing, age structure, and behavior) allows managers to assess whether changes are occurring, and if so, are they likely caused by changing environmental factors (e.g., altered thermal regimes influenced by climate change). Dam counts, smolt monitoring indices, PIT tag detections, spawning surveys, adult sampling, and water quality monitoring (temperature, etc) are all tools that can be used to assess if changes are occurring, and, if they are, what environmental factors are likely responsible. This information will also be vital to assess whether these changes are adaptive or not.

Analysis (8a): Current sampling regimes and analytical techniques appear to be sensitive enough to detect changes in run timing, spawn timing, age structure, and behavior). These approaches should continue, and, when practicable (see Gaps section below), be expanded to enhance our understanding of the passage of juveniles exhibiting the "reservoir" life history pattern.

Status (8a): The adult migration is monitored in its entirety through mainstem dam counts and PIT tag detections of known source fish tagged as juveniles. Juvenile passage is currently monitored (smolt monitoring indices or juvenile PIT tag detections) from April through October, when the great majority of juveniles are actively migrating. Environmental variables (primarily water temperature) are also recorded during this time. Spawning surveys occur on a weekly basis in October and November. Together, these sources of information should be sufficient to assess whether run timing and behavior is changing and if those changes are related to environmental variables (e.g., later adult migrations or earlier juvenile migrations that could be attributed to increasing summer temperatures). These sources of information are expected to continue indefinitely.

Gaps (8a): Juvenile passage monitoring typically does not occur from November to March as screened bypass systems are removed from service for maintenance and to avoid environmental conditions (ice) that could damage them. Extending the monitoring season (by expanding the amount of time screens and juvenile bypass systems operate into November, December, and March) would contribute to improving managers' understanding of juvenile passage timing, especially targeting those individuals that spend a portion of the fall and winter passing downstream in reservoirs prior to entering the ocean as yearlings. See Monitoring Question (6a) for additional information.

Monitoring Question (8b): Are relative contributions of the subyearling and overwintering life history patterns to natural production changing over time? Are the changes consistent or not with expectations regarding climate change?

Understanding the relative contribution of environmental factors and genetic mechanisms to the relative proportions of juveniles exhibiting each of the basic life-history pathways is important for determining how climate change might affect the population. Information on the production of subyearling and yearling outmigrants, and their life stage survivals, provides valuable insights into changes in life history patterns and the contributions of the alternative pathways to adult returns. Currently, most natural-origin juveniles from the Snake River drainage migrate seaward early and enter the ocean as subyearlings, while most natural-origin juveniles in the Clearwater River drainage migrate late and enter the ocean as yearlings. Later emerging and migrating juveniles, such as those from the Clearwater drainage, may be especially at risk if water temperatures rise toward 20 °C in the lower Snake River and Lower Granite reservoir and predation also increases.

Approach (8b): See approaches for Monitoring Questions (1a) and (1b). Scales are sampled from the adults collected under approach (1a) to determine age at ocean entry.

Analysis (8b): The proportions of subyearling and yearling ocean entrants can be monitored over time for change. For example, if temperature-related predation increases on the later migrants destined to be yearling ocean entrants then the proportion of late migrating juveniles would decrease over time as would the contribution of that life history pattern to adult returns.

Status (8b): See status for Monitoring Questions (1a) and (1b).

Gaps (8b): See gaps for Monitoring Questions (1a) and (1b).

Monitoring Question (8c): How are environmental and behavioral factors influencing emergence, growth, emigration size, emigration, and age-at-seaward entry? Are the changes consistent or not with expectations regarding climate change?

Answering this question will help determine how environmental variability influences important phenotypic traits of the population. If fall Chinook salmon delay spawning because of warmer water temperatures, it could then trigger a delay in fry emergence; however, incubation rates could also increase due to warm water temperatures, so that fry emergence occurs near the same time, or even earlier, than it does today. A change in fry emergence could shift the timing of dispersal to nearshore areas and, later, downstream. Such a change could be either beneficial or detrimental depending on location, size and prey availability. The information generated to answer this question, along with the life cycle modeling assessments, will provide important insights into how survivals during this life stage are changing in response to climate change.

Approach (8c): See approach for Monitoring Question (5c).

Analysis (8c): See analysis for Monitoring Question (5c).

Status (8c): See status for Monitoring Question (5c).

Gaps (8c): See gaps for Monitoring Question (5c).

Monitoring Question (8d): How are environmental and behavioral factors influencing pre-spawning survival and egg viability? Are the changes consistent or not with expectations regarding climate change?

Current thermal regimes in Lower Granite Reservoir and some spawning areas may be reducing pre-spawning survival and egg viability. Increased water temperatures in the lower Snake River dam fish ladders during September and October may increase the risk that Snake River fall Chinook salmon delay passage, leading to increased mortality, reduced spawning success, or egg viability because of lethal temperatures. Gaining information on current levels and annual variation in pre-spawning survival and egg viability will help determine whether changes in September and October temperatures significantly affect pre-spawning survival rates and gamete viability, and how effective cold-water releases from Dworshak Reservoir and other measures are reducing the risks. Evaluations of structures or operations at Lower Granite Dam are also needed to address adult passage blockages caused by warm surface waters entering the fish ladders.

Approach (8d): See approach for Monitoring Question (5a).

Analysis (8d): See analysis for Monitoring Question (5a).

Status (8d): See status for Monitoring Question (5a).

Gaps (8d): See gaps for Monitoring Question (5a).

Monitoring Question (8e): How is ocean productivity of Snake River fall Chinook salmon changing? Are the changes consistent or not with expectations regarding climate change?

The scope and magnitude of any effect experienced by Snake River fall Chinook salmon in the ocean environment will be a function of how the climate actually changes (e.g., rate and magnitude) and how these changes ultimately affect physical and biological processes (Tolimieri and Levin 2004). In the ocean, salmon can potentially be affected by climate-driven changes in the ocean's physical (e.g., temperature, circulation, stratification, upwelling), chemical (e.g., acidification, nutrient input, oxygen content), and biological (e.g., primary production, species distributions, phenology, foodweb structure, community composition and ecosystem functions/services) components and processes (NWFSC 2014).

Currently, most of the risk factors related to climate change are poorly understood. There is little direct information on if, and how, changes in physical factors would affect salmon. The consequences of climate change for Snake River fall Chinook salmon and other species depends on potentially complex shifts in prey availability, and abilities of salmon to change life history strategies and diets. Consequently, assessing the consequences of climate change will require use of tools, such as life cycle modeling, that can consider the interactions of individual effects as they multiply across life stages within generations and across generations within populations. Work should continue to develop and refine indicators of ocean conditions that are relevant to salmon performance, particularly early marine survival and adult returns. More information is also needed to determine the spatial and temporal distribution of Snake River fall Chinook salmon in the ocean.

Approach (8e): Continue to monitor physical and biological oceanic and large-scale atmospheric variables that can influence survival of Snake River fall Chinook salmon, particularly during the critical year of ocean entry. Continue to develop statistical analyses and life-cycle models that can better delineate and predict the effects of changes in these variables on the survival, abundance, and distribution of Snake River fall Chinook salmon.

Analysis (8e): A variety of physical and biological variables of importance to Snake River fall Chinook salmon currently are monitored over a range of geographical scales in the California Current and Alaska Current regions, and these will need to continue. For example, NOAA's California Current Integrated Ecosystem Assessment annually summarizes key environmental factors influencing the California Current as a whole (CCIEA 2015), while NMFS' Ocean Ecosystem Indicators project reports on 22 physical and biological indicators relevant to salmon marine survival in the northern California Current region (Peterson et al. 2014). Oceanic data portals relevant to Snake River fall Chinook are maintained by consortia of governmental and academic entities. These include the Alaska, Pacific Northwest, Central California, and Northern California Ocean Observing Systems (IOOS 2015).

At least two statistical analyses currently link physical and biological ocean ecosystem indicators during the year of juvenile ocean entry to abundance of all returning Snake and Columbia River fall Chinook salmon, including Snake River fall Chinook, two years later (Peterson et al. 2014). The ocean variables explain approximately 50 percent of the variance in adult fall Chinook returns and these relationships have been used to predict future adult fall Chinook abundance at Bonneville Dam. New statistical analyses are currently underway and continued development of functional relationships between ocean conditions and Snake River fall Chinook abundance and survival will be important for assessing effects on this species as ocean conditions climate.

The distribution of Snake River fall Chinook salmon in the ocean may also be affected by climate change. For example, Abdul Aziz et al. (2011) and Cheung et al. (2015) have predicted northward shifts in the distribution of Chinook salmon and other species in the northeast Pacific Ocean. As Cheung et al. (2015) explain, "The projected changes in species assemblages may have large ecological and socio-economic implications through mismatches of co-evolved species, unexpected trophic effects, and shifts of fishing grounds. These results provide hypotheses of climate change impacts that can be tested using data collected by monitoring programmes in the region." Continued monitoring of ocean temperatures and fish distributions will be invaluable in testing these hypotheses.

Ocean acidification from climate change may also affect the distribution and survival of Snake River Chinook prey species or lower trophic levels supporting salmon prey. It will be important to continue ocean acidification monitoring through periodic ship surveys and continuous readings from sensors on fixed buoys. Buoys have been installed off the coasts of Washington and Oregon that continuously monitor ocean pH.at fixed locations (IOOS 2015). Periodic cruises, such as those described in Feeley et al. (2008) and Bednarsek et al. (2014), are monitoring both ocean chemistry and biological characteristics such as degree of shell dissolution in some species. Continuation of experimental and modeling studies to link changes in ocean pH to survival of species in the food chain of salmon will be important to continue (e.g., Busch et al. 2013, 2014).

Status (8e): Most of the monitoring and associated analyses and experimental studies that are needed are currently underway, as described by examples above. However, to be useful, the monitoring must continue and funding for some components is uncertain.

Gaps (8e): There currently is not a gap, but gaps could develop if current monitoring and research programs lose funding in the future.

Objective 9: Determine the effects of harvest on the viability of Snake River fall Chinook salmon.

Snake River fall Chinook salmon are caught in ocean fisheries from Alaska to northern California, and in river fisheries from the Columbia River mouth up to Hells Canyon Dam. In recent years, there has been increasing interest and harvest of Snake River fall Chinook salmon in fisheries upstream from Lower Granite Dam. Fisheries in the ocean and mainstem Columbia River have been subject to ESA-related constraints since listing. Those constraints have required that fisheries in the ocean and Columbia River be reduced by thirty percent relative to what occurred from 1988 to 1993. In 2008, management of the in-river fisheries was modified to implement an abundance-based framework that allowed harvest to increase or decrease relative to the previous benchmark depending on the abundance of natural-origin Snake River fall Chinook salmon. Harvest reductions in ocean and in-river fisheries were implemented shortly after listing as interim measures recognizing that there was some uncertainty about whether harvest constraints would be sufficient to allow for long-term recovery. The harvest reductions, coupled with other survival improvements throughout the system, allowed for substantial improvement in the status of the species. Nonetheless, a robust monitoring and evaluation program is needed to insure that fisheries are being implemented as intended, and that ESA-approved harvest levels continue to be consistent with evolving information and the expectation of survival and recovery.

Monitoring Questions:

- What is the cumulative exploitation rate on naturally produced Snake River fall Chinook salmon in ocean and in-river fisheries?
- Are current harvest limits consistent with the expectation of survival and recovery of natural-origin Snake River fall Chinook salmon and are they robust to variations in ocean survival?
- What is an appropriate harvest regime for new fisheries upstream from Lower Granite Dam?

Monitoring Question (9a): What is the cumulative exploitation rate on naturally produced Snake River fall Chinook salmon in ocean and in-river fisheries?

Harvest of Snake River fall Chinook salmon in ocean and Columbia River fisheries has been constrained for more than twenty years by ESA consultation requirements. All ocean fisheries combined are required to reduce impacts by thirty percent relative to what occurred from 1988 to 1993. Fisheries in the Columbia River were also required to reduce impacts by thirty percent relative to a 1988 to 1993 base period until 2008 when management switched to an abundance-based harvest schedule. Although ocean and in-river fisheries are reviewed separately for compliance with the applicable standards, there has not been a recent comprehensive analysis of the cumulative effects of all harvest.

> ***Approach (9a):*** Measures of the cumulative exploitation rate of natural-origin Snake River fall Chinook salmon can be developed through a contemporary retrospective analysis using the CWT data and available management models.
>
> ***Analysis (9a):*** An analysis of the exploitation rate for recent years can be accomplished through a routine assessment of the available CWTs. An assessment of harvest effects for earlier years may require greater reliance on harvest management models.
>
> ***Status (9a):*** A comprehensive analysis has not been yet initiated.
>
> ***Gaps (9a):*** Our ability to measure harvest effects was limited at the time of listing and through the years following by the relative absence of representative CWT groups. The limitation was related to a shortage of broodstock needed to develop the Lyons Ferry Hatchery program and the resulting emphasis on yearling releases for several years. Yearling hatchery fish are not representative of the predominant subyearling life-history type of Snake River fall Chinook salmon. As a consequence there is a significant gap in the CWT data base that complicates our ability to estimate exploitation rates for all years before and since ESA listing. Better information is available for more recent years.

Monitoring Question (9b): Are current harvest limits consistent with the expectation of survival and recovery of natural-origin Snake River fall Chinook salmon and are they robust to variations in ocean survival?

Whether a particular harvest regime is adequately protective depends on the productivity of the stock and the survival rates that affect all stages of the life history. The current harvest regime has been coincident with significant increases in the abundance of hatchery and natural-origin fish, suggesting that it may be adequately protective. However, the observed growth is confounded by the large contribution of hatchery-origin fish from the supplementation program. It is unknown if the natural-origin fish can sustain themselves in the absence of hatchery fish. In addition, the observed population growth has occurred during a period of relatively high ocean survival, particularly in recent years. Thus, it is unknown if the natural-origin fish can sustain themselves through a broader range of ocean survival conditions.

> ***Approach (9b):*** A complete life-cycle analysis approach will be needed to determine if the current harvest regime is consistent with expectations of survival and recovery.

Whether a particular harvest regime is adequately protective depends on the productivity of the stock and the survival rates that affect all stages of the live history.

Analysis (9b): The analysis will require a life-cycle modeling approach (see Objective 13).

Status (9b): Because the life-cycle model has not yet been developed, a comprehensive analysis has not been initiated.

Gaps (9b): A complete life-cycle analysis approach will be needed to determine if the current harvest regime is consistent with expectations of survival and recovery. The life-cycle model is currently under development (see Objective 13).

Monitoring Question (9c): What is an appropriate harvest regime for new fisheries upstream from Lower Granite Dam?

Until recently, there has been little or no harvest of Snake River fall Chinook salmon in fisheries above Lower Granite Dam. At the time of listing, and for some time thereafter, the numbers were low and the priority was to protect and rebuild the population. Tribal fisheries targeting fall Chinook salmon were closed. Recreational fishers upstream of Lower Granite Dam focused on steelhead; although, there was some incidental catch of Chinook salmon. However, as the return of Snake River fall Chinook salmon increased from hundreds to thousands to tens of thousands, particularly over the last five years, there has been increased interest in expanded harvest opportunity. With returns to Lower Granite Dam approaching 60,000 in the last couple of years, there is clearly more harvest opportunity. A new abundance-based harvest schedule should be developed that allows more or less harvest depending on the year-specific circumstances and is consistent with recovery objectives.

Approach (9c): An abundance-based harvest regime that accounts for the relative and absolute abundance of hatchery and natural-origin fish should be developed to provide for conservation and access to harvestable fish. The harvest regime should be developed by the relevant co-managers in conjunction with NOAA Fisheries through the ESA Section 4(d) process.

Analysis (9c): The proposed harvest regime will be subject to the ESA Section 4(d) review process including consideration of whether it is consistent with expectations of survival and recovery of the species.

Status (9c): Preliminary discussions are underway between the co-managers and NOAA Fisheries related to the development of an abundance-based harvest regime.

Gaps (9c): Development of a new harvest regime requires that the co-managers complete an acceptable proposal and subsequent review and approval by NOAA Fisheries.

Objective 10: Determine the effects of disease, predation, prey base, competition, non-native species, and other ecological interactions on the viability of Snake River fall Chinook salmon.

The productivity of juvenile Snake River fall Chinook salmon depends in part on the food webs that support growth and survival, and on the interactions of juvenile fall Chinook salmon with predators and competitors. Because juvenile fall Chinook salmon exhibit a transitory rearing strategy, they encounter many different environments, each replete with predators, competitors, and varying prey items. The prey communities that support juvenile growth vary among riverine, reservoir, and estuarine habitats. It is important to understand the capacity of the food web to support current and future levels of juvenile fall Chinook salmon abundances, and how juvenile Chinook salmon may be affected by changing predator and prey resources resulting from invasion by nonnative species. Competition with both conspecifics and other native fishes will also affect juvenile fall Chinook salmon productivity. The wider array of juvenile fishes inhabiting reservoirs may result in competition being more intense in those habitats and that may affect growth potential and the time fish are vulnerable to predators. The high abundance of non-native predators like smallmouth bass and walleye in the Snake and Columbia Rivers may be an important agent of mortality on juvenile fall Chinook salmon. Subyearlings emigrating during summer may be especially vulnerable to predation because of the higher feeding rates of predators at warmer temperatures. It is therefore important to monitor changes in the prey items, competitors, and predators.

Monitoring Questions:

- What is the capacity of prey resources to support juvenile fall Chinook salmon during rearing and migration?
- How will alterations to the food web (e.g., invasive species) influence the growth opportunity of juvenile fall Chinook salmon?
- To what extent are competitive interactions influencing juvenile fall Chinook salmon growth and survival?
- What is the status and trend of predation on juvenile fall Chinook salmon?

Monitoring Question (10a): What is the capacity of prey resources to support juvenile fall Chinook salmon during rearing and migration?

Fish growth is dependent in part on both the quantity and quality of prey. Prey resources differ between riverine to reservoir habitats, and prey availability and energetic content change seasonally as invertebrate prey move through different life stages. The capacity of prey to support fish growth is also dependent on the number of fish competing for and relying on the prey. Recent work suggests that in the un-impounded Snake River, juvenile fall Chinook salmon consume a higher energy content diet and exhibit higher growth than fish that disperse downstream and rear in a reservoir (Tiffan et al. 2014). Paradoxically, prey biomass is higher in the reservoir, but the functional availability of prey and the extent of competition for that prey are unclear. Snake and Columbia River reservoirs support many native and non-native resident fishes as well as migrating salmonids that use prey resources along with Snake River fall Chinook salmon. Whether there is sufficient food to support the growth of these fishes in reservoirs during rearing and migration has been a concern since the early 1990s (e.g., Curet 1993). This is significant considering the food web changes that have occurred recently (see Monitoring Question 9b), the increased number of fish depending on available prey, and density-dependent changes in fall Chinook salmon growth that is affected by prey resources (Connor et al. 2013).

Approach (10a): The density and quality of prey resources can be measured by routinely sampling the benthic, epibenthic, and pelagic invertebrate communities in select index reaches. The USGS under BPA project 200203200 has collected seasonal prey information with drift nets, benthic trawling, and vertical plankton tows. Diet information has been and can be collected with non-lethal lavage from subyearlings captured in beach seines. Growth can be estimated in river and reservoir reaches by PIT tagging and recapturing juvenile fall Chinook salmon. Together, growth and diet information can be related to prey resources with a bioenergetics model. This modeling approach would be useful for explaining how prey quantity and quality affect fall Chinook salmon growth at different levels of fish abundance. It could be applied at small reach scales or to larger hydrosystem-level reaches.

Analysis (10a): Routine prey sampling would provide information on seasonal and annual changes in species composition, abundance, distribution, and availability to fall Chinook salmon. Bioenergetics modeling can predict the amount of food required to support observed growth, which can also serve as a measure of how well the fish population is supported by the available prey base. Alternatively, the model can be used to predict fish growth based on observed consumption. The latter allows evaluation of different prey resource scenarios that could arise from increased competition or food web changes brought about by invasive species. Bioenergetics modeling requires estimates of fish growth (obtained from PIT tags), estimates of diet composition (obtained empirically), diet energy content (available from the literature), and temperature (available from thermographs or the dams).

Status (10a): Data on prey resources for Snake River fall Chinook salmon are generally lacking. Extensive sampling of the Snake River reservoirs was conducted by the University of Idaho in the 1980s, 1990s, and periodically in the 2000s, and provides a historical context of prey resources. However, significant changes have occurred in the food web in lower Snake River reservoirs since that time. The most recent work on juvenile fall Chinook salmon diet and growth was conducted during 2009-2011 by Tiffan et al. (2014). However, data are sparse to non-existent for the un-impounded Snake and Clearwater Rivers. In the lower Columbia River, Haskell et al. (2006a, 2013) provide insights into the zooplankton community in John Day Reservoir that is available to later-migrating Snake River fall Chinook salmon. In the Columbia River below Bonneville Dam and the estuary, prey resource data are available from various backwater and shoreline locations but are not specific to Snake River fall Chinook salmon.

Gaps (10a): To date, most recent work has focused in the un-impounded Snake River and Lower Granite Reservoir and little diet and prey data have been collected in other Snake and Columbia River reservoirs. The status of prey resources in other reservoirs and river reaches should be assessed. Most studies of fall Chinook salmon feeding and prey are dated (e.g., Muir and Emmett 1988; Rondorf et al. 1990; Curet 1993). There is a current lack of understanding of the contemporary prey base that currently supports fall Chinook salmon and its capacity to support continued fall Chinook salmon recovery in light of other food web changes and demands on it by other species.

Monitoring Question (10b): How will alterations to the food web (e.g., invasive species) influence the growth opportunity of juvenile fall Chinook salmon?

The importance of food webs to salmon recovery has been largely ignored, but they are critically important to providing the resources necessary for growth and survival (Naiman et al. 2012). Food webs are not static but change over time due to a variety of factors including changes in productivity, invertebrate and fish community changes, and invasion by non-native species. This is particularly true in the Snake and Columbia Rivers where many invasive species have become established (Sanderson et al. 2009). In Lower Granite Reservoir, the proliferation of two non-native and one native species could affect the growth opportunity of juvenile fall Chinook salmon. Siberian prawns (native to East Asia) have become established in the Snake and Columbia Rivers but ecological consequence of this invasion is currently unknown (Haskell et al. 2006b). The opossum shrimp, *Neomysis mercedis*, was absent 20 years ago but has become very abundant in the Snake River and at times composes 98 percent of the invertebrate biomass in Lower Granite Reservoir (Tiffan et al. 2014). *Neomysis* may be a competitor with fall Chinook salmon for zooplankton or be prey themselves, but their role in the food web and relation to fall Chinook salmon is poorly understood (Tiffan et al. 2014). Finally, the native sand roller was absent in Lower Granite Reservoir as of about 2003, but is now extremely abundant throughout the lower Snake River (USGS, unpublished). Sand rollers have the potential to compete with fall Chinook salmon for food or act as a buffer against predation (see Monitoring Question 9d). Changes to the food web of this magnitude in Lower Granite Reservoir and elsewhere should be cause for concern given that so little is known about their ecological effects, not only Snake River fall Chinook salmon, but on other species as well.

Approach (10b): The status and trends of specific food web components, such as important invertebrate prey and resident fish, can be routinely sampled to document changes to the community that could potentially affect fall Chinook salmon. Sampling within select index reaches would be a practical approach. Benthic beam trawls, drift nets, benthic dredges, and plankton nets are effective gears. Periodic assessments of fall Chinook salmon growth (via PIT tagging and recapture) are needed to relate growth to prey resources and food web changes. Beyond status and trends monitoring, further research is needed to understand the ecological effects of invasive species on fall Chinook salmon and the food web. For example, stable isotope analysis can provide insight into trophic linkages between different species and the flow of energy through the food web. Food web models can be developed to predict fall Chinook salmon response to food web changes (e.g., Bellmore et al. 2013).

Analysis (10b): Trends in species occurrence, distribution, abundance, and biomass can be examined over time and statistically compared between sample reaches. Analysis of stable isotopes collected from fall Chinook salmon prey and potential competitors can reveal the important energy pathways that are supporting fall Chinook salmon. Furthermore, determining the trophic positions of the consumers in the food web can reveal the fish species that are potentially competing with fall Chinook salmon for different prey. This is important for understanding, for example, the relative importance of an invasive species like *Neomysis* to fall Chinook salmon in terms of whether they are providing a benefit as prey or reducing their growth as a competitor.

Status (10b): No systematic sampling plan currently exists to monitor invasive species or changes in food web components that support fall Chinook salmon. To date, relevant data has been collected haphazardly or ancillary to other data collection efforts. The collection of invertebrate and non-salmonid bycatch at mainstem dams is routinely tabulated by the U.S. Army Corps of Engineers. The USGS under BPA project 200203200 has collected four years (2011-2014) of data on invertebrates (e.g., *Neomysis*, Siberian prawns). This sampling was conducted at systematic and random sites in Lower Granite and Little Goose reservoirs to examine trends in abundance and increase the understanding of the ecology of these invertebrates as it relates to fall Chinook salmon. Some stable isotope data have been collected from fish and invertebrates in Lower Granite and Little Goose reservoirs, and analyses are ongoing (USGS, unpublished).

Gaps (10b): Little information exists on the current structure and function of riverine and reservoir food webs that support Snake River fall Chinook salmon. Describing the structure (e.g., invasive species occurrence and food web changes) is a necessary first step to subsequently understanding the function (e.g., ecological roles of primary species) as it relates to fall Chinook salmon. A conceptual model of how Snake River fall Chinook salmon fit into existing food webs is needed to allow formulating and testing hypotheses about how food web changes would affect their growth during rearing and migration, and ultimately their survival. Both systematic, routine monitoring and research to test hypotheses about food web function as it relates to fall Chinook salmon growth opportunity are needed.

Monitoring Question (10c): To what extent are competitive interactions influencing juvenile fall Chinook salmon growth and survival?

Since the listing of Snake River fall Chinook salmon in 1992, recovery efforts have led to a large increase in the juvenile population to the point of density-dependent changes in growth (Connor et al. 2013). Although juvenile fall Chinook salmon growth has declined only slightly in riverine habitats, it has declined significantly in reservoir habitats. Fall Chinook salmon that disperse downstream from riverine habitats into Lower Granite Reservoir rear along shorelines also inhabited by many native and non-native resident fishes. The potential for competition for food and space is probably higher in reservoir than in riverine habitats and may explain growth differences, but this has not been confirmed. Slower growth in reservoir habitats may increase the time fall Chinook salmon are vulnerable to predation.

Approach (10c): Documenting the effects of competition can be difficult and uncertain. Measuring competition directly would best be accomplished in a controlled laboratory setting where specific mechanisms, such as interspecific competition for food or habitat, could be tested. Indirect measures of competition could be obtained from the field, but perhaps with reduced certainty. Collection of diet, stable isotope, habitat, fish density, and growth data on fall Chinook salmon as well as potential competitor resident species can be analyzed to draw inferences about the degree to which competition is occurring.

Analysis (10c): Diets of fall Chinook salmon could be compared to that of other species to measure the degree of overlap as an indirect measure of competition. Stable isotope data could be used to determine the trophic position of fall Chinook salmon and potential competitors. Fish occupying the same trophic position (determined from the ^{15}N isotope) have a higher probability of competing for the same food if they occupy a position similar to the prey they consume (determined from the ^{13}C isotope). The degree to which fall Chinook salmon rearing habitat overlaps with that of other resident fish species could be compared as indirect indicator of potential competition for space. Relating fall Chinook salmon growth to fish density in rearing habitats would be tenuous given their transient rearing strategy. Bioenergetics modeling is another approach that can be used to test different hypotheses about the effects of intra- and interspecific competition on fall Chinook salmon growth. Analyses would require growth, diet, temperature, and abundance data on fall Chinook salmon and their potential competitors.

Status (10c): The incidence of competition affecting juvenile fall Chinook salmon growth is speculative and anecdotal at best. Some inferences can be made from the recent work of Connor et al. (2013) and Tiffan et al. (2014) that provided evidence that reductions in growth of fall Chinook salmon rearing in Lower Granite Reservoir could partly be due to competition. Otherwise, no field or laboratory work is being done to address this monitoring question.

<u>Gaps (10c)</u>: Formal laboratory or field studies examining competition between resident fish or invertebrates and juvenile fall Chinook salmon for food and space have not been conducted. Little to no quantitative information exists on this topic to guide fall Chinook salmon adaptive management and recovery efforts.

Monitoring Question (10d): What is the status and trend of predation on juvenile fall Chinook salmon?

Snake River fall Chinook salmon may be particularly vulnerable to predation because of their relatively small size and because their main-stem rearing habitats often overlap or are in close proximity to habitats used by predators (Curet 1993; Nelle 1999; Naughton et al. 2004). Smallmouth bass are abundant in the Snake River and are probably the main predator of fall Chinook salmon along with northern pikeminnow. Past studies of smallmouth bass predation in the Snake River documented relatively low consumption of juvenile fall Chinook salmon (0-11% of the diet; Anglea 1997, Nelle 1999, Naughton et al. 2004). However, these studies were conducted soon after ESA listing when fall Chinook salmon abundance was at an historic low, which may explain why consumption rates were relatively low. Both Zimmerman (1999) and Naughton et al. (2004) showed that fish can comprise a large portion of smallmouth bass diets. Considering that subyearlings probably now make up a larger portion of the forage fish population, it is plausible that they may be at greater risk of predation. Fall Chinook salmon produced in the Clearwater River may be at particular risk to predation when they enter the warmer waters of Lower Granite Reservoir in the summer. Past studies have documented fall Chinook salmon mortality in the lower Clearwater River and the area downstream of its confluence with the Snake River that is likely due to predation (Tiffan et al. 2012b). However, predation pressure on fall Chinook salmon could be reduced by increases in alternative prey.

<u>Approach (10d)</u>: The approach is similar to that of the predation studies conducted in the mid-1980s to 1990s in the Snake and Columbia Rivers. Predators are collected at regular intervals during the fall Chinook salmon rearing and outmigration period to obtain diet information and to estimate their abundance. Given predator abundance and consumption rates, the total loss of juvenile fall Chinook salmon and other prey fish can be estimated for each sampling interval. The losses are summed over all sampling intervals to arrive at a season-wide total for the sampling area.

<u>Analysis (10d)</u>: Predator diets are analyzed to determine the occurrence of major prey taxa by weight. Prey fish are identified from diagnostic bones and their weight at ingestion is estimated from regressions. Daily fall Chinook salmon consumption is estimated using meal-weight and gastric emptying equations for the predator of interest. Predator abundance is estimated using mark-recapture methods and either open or closed population models depending on the sampling design. Fall Chinook salmon loss is estimated by multiplying the daily consumption by the number of days in the sampling interval by the predator abundance. Season-wide loss is determined by summing the loss estimates for each sampling interval.

Status (10d): The USGS has conducted the most recent (2011-2014) smallmouth bass predation assessment of Snake River fall Chinook salmon. They have estimated consumption and loss in Hells Canyon under BPA project 199102900 to provide a comparison to the study conducted by Nelle (1999). They have estimated consumption and loss in the upper reaches of Lower Granite Reservoir under BPA project 200203200 to provide a comparison to the study conducted by Naughton et al. (2004). These short-term studies will conclude in 2015 and will provide insight into predation risk that smallmouth bass pose to fall Chinook salmon. The USGS is also examining the prevalence of channel catfish predation on fall Chinook salmon in Lower Granite Reservoir. Furthermore, northern pikeminnow predation on fall Chinook salmon is indexed and monitored every three years in the Snake River under BPA project 199007700.

Gaps (10d): Other than the routine index sampling conducted under the system-wide predator control program, no recent predation assessments have been conducted in lower portions of Lower Granite Reservoir or other lower Snake River reservoirs. The effect of walleye and channel catfish predation on fall Chinook salmon remains largely unknown due to the low collection numbers of these species. Also, little information currently exists on habitat-related predation vulnerability. Smallmouth bass, for example, are more abundant in riprap than in non-riprap habitats. This is relevant to the amount of fall Chinook salmon rearing habitat (which is less preferred by bass) that exists in Hells Canyon and lower Snake River reservoirs that could reduce predation-related mortality.

Objective 11: Identify federal, state, tribal, and local regulatory mechanisms that conserve Snake River fall Chinook salmon and determine the adequacy of those regulatory mechanisms.

There are several federal, state, tribal, and local regulatory mechanisms that protect Snake River fall Chinook salmon and their habitat. Any delisting decision would need to be supported by evidence that the threats facing the species have been ameliorated and that regulatory mechanisms are in place to continue conserving the species and help prevent a recurring need to re-list the species. Therefore, monitoring the status and trend of existing regulatory mechanisms and their enforcement of existing regulations is needed. This will provide a foundation from which to build lasting agreements for conserving the species in the event of a delisting.

Monitoring Questions:

- What regulatory mechanisms are in place to protect the species or to further reduce risk of the primary limiting factors associated with habitat, hydropower, harvest, disease and predation, and hatcheries?
- Would regulatory protections endure if there were to be an ESA delisting?

Monitoring Question (11a): What regulatory mechanisms are in place to protect the species or to further reduce risk of the primary limiting factors associated with habitat, hydropower, harvest, disease and predation, and hatcheries?

There are several regulatory mechanisms in place to protect the species and/or reduce the risk of the primary limiting factors associated with the abundance, productivity, diversity, and spatial structure of Snake River fall Chinook salmon. There are regulatory mechanisms associated with habitat and hydro (e.g., FERC licenses, the FCRPS Biological Opinion, and the Clean Water Act), harvest (e.g., regulations under U.S. v OR and the Pacific Salmon Treaty), and hatcheries (e.g., ESA HGMPs). A complete listing of the regulatory mechanisms, including those that depend on ESA implementation, would help determine if there are gaps in regulations and protection measures, and would also help with evaluating the need for additional regulations and agreements that would endure in the event of an ESA delisting.

> ***Approach (11a)**:* As overviewed in Section 2 (Background of the Recovery Plan) and in Sections 5 (Threats and Limiting Factors) and Section 6, there is a comprehensive set of regulatory mechanisms already in place for conserving Snake River fall Chinook salmon. However, a complete listing of all the regulatory mechanisms that affect Snake River fall Chinook salmon and their habitats, clearly identifying those that depend on ESA authorizations, should be compiled. This includes all federal, state, tribal, and local regulations across all sectors (e.g., habitat, harvest, hatcheries, and hydro projects).
>
> ***Analysis (11a):*** A qualified individual with legal and/or policy experience will conduct a critical review of all regulatory mechanisms within the sectors and evaluate the effects of those mechanisms on limiting factors within each sector. The individual will also identify any gaps in protection within the different sectors.
>
> ***Status (11a):*** Regulations associated with Snake River fall Chinook salmon occur within the respective jurisdictions of county, state, federal, and tribal agencies. Each entity is responsible for maintaining and enforcing their respective regulatory programs.
>
> ***Gaps (11a):*** A complete listing of all the regulatory mechanisms affecting Snake River fall Chinook salmon and their habitat is not available in one place. As noted above, they exist within the respective jurisdictions of county, state, federal, and tribal agencies. Funding would be needed to hire a person with legal and/or policy experience to compile and evaluate the existing regulatory mechanisms.

Monitoring Question (11b): Would regulatory protections endure if there were to be an ESA delisting?

There are several regulatory programs, such as Section 7 consultations and Section 10 permits, and those associated with the ESA-listing of a species. In addition, other existing regulations may be more strongly enforced when they protect ESA-listed species. Once the species is delisted, however, ESA-driven regulatory programs would no longer be required to be enforced and the benefits of those regulatory programs could disappear. It is therefore important to know which regulations will endure after delisting and how enforcement of those regulations may change.

> ***Approach (11b):*** Based on the regulations compiled under Monitoring Question 10a, each regulation will be evaluated for its potential to endure after the delisting of Snake River fall Chinook salmon.
>
> ***Analysis (11b):*** A qualified individual with legal experience will review each of the regulatory mechanisms by sector to determine which regulations are likely to endure after delisting Snake River fall Chinook salmon. A complete list of regulations that are unlikely to endure or be enforced will be complied and reviewed with the responsible agency. Also provided will be reasons why a regulation will not endure.
>
> ***Status (11b):*** A complete listing and evaluation of all regulations by sector has not occurred for Snake River fall Chinook salmon. This work is needed to evaluate which regulations are likely to endure if Snake River fall Chinook salmon are delisted.
>
> ***Gaps (11b):*** As noted under Gaps 10a, funding is needed to hire a qualified individual to evaluate all regulatory mechanisms associated with Snake River fall Chinook salmon and their habitat.

Objective 12: Determine the influence of hatchery supplementation programs on the viability of the natural population of Snake River fall Chinook salmon.

Hatchery production of Snake River fall Chinook salmon was initiated as mitigation for production losses associated with the construction of Snake and Columbia River hydroelectric dams. Following listing, the ongoing program was adapted to include a directed supplementation effort shifting a significant proportion of releases upstream of Lower Granite Dam. The goals of that effort were to increase the natural spawning population, sustain long-term preservation and genetic integrity of the population, keep ecological effects within acceptable limits, assist in recovery and delisting, and provide harvest opportunities for both tribal and non-tribal anglers. Monitoring the annual escapement of hatchery adults and their relative contribution to spawning across major spawning areas is a basic requirement for assessing natural production. Specifically, monitoring is needed to assess the direct demographic contributions and effects of the ongoing supplementation program on the natural population and to evaluate the effects of the program on genetic or life history characteristics of the natural population. Monitoring is also needed to assess the degree that naturally produced juveniles are influenced by or are interacting with supplementation smolts. That is, the presence of hatchery smolts in natural rearing and migration reaches may adversely affect natural production through increased competition for high quality rearing habitats or through increased exposure to or attraction of predators.

Monitoring questions:

- Is supplementation enhancing the natural production of Snake River fall Chinook salmon?
- Is supplementation altering natural development of genetic or life history characteristics of the natural-origin Snake River fall Chinook salmon population?
- To what extent are ecological relationships affecting natural production of Snake River fall Chinook salmon impacted by hatchery production?
- Are out-of-basin strays altering the genetic profile of naturally produced Snake River fall Chinook salmon?

Monitoring Question (12a): Is supplementation enhancing the natural production of Snake River fall Chinook salmon?

As with other directed supplementation programs, the Snake River fall Chinook hatchery programs are based on a series of assumptions regarding the ability of a hatchery program to boost the production of adult returns relative to production from fish spawning in nature. Ultimately, the evaluation of the hatchery program to supplement natural production should be measured in terms of changes in natural-origin production – are the fish taken into the hatchery program resulting in a net increase in natural production in the population? As with most other supplementation evaluation efforts, evaluation of this important demographic objective breaks the overall question into two parts: (1) does a spawning pair in the supplementation program produce more returns to the spawning grounds than a corresponding spawning pair in nature and (2) is natural production from spawning in nature, including the hatchery supplementation returns, increased relative to what it would have been in the absence of supplementation?

> ***Approach (12a):*** Monitoring and evaluation of the relative production of smolts and returning adults from fish taken into the hatchery program relative to natural production is conducted annually. The methods and results of annual evaluations are routinely reported by the Washington Department of Fish and Wildlife and the Nez Perce Tribe in annual reports to the Bonneville Power Administration and Lower Snake River Compensation Plan. In general, brood-year cohort reconstructions of returns for hatchery releases organized by general release strategy (e.g., location and age at release) are compiled based on the abundance estimates and trap sampling results at Lower Granite Dam (see Objectives 1 and 2). Direct estimation of the changes in natural production resulting from the addition of the returning hatchery fish to natural spawning is problematic for this population, largely because carcass sampling has not been successful in most spawning areas.

> ***Analysis (12a):*** Indirect estimates of the potential effects of the supplementation program based on fitting stock-production relationships, including alternative possible relative reproductive success assumptions derived from studies of other stocks, have been

conducted to provide insights into possible effects. The estimated contributions of natural-origin and hatchery-origin (Snake River programs and out-of-basin) sources to the run at Lower Granite Dam are generated by expanding from trap samples using ladder counts. The contributions of those groupings to the aggregate spawning run over Lower Granite Dam is estimated from the Lower Granite runs by accounting for broodstock removals and estimated fall back (e.g., Young et al. 2012).

Status (12a): Ongoing trapping of adult returns at Lower Granite Dam provides the primary source of information on possible hatchery effects on genetic and life history characteristics of the Lower Snake River fall Chinook salmon.

Gaps (12a): It is not possible to specifically estimate the contributions of the supplementation program to the recent increases in natural returns, largely because of the inability to determine relative reproductive success of hatchery-origin vs. natural-origin spawners in any of the natural production areas. In the future, it may be possible to develop estimates of relative contributions of natural-origin vs. hatchery-origin spawners from area-specific natural-origin juvenile sampling taking advantage of PBT and/or otolith analyses.

Monitoring Question (12b): Is supplementation altering natural development of genetic or life history characteristics of the natural-origin Snake River fall Chinook salmon population?

Evaluating the effects of the supplementation program on genetic or life history characteristics of the natural population is based on monitoring programs aimed at both the potential effects of fish culture practices and of the subsequent effects on natural production of supplementation returns to natural spawning areas. This question is related to Objective 3, as large hatchery programs have considerable potential to affect the genetic structure of populations with which they interact.

Approach (12b): Monitoring the effects of fish culture relative to program objectives follows the protocols outlined in the Ad Hoc Supplementation Monitoring and Evaluation Workgroup document (Galbreath et al. 2008). A full description of the objectives, indicators, and metrics employed for minimizing detrimental effects of culture practices can be found in the NOAA Fisheries Snake River HGMP Biological Opinion (NMFS 2012). As with other programs, evaluating potential effects of an ongoing supplementation program is a difficult proposition and involves monitoring or periodic studies directed specifically at the population as well as considering results from intensive studies in other production areas or multivariate analyses across combined data sets including supplemented and non-supplemented populations (NMFS 2012).

Assessment of the potential effects of the ongoing supplementation program on genetics and life history characteristics begins with data from the annual trapping program described under Objectives 1 and 2. Genetic samples of natural-origin and hatchery-origin returns are analyzed to evaluate genetic patterns across time and between the programs (see Status 11a). Life history patterns, specifically including age-at-return, size-at-age, and trends in overwintering versus subyearling migration, are also monitored at the aggregate population level. Annual monitoring is accompanied by directed studies to evaluate potential effects; for example, the potential effects of hatchery returns from yearling releases on the relative proportions of subyearling versus overwintering in natural production from those spawners (see NPT/NWFSC study).

The inability to obtain carcass samples hampers the ability to evaluate subpopulation structure within the Lower Snake River fall Chinook salmon population. The use of an aggregate broodstock collected at Lower Granite Dam combined with relatively high levels of releases across major spawning areas may be preventing local adaptation and the development of natural patterns of subpopulation structure.

Analysis (12b): In the absence of a true supplemented control population, or a reasonable reference population, as is the case with the Snake River fall Chinook salmon population, the only approach available is analysis of trends, such as changes in age composition, or per capita density corrected productivity. Not currently available, but likely available soon will be genomic tools to relate signals in genetic samples to quantitative traits.

Status (12b): Ongoing trapping of adult returns at Lower Granite Dam provides the primary source of information on possible hatchery effects on genetic and life history characteristics of the Lower Snake River fall Chinook salmon. Potentially useful genomic tools are being developed in many laboratories in the region.

Gaps (12b): Developing the means to evaluate and or monitor sub-population genetic structure across the major spawning areas within the Lower Snake River population is currently a significant gap. As returns from the PBT program come online, it may be possible to characterize genetic patterns based on samples from naturally produced juveniles in specific areas (e.g., the Upper Snake River, the Lower Snake River, the Clearwater River, and the Grande Ronde River). It is also possible that otolith patterns may allow for identification of naturally produced juveniles as well. However, given the current contribution rates of hatchery returns to potential spawning across all major spawning areas, it is likely that homogenization of genetic patterns is present. Possible exceptions would include the proposed South Fork Clearwater River component of the Nez Perce Tribe Hatchery Program, which is intended to use a specific broodstock in support of developing an earlier spawning run adapted to environmental conditions in that area. Reducing or eliminating hatchery releases across the population or within targeted major spawning areas should promote development of natural subpopulation structure. Developing the means to assess responses to such changes would be an important component of a future RM&E implementation plan.

Monitoring Question (12c): To what extent are ecological relationships affecting natural production of Snake River fall Chinook salmon impacted by hatchery production?

Recent patterns in natural-origin adult returns and in juvenile production indices are consistent with relatively high density-dependent effects at current spawning levels. The degree to which naturally produced juveniles are influenced by or interacting with direct release supplementation smolts is not understood. The presence of hatchery smolts in natural rearing and migration reaches may adversely affect natural production through increased competition for high quality rearing habitats or through increased exposure to or attraction of predators.

Approach (12c): The approach at this time is unclear. No general understanding of effects is available (see Status), or of large-scale experimental designs to detect effects. Moreover, this is a difficult population to study because of the large stream habitat it occupies, even for large-scale phenomena. Studying effects as subtle as ecological interactions is expected to be very challenging. A possible starting point is a detailed literature search on ecological effects of hatchery releases on natural-origin fish.

Analysis (12c): Unknown at this time.

Status (12c): Direct information on interactions between hatchery releases and natural production is not readily available. Brood year return rates of naturally produced adults and juvenile production indices can be used in correlative analyses to look for patterns that may indicate ecological interactions. Studies of density-dependent movement patterns, growth rates, or stage survivals may provide additional insights in the future.

Gaps (12c): A specific study design for elucidating possible ecological effects is lacking. However, a possible approach is the use of the Predation, Competition, Disease (PCD) Risk model (Pearsons and Busack 2012). The model generates hatchery and natural fish of specified size distributions. It then randomly pairs them for interactions for a specified number of days and encounters. Wild fish are subjected to predation if they are less than 50 percent the length of hatchery fish; otherwise they are subjected to competition. After all of the allowable competition and predation occurs, survivors are subjected to disease risk. The model can provide either deterministic or probabilistic output. Deterministic output includes the number and proportion of wild fish that die from predation, competition, disease, and from all interactions combined. Probabilistic output includes probability distributions of the number and proportion of mortalities, based on user-specified uncertainty input either as uniform or triangular distributions for any of several variables.

Although the model is a simulation involving many variables for which quantitative data are currently unavailable and must be estimated from expert opinion, many of the variables included are key factors in determining the quantity and type of ecological interaction, such as habitat segregation and complexity. Thus, even though the modeling involves a considerable degree of expert panel input, the simulations involve a considerably greater degree of realism than previous approaches, such as making evaluations based on comparisons of size and timing of hatchery and natural-origin fish. Recently a large evaluation of hatchery programs in the Upper Columbia (Mackey et al. 2014) demonstrates the value of the approach.

Monitoring Question (12d): Are out-of-basin strays altering the genetic profile of naturally produced Snake River fall Chinook salmon?

Straying of out-of-basin hatchery production into the Lower Snake River is monitored as part of the trap sampling efforts described under Objective 1. In the early 1990s, substantial numbers of hatchery-origin fish from the Bonneville and Priest Rapids Hatchery programs were identified in broodstock taken at Ice Harbor Dam and Lower Granite Dam. Mark spawning at the Lyons Ferry Hatchery, along with screening to avoid use of returns from earlier brood year releases that had included out-of-basin fish, was employed to minimize the incorporation of those fish in the Snake River Egg Bank program (e.g., Bugert et al. 1990). A substantial portion of the returns were unmarked releases of Priest Rapids stock into the Umatilla River. After 1994, 100 percent of the Umatilla River releases were marked and the program was reduced substantially. The combination of reduced release sizes and the dramatic increase in Snake River fall Chinook salmon returns has led to much lower out-of-basin proportions in recent years.

Approach (12d): The broodstock removal program at Lower Granite Dam results in a systematic sample of hatchery contributions across the annual return. Hatchery fish identified as having a CWT are taken to Lyons Ferry or the Nez Perce Hatchery and held until spawning. Mark spawning procedures are used at the hatcheries to avoid incorporating out-of-basin stocks into the Snake River Egg Bank program. The proportional contribution of out-of-basin stocks are estimated based on the CWT proportions in the samples. A basic assumption is that the fish removed at the trap for broodstock represent a random sample across the run. Therefore, the run over Lower Granite Dam is assumed to be represented in the broodstock. It is unknown the extent to which out-of-basin strays over Lower Granite Dam fall back below the dam or if those remaining do actually contribute to natural production (NMFS 2012). Since the genetic profile (allele frequencies at microsatellite or single nucleotide polymorphism [SNP] loci) of Snake River fall Chinook salmon will differ from that of other populations from which immigrants may originate, contributions to natural production by stray fish will be detectable as allele frequency changes over time.

Analysis (12d): Allele frequencies of Snake River fall Chinook salmon and nearby populations that are potential sources of strays must be periodically monitored. Changes in the direction of another population, above which would be expected by genetic drift, would be considered evidence of contribution by strays.

<u>Status (12d)</u>: The current routine genetic sampling of Snake River fall Chinook salmon for PBT will yield the necessary information for the population, and current levels of sampling of other populations, which can be expected to continue, will likely provide adequate information for the potential stray-source populations.

<u>Gaps (12d)</u>: There are two key issues associated with this monitoring measure that need to be resolved: 1) determining what a biologically meaningful signal would constitute, and 2) determining what level of sampling would be needed to detect a signal above the noise generated by genetic drift of the populations and by "normal" levels of gene flow between them.

Objective 13: Develop life-cycle models to identify and assess potential factors that could limit the viability of Snake River fall Chinook salmon, including effects under current climate change projection scenarios.

Multi-stage life cycle models that are under development for Snake River fall Chinook salmon should improve our understanding of the combined and relative effects of actions across the life cycle. These models incorporate empirical information and working hypotheses on survival and capacity relationships at different life stages. The models would provide a valuable framework for systematically assessing the potential response of Snake River fall Chinook salmon to alternative management strategies and actions under alternative climate scenarios. In addition to informing decisions about near-term management strategies, fall Chinook salmon life-cycle modeling can also be used in identifying key research, monitoring and evaluation priorities to improve future decision making. The development of multi-stage, life-cycle models will produce insights into potential density-dependent effects as a function of environmental conditions and provide a framework for evaluating the potential combined effects of management actions across life stages. Once fitted, the models will be used to assess "what if" scenarios. For example, changes in productivity resulting from changes in habitat, ocean conditions, harvest, and hatchery operations will be predicted.

Monitoring Questions:

- What factors are currently most limiting on natural production for the Snake River Fall Chinook Salmon population?
- How do alternative life history pathways (e.g., subyearling and yearling emigration/ ocean entry variations) contribute to natural production under varying environmental conditions?
- Integrating across current life stage survival and capacity estimates, what are the short and long term risks relative to survival and recovery criteria?
- How would natural production of Snake River Fall Chinook Salmon respond to future climate variations, including projected climate change scenarios?

- How would the population respond to alternative management actions across sectors (e.g., habitat, hydropower, harvest and hatcheries) either individually or in combination?

Approach: The starting point for model development is the recent historical series of estimated adult spawners and juvenile recruits for the population (See Objective 1).

Analysis: A three-stage life cycle model of the extant Lower Snake River fall Chinook salmon population is being developed using information generated by efforts aimed at several of the specific monitoring objectives listed in this Appendix B. Brood year adult production from each spawning year is estimated by reconstructing each cohort by age adding in harvest and passage losses (See Objectives 6 and 9). Estimates of natural-origin juvenile migrants produced from each brood year are compared to parent spawning levels to estimate a production function for the first stage included in the model (See Objective 1). Functional relationships describing survival through the second stage, downstream migration, will be based on information generated through Objective 6. Functional relationships or current survival distributions developed through efforts under Objective (7), describing current survival levels in the estuary/plume environments, will be incorporated. Ocean exploitation rates on mature and immature cohorts as well as in-river harvest rates (See Objective 9) will be used to establish baseline runs. Initial versions of the model could incorporate relatively simple assumptions regarding hatchery spawner effects. In the future, any information generated by actions to address Objective (12) could also be used.

Status: Spawner to returning adult data series are available through return year 2014 and it is anticipated that future years will be routinely added. Methods described under Objective (1c) are being used to develop a data series of annual natural-origin emigrant production estimates expressed as arrival at Lower Granite Dam. Arrival timing and relative proportions of known PIT-tag groups are being explored as approaches to estimate natural juvenile production by subarea (e.g., mainstem Snake River vs. Clearwater River). Additional relationships can be explored based on the results of recent juvenile survival studies. Adult returns to Lower Granite Dam are routinely generated and reported annually. Upstream adult passage survivals based on PIT-tag monitoring using data stored in the Pit Tag Information System (http://www.ptagis.org). Ocean exploitation rates based on extrapolation from Lyons Ferry CWT tagged releases and in-river harvest rates generated by the *U.S. v Oregon* Technical Advisory Committee are available annually.

Gaps: Estimates of representative downstream passage survival for subyearling and yearling emigrants are under development, but are not yet available (See Gaps 6a). Functional relationships for juvenile and adult life stages that would allow for evaluating the potential impacts of variations or trends in temperature or flow have not been developed but would be necessary to translate potential action scenarios into projected changes in population performance.

Objective 14: Determine the influence of toxic contaminants on the viability of Snake River fall Chinook salmon.

Recent studies have documented accumulation of persistent organic pollutants, including dichlorodiphenyltrichloroethane (DDTs), polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers (PBDEs) in migrating juvenile Snake River fall Chinook salmon collected in the Lower Columbia River and estuary (Sloan et al. 2010; Johnson et al. 2013). NMFS Biological Opinions on current use pesticides have also identified Snake River fall Chinook salmon as at risk because of application of several of these compounds to their critical habitat (NMFS 2008a, 2009, 2010, 2011). The NMFS Biological Opinion on the Oregon Water Quality Criteria (NMFS 2012) has also identified copper, ammonia, cadmium, and aluminum as threats to Snake River fall Chinook salmon at water quality criterion concentrations. It is unknown to what extent Snake River fall Chinook salmon are exposed to other contaminants of emerging concern, such as pharmaceuticals and personal care products. Even for those contaminant classes whose effects are better characterized, understanding of their interactions with other stressors, food-web mediated effects, and effects in complex mixtures is limited. This lack of knowledge may lead to underestimating the risks associated with currently permitted concentrations of these toxicants. Therefore, it is important to monitor and assess contaminant exposure and bioaccumulation in Snake River fall Chinook salmon, especially from locations where monitoring is limited (e.g., lower Snake River and the middle Columbia River). It is also important to assess the effects of toxics on individuals, spawning aggregates, and the population.

Monitoring Questions:

- What are contaminant exposure profiles in Snake River fall Chinook salmon?
- What proportions of fish are exposed to or are accumulating concentrations of contaminants at above levels associated with toxic effects?
- What are the major areas where exposure is occurring and sources of exposure?
- What are estimated population level effects of exposure, or to what extent would reduction in exposure contribute to population productivity for Snake River fall Chinook salmon?
- What is the effectiveness of actions undertaken to minimize exposure?

Monitoring Question (14a): What are contaminant exposure profiles in Snake River fall Chinook salmon***?***

This question focuses on obtaining adequate information on exposure to and uptake of contaminants of concern in Snake River fall Chinook salmon. Contaminants of concern include persistent organic pollutants (polycylic aromatic hydrocarbons [PAHs], PCBs, DDTs, other organochlorine pesticides, and PBDEs); metals including copper, cadmium, aluminum, and possibly mercury; current use pesticides; and pharmaceuticals and personal care products. Other considerations include exposure for specific life stages: eggs and larvae, outmigrant juveniles, and returning adults.

Approach (14a): The approach would initially rely on reviewing existing literature for documentation of contaminant concentrations in Snake River fall Chinook salmon of various life stages and in their critical habitat, as well as land use information that might provide data on pesticide applications, locations of industrial and municipal outfalls, etc. In some cases, data may be available on biological indicators that provide evidence of exposure to certain classes of compounds (e.g., vitellogenin induction in male or juvenile fish as evidence of exposure to environmental estrogens). The next steps would be to identify data gaps and develop and implement a plan to collect the needed data.

Analysis (14a): An analysis would include identifying and assessing the quality of available contaminant data in terms of the analytical methods used, how recently they were collected, and identifying major gaps in the information available. Efforts would then be made to develop plans to collect samples and perform analyses to obtain data that are lacking. To the extent possible this would take advantage of ongoing studies and collection efforts by agencies and entities involved in salmon or contaminant research for other purposes.

Status (14a): Concentrations of PBDEs, PCBs, and DDTs in outmigrant juvenile Snake River fall Chinook salmon collected in the Lower Columbia River have been measured in studies conducted by the NWFSC in collaboration with the Lower Columbia Estuary Partnership and the Bonneville Power Administration (LCREP 2007; Sloan et al. 2010; Johnson et al. 2013). Data are also available on PAH metabolites in the bile of Columbia River fall Chinook salmon, but not specific information on Snake River fall Chinook salmon (Yanagida et al. 2012). The Columbia River Inter-Tribal Fish Commission and EPA have collected data on concentrations of PCBs, DDTs, and other organochlorine pesticides, dioxins, and furans, and several metals including aluminum, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, selenium, vanadium, and zinc in eggs, filets, and whole bodies of adult fall Chinook salmon from the Columbia River (EPA 2002), but the data are not specific to Snake River fall Chinook salmon. Some additional data on concentrations of these contaminants in fall Chinook salmon are presented in the NMFS Biological Opinion on the Oregon Water Quality Standards (NMFS 2012), but again, are not specific to Snake River fall Chinook salmon. Oregon, Washington, and Idaho have monitoring programs to collect information on resident fish species in the Snake and Columbia Rivers. These studies may highlight areas of critical habitat where contaminants may be a concern, and could serve as a vehicle for collection of salmon samples for chemical analysis. NOAA's biological opinions on current use pesticides (e.g., NMFS 2008b, 2009, 2010, 2011) provide information on land use and pesticide application in critical habitat of Snake River fall Chinook salmon. The NMFS Biological Opinion on Oregon Water Quality Standards (NMFS 2012) contains data on exposure to ammonia, arsenic, lindane, cadmium, chromium (III), chromium (VI), copper, dieldrin, endosulfan-alpha, endosulfan-beta, endrin, heptachlor epoxide, lead, nickel, pentachlorophenol, selenium, silver, tributyltin, and zinc. Pharmaceuticals and chemicals of emerging concern have been detected in waters that are part of critical habitat for Snake River fall Chinook salmon (Morace 2012). Abnormal induction of the yolk protetin, vitellogenin, which is an indicator of exposure to environmental estrogens, has also been reported in outmigrant juvenile Chinook salmon from the Lower Columbia River (LCREP 2007). However, this finding is not specific to Snake River fall Chinook salmon.

Gaps (14a): No specific information is available on contaminant concentrations in returning Snake River fall Chinook salmon, or on eggs and larvae at spawning grounds and in natal streams. Data are very limited on exposure of fall Chinook salmon to pharmaceuticals and personal care products, and no specific data are available for Snake River fall Chinook salmon. Mercury has been identified as a contaminant of concern for resident fish in the Columbia River, but risks to Snake River fall Chinook are uncertain. Some available data may be out of date, collected ten year ago or more.

Monitoring Question (14b): What proportions of fish are exposed to or are accumulating concentrations of contaminants at above levels associated with toxic effects?

This question focuses on assessing risk of chemical contaminants to Snake River fall Chinook salmon based on contaminant exposure profiles and available data on contaminant toxicity. Contaminants of concern include persistent organic pollutants (PAHs, PCBs, DDTs, and other organochlorine pesticides, and PBDEs), metals (copper, cadmium, aluminum, and possibly mercury), current use pesticides, and pharmaceuticals and personal care products. Other considerations include exposure for specific life stages: eggs and larvae, outmigrant juveniles, and returning adults.

Approach (14b): The approach would compare available data on contaminant exposure profiles for chemicals of concern in Snake River fall Chinook salmon to concentrations associated with lethal or sublethal injury to salmon, either directly or indirectly through effects on the prey base.

Analysis (14b): The analysis would involve calculating proportions of Snake River fall Chinook salmon above threshold concentrations for those contaminants for which such information is available, and developing a risk assessment for likelihood of lethal or sublethal injury to salmon, either directly or indirectly through effects on the prey base.

Status (14b): Threshold tissue residue concentration associate with injury in salmon have been estimated for PCBs, DDTs, PBDEs, and mercury (Meador et al. 2002; Beckvar et al. 2005; Arkoosh et al. 2011). For PAHs, there are dietary estimates as well as threshold values for bile metabolites (Meador et al. 2008). Based on existing data on PCBs, PBDEs, and DDTs in outmigrant juvenile Snake River fall Chinook salmon, it is estimated that 20 percent exceed the thresholds for DDTs and PCBs and 25 percent exceeded the threshold for PBDEs (Johnson et al. 2013). NMFS Biological Opinions have identified areas of critical habitat affected by application of current use pesticides (NMFS 2008, 2009, 2010, 2011). The NMFS Biological Opinion on Oregon Water Quality Standards (NMFS 2012) reviewed the effects of a number of contaminants at water quality criterion levels on Snake River fall Chinook salmon and determined that levels of copper, ammonia, cadmium, and aluminum allowed under the water quality standards could jeopardize this stock and adversely modify its critical habitat.

Gaps (14b): There is uncertainty about threshold exposure concentrations associated with toxicity to salmon for some classes of contaminants, as well as uncertainty about the indirect effects of contaminants on the salmon prey base. Mercury has been identified as a contaminant of concern for resident fish, but the proportion of Snake River fall Chinook salmon, especially the proportion of juveniles, with levels of concern, is unknown.

Monitoring Question (14c): What are the major areas where exposure is occurring and sources of exposure?

This question focuses on obtaining adequate information on contaminant sources and areas of Snake River fall Chinook salmon critical habitat that are impaired by chemical contaminants. Contaminants of concern include persistent organic pollutants such as PCBs, DDTs, PBDEs, PAHs, as well as some metals such as copper, cadmium, aluminum, and possibly copper.

Approach (14c): The approach would rely on documentation of contaminant concentrations in fall Chinook salmon of various life stages in different areas of critical habitat and to identify areas of exposure to a major risk factor and sources of contamination.

Analysis (14c): An analysis would involve examining existing contaminant monitoring and land use data across the critical habitat of Snake River fall Chinook salmon to identify contaminant hot spots and to pinpoint, where possible, sources of contamination. Where available, data on exposure levels in salmon or resident fish could also be used to identify regions where contaminants are a concern and to highlight the classes of contaminants that pose the greatest problems.

Status (14c): In NWFSC studies on juvenile fall chinook salmon from the Columbia River, higher concentrations of PCBs have consistently been observed in all stocks, including Snake River fall Chinook salmon collected from sites at or below the Portland/Vancouver area than in fish collected in the Columbia Gorge (between Bonneville Dam and Troutdale) (LCREP 2007; EPA 2009; Johnson et al. 2011). This highlights the Portland/Vancouver area and downstream areas as major sources for PCB uptake in salmon. NMFS Biological Opinions have identified areas of critical habitat affected by application of current use pesticides (NMFS 2008b, 2009, 2010, 2011). The

NMFS Biological Opinion on Oregon Water Quality Standards (NMFS 2012) provides information on 303(d) listed water bodies in Oregon, as well as spatial distribution of contaminant discharges in relation to fish distribution. Additional data are also available from monitoring conducted by EPA, USGS, and the states of Oregon, Washington, and Idaho.

Gaps (14c): Although environmental data on contaminant levels are available for many areas, specific data on contaminant concentrations in Snake River fall Chinook salmon of all life stages that would confirm uptake and exposure are limited or lacking. Some available data may no longer be accurate as the information was collected ten years ago or more.

Monitoring Question (14d): What are estimated population level effects of exposure, or to what extent would reduction in exposure contribute to population productivity for Snake River fall Chinook salmon?

This question focuses on obtaining adequate information on exposure to and uptake of contaminants in Snake River fall Chinook salmon. Contaminants of concern include persistent organic pollutants such as PCBs, DDTs, PBDEs, and PAHs. Other considerations include exposure for specific life stages: eggs and larvae, outmigrant juveniles, and returning adults.

Approach (14d): The approach would compile data on contaminant exposure profiles and likely extent of injury to Snake River fall Chinook salmon expressed as changes in growth, mortality, and reproductive rates. This information would then be incorporated in population models to estimate how injury associated with contaminants might affect population growth rates and abundance of Snake River Chinook salmon. The most comprehensive model is that used for pesticides BiOps and it could be adapted for other classes of contaminants including copper, persistent organic pollutants (POPs), and endocrine disrupting contaminants (EDCs).

Analysis (14d): The analysis would incorporate available data on changes in growth, mortality, and reproductive rates of Snake River Chinook salmon into population models to estimate effects of contaminant-related injury on parameters such as population growth rates, probability of and time to extinction, and abundance. For maximum utility, the models would incorporate not only direct effects of contaminant exposure on vital rates of salmon, but indirect effects associated with impacts on the salmon prey base.

Status (14d): Some effort has been made to address the population-level effects of various classes if contaminants, including POPs (Loge et al. 2005; Spomberg and Johnson 2008), current use pesticides (Baldwin et al. 2009; NMFS 2008b, 20009, 2010, 2011), and metals such as copper (NMFS 2012) on Columbia River fall Chinook salmon. The model developed by the NWFSC to address direct and indirect effects of current use pesticide exposure to Pacific Northwest salmon and used in the Section 7 national pesticide consultations (NMFS 2008b, 2009) is the most comprehensive of these efforts. This model explicitly defines pesticide exposures (duration and concentration) for salmon with different life history strategies (ocean-type and stream-type Chinook, sockeye, and coho) and models salmon growth rate as a function not only of the fish's ability to capture food, which can be directly affected by pesticide exposure, but also by the availability of food to capture, which is determined by the toxicity of the pesticide to the salmon prey base. The models are also modified to fit the specific life history pattern (e.g., life span, age-specific survival, age-specific reproduction) for each species. The NMFS Biological Opinion on the Oregon Water Quality Criteria (NMFS 2012) also includes analyses of the effects on fall Chinook salmon population growth rates of direct mortality associated with exposure to water quality criterion concentrations of ammonia, arsenic, lindane, cadmium, chromium (III), chromium (VI), copper, dieldrin, endosulfan-alpha, endosulfan-beta, endrin, heptachlor epoxide, lead, nickel, pentachlorophenol, selenium, silver, tributyltin, and zinc. A more comprehensive analysis examines population-level effects of copper exposure on both growth and mortality. However, all of these models are limited for assessment of risks to Snake River fall Chinook salmon populations in that they do not include exposure profiles and growth and survival information specific to this stock.

<u>Gaps (14d)</u>: None of the population models developed to date incorporate ESU-specific growth, survival and reproductive data or contaminant exposure scenarios specific to ESUs. To quantify contaminant-attributable reductions in survival for the Snake River fall Chinook salmon ESU, an exposure analysis would be needed to more accurately estimate exposure concentration, timing, duration, and location within the habitats used by this stock, and would need to be parameterized with stock-specific growth and survival data for the Snake River fall Chinook salmon ESU. This information may not be available for all contaminants of concern. Indirect effects of contaminants on the salmon prey base have been assessed and incorporate only into models dealing with current-use pesticides, and should be considered for other classes of contaminants. Also, modeling efforts to date have been conducted to deal with effects of specific classes of contaminants (e.g., pesticides, dissolved copper, POPs), but analyses incorporating combined effects of multiple contaminant stressors are needed to provide a comprehensive assessment of risks associated with toxicants.

Monitoring Question (14e): What is the effectiveness of actions undertaken to minimize exposure?

This question focuses on obtaining information on the effectiveness of ongoing efforts (e.g., Portland Harbor cleanup) to reduce toxicant exposure and minimize toxicant-related injury in Snake River fall Chinook salmon.

Approach (14e): The approach would rely on effectiveness monitoring at locations where toxics reduction actions are conducted. Ideally such activities would be incorporated into clean-up, remediation, and restoration plans for areas of concern, such as superfund sites. Long-term monitoring would also be needed to assess trends in exposure associated with regulations banning certain contaminants such as some PBDEs. Collaboration among multiple agencies would be needed to implement and support such a program.

Analysis (14e): An analysis would involve compiling baseline data on current exposure profiles and/or health indicators for Snake River fall Chinook salmon of various life stages at areas where toxics reduction efforts are planned, then conducted follow-up monitoring after these measures have been put into place to see whether conditions have improved.

Status (14e): A variety of toxics reduction efforts are underway that could affect Snake River fall Chinook salmon. These include Superfund and Natural Resource Damage and Restoration actions in Portland Harbor, Bradford Island, and other areas. Substantial baseline data are available on concentrations of several classes of contaminants at some sites, such as Portland Harbor, including some data for fall Chinook salmon. NMFS has also proposed a variety of reasonable and prudent alternatives for reducing the risk of current use pesticides to salmon, and programs conducted by the Oregon Department of Ecology are collecting information to document their effectiveness. The Lower Columbia Estuary Partnership's Ecosystem Monitoring program provides limited information on time trends for toxic contaminants at representative sites, but is not designed to assess changes associated with specific cleanup or toxics reduction activities.

Gaps (14e): Clear plans and/or funding are often lacking for toxics reduction effectiveness monitoring at sites where remediation and restoration activities are planned or underway. Currently, there is no long-term monitoring plan for toxic contaminants in the Columbia River.

Objective 15: Determine the feasibility of restoring passage to fall Chinook salmon populations in habitats upstream of the Hells Canyon Complex.

Before mainstem dam construction, significant fall Chinook salmon spawning occurred in the upper reaches of the Middle Snake River upstream of the present-day Hells Canyon Dam site. The most important areas were generally upstream of the confluence of the Snake River and the Boise River up to Auger Falls. Large groundwater inflows associated with discharge from the Eastern Snake River Plain Aquifer strongly influenced the thermal regime favoring ocean-type production of fall Chinook salmon. There are several large tributaries that enter into the middle Snake River, including the Bruneau River, Boise River, Owhyee River, Payette River, Weiser River, Malheur River, Burnt River and Powder River. There are a few anecdotal accounts of the lower portions of these rivers being used for spawning by fall Chinook salmon, but these rivers were affected early by mining and dam construction and their historic significance relative to

Snake River Fall Chinook salmon is unknown. Construction of Swan Falls Dam in 1901 created a barrier to fall Chinook salmon migration and limited spawning to areas downstream from Swan Falls Dam. The area referred to as the Marsing Reach, between Swan Falls Dam and the town of Marsing, was the primary spawning area in the middle Snake River before construction of the Hells Canyon Complex, which ultimately eliminated access to the middle Snake River. Dam construction upstream of Swan Falls further fragmented the river into five reaches separated by dams. The largest riverine reaches are downstream from Bliss Dam and downstream from Swan Falls Dam. Habitat quality in all reaches are influenced by various land uses, especially irrigated agriculture both in terms of heavy sediment and nutrient loading from irrigation returns and altered hydrographs.

Monitoring Questions:

- Are there suitable habitats for incubation, rearing, and adult holding available in reaches upstream from Hells Canyon under present-day conditions?
- For candidate reintroduction reaches, what are egg-to-emigrant survival rates associated with current and improved habitat conditions?
- Given downstream emigrant survival rates for naturally produced juveniles from the extant lower Snake population, what levels of egg-to-emigrant, downstream passage, or transport survival would be required to establish sustained natural production in suitable reaches upstream from the Hells Canyon Complex and what reaches are best suited for reintroduction?
- Is a collection and/or passage system feasible with survival levels necessary to sustain a population?

Monitoring Question (15a): Are there suitable habitats for incubation, rearing, and adult holding available in reaches upstream from Hells Canyon under present-day conditions?

This question focuses on identifying river segments upstream from Hells Canyon Dam that have the physical habitat attributes to support spawning and rearing of fall Chinook salmon. Considerations for suitable habitats include thermal regimes and associated life histories, availability of suitable spawning and incubation gravels, and suitable juvenile rearing and migration, and adult holding habitats.

> ***Approach (15a):*** The approach would rely on documentation of historical spawning locations where available, or identification of areas that have attributes similar to known spawning areas observed in the extant population downstream of Hells Canyon Dam. Reaches where spawning habitat appears to be available would be delineated. Within these reaches, year-round monitoring of water quality metrics such as turbidity and temperature are needed at biologically relevant locations, including the main river, its hyporheic zone, tributary confluences, and other areas likely to provide thermal refuge. A description of the fish assemblages within these reaches, with focus on potential

predators/competitors of rearing and emigrating juvenile fall Chinook salmon, would provide indication of potential factors that would influence survival during the rearing and migration periods. A description of Snake River reservoir characteristics associated with these reaches will be necessary to determine potential migration and passage of juvenile fall Chinook salmon.

Analysis (15a): An analysis would include calculating thermal statistics that describe anticipated emergence timing based on past/present-day observations of spawning distributions. Note that there may be spatial variability in this quantity. Based on our observations in the extant population downstream from Hells Canyon Dam, it is anticipated that predator/competitor interactions would occur during the rearing and emigration period. In general, warmer temperatures will likely increase feeding activities by warm-water predators such as bass and catfish.

Status (15a): The Idaho Power Company relicensing reports describe historic spawning locations in reaches upstream of the Hells Canyon Dam. The reports also describe thermal regimes of different reaches upstream of Hells Canyon Dam as well as potential emergence timing of fall Chinook salmon assuming present-day temporal spawning distributions. The Idaho Power Company initiated temperature and turbidity monitoring of reaches in the Middle Snake River in the 1990's and it is still ongoing. The Idaho Power Company has conducted fish community surveys at 5-year intervals in the riverine and reservoir reaches of the Middle Snake River and will continue these in the future.

Gaps (15a): There are no gaps for this monitoring question.

Monitoring Question (15b): For candidate reintroduction reaches, what are egg-to-emigrant survival rates associated with current and improved habitat conditions?

Because of the predominate agricultural land-use associated with the Middle Snake River, heavy sediment/nutrient loads known to impair salmonid spawning habitats are prevalent. Large macrophyte beds have developed throughout known historic spawning habitats. Macrophyte beds accumulate fine sediments that infiltrate salmon redds and degrade the quality of spawning habitats. Hydrographs have been altered because of agricultural storage reservoirs distributed throughout the Upper and Middle Snake River basins. Diversion of water for irrigation purposes has changed the hydrology such that spring-freshets are no-longer common, and limited flushing flows to clean gravels or scour macrophyte-dominated areas rarely occur.

Approach (15b): Relative egg-to-emergence (incubation) survival can be quantified by putting live eggs (green or eyed) into containers within simulated redds within historic habitats and within extant habitats. Measures of extant incubation survival can provide a metric for expected survival rates under improved habitat conditions. An approach to quantify and partition emergence through emigrant survival is problematic, with sampling problems similar to the extant areas. Screw traps could be deployed to estimate survival of various release groups; however, trap efficiencies may be low in a river this size and interactions between trap efficiency and flow lead to uncertain estimates. Radio, hydroacoustic, or PIT-tag technologies could be deployed using hatchery-reared individuals. However this could only be accomplished using larger/older juvenile pre-smolts just before or during emigration. If we are successful in estimating emigration survival, then early rearing survival could be derived from overall survival and emigration survival. The availability of hatchery fish for various release groups and egg sources will need to be determined.

Analysis (15b): Egg-to-emergent fry survival can be directly quantified from containers in the gravel. Estimates of survival of various release groups could be made through captures in screw traps. Survival from late rearing through emigration could be roughly quantified based on mark/recapture techniques of transmitters past points downstream of spawning areas. These estimates will help populate model parameters for a life-cycle model (discussed further under Monitoring Question 14c) that could be used to quantify what survival levels through various egg-to-emigrant periods would be necessary to sustain returns given survival parameters of other life stages quantified from the extant population.

Status (15b): In their final Environmental Impact Statement for the Hells Canyon Complex relicensing, the FERC identified monitoring needs associated with the quality of historic spawning habitats relative to implementation of defined total maximum daily loads (TMDLs) throughout the Middle Snake River reach. The Idaho Power Company has evaluated egg-to-emergence survival during three incubation seasons in the Marsing Reach of the Snake River using live eggs in containers placed in simulated redds.

Gaps (15b): There are no gaps for this monitoring question.

Monitoring Question (15c): Given downstream emigrant survival rates for naturally produced juveniles from the extant lower Snake population, what levels of egg-to-emigrant, downstream passage, or transport survival would be required to establish sustained natural production in suitable reaches upstream from the Hells Canyon Complex and what reaches are best suited for reintroduction?

Reintroduction will provide a demographic benefit to the Snake River ESU only if all life stages originating in the new, upstream spawning areas experience sufficient survival and avoid having adverse effects on the extant population downstream from Hells Canyon. The ability to parse out those components of survival associated with collection, transport, spawning, and rearing in the new areas, and downstream migration (or transport) is essential to evaluating potential for success. Anticipating what levels of survival might be under present-day conditions is necessary to assess potential success of a reintroduction effort and prioritize factors that would need to be addressed to implement a successful program.

Approach (15c): The approach would be the development of a multi-stage life-cycle model that incorporates estimates of survival through various stages of the salmon life cycle to assess population viability. Incorporation of realistic management operations, such as trapping, transport, entrainment, and/or hatchery operation, in addition to natural demographic processes (e.g., reproduction, survival), is essential. Such a tool would allow direct estimation of future viability under alternative scenarios as well as intermediate indicators such as abundance and intrinsic population productivity. The outcome would be the ability to estimate what levels of early survival would be required, both during the two periods of assisted migration and within the upstream reintroduction area to realize success. In addition, the model will assess the ESU as a whole, considering interactions between the two spawning areas. This life-cycle model would be developed largely from similar data sets used to develop the multi-stage life-cycle model described under Objectives 1 and 12, and estimation of parameters described under Monitoring Question 15b. For Snake River fall Chinook salmon, intrinsic productivity has been estimated using two procedures: (1) the basic averaging method (ICTRT 2007) and (2) by fitting stock-recruitment functions (see Monitoring Question 1c).

Analysis (15c): Monitoring Question 1c focuses on alternative viability criteria metrics for Snake River fall Chinook salmon. Section 4 of the Recovery Plan requires estimates of productivity (including a measure of statistical uncertainty) at either of two different spatial levels: (1) the aggregate population or (2) for a targeted set of one or more major spawning areas. A similar analysis would be necessary to evaluate potential productivity of additional spawning aggregates associated with reintroduced populations upstream from Hells Canyon Dam. Additional questions would be measures of intrinsic productivity and viability of the ESU if other populations were added, and if the intrinsic productivity of the extant population is affected by reintroduction efforts.

Status (15c): A modeling approach separate from that described in Objectives 1 and 13 was initiated by the Idaho Power Company and Oak Ridge National Laboratory to assess population viability of the extant population and to understand how access to additional spawning areas in the blocked habitat upstream of Hells Canyon Dam will affect the viability of the extant population and the ESU as a whole. The current Population Viability Analysis (PVA) model represents groups of salmon by age, juvenile life history, spawning area of origin (above or below), and tagging status. In addition to natural processes, the model simulates assisted passage and hatchery operation. The PVA is used in a Bayesian multi-modeling framework whereby parameters producing hind-casts that are more likely, given the historical reconstruction data, are assigned higher weight in forward projections. The model is still under development to refine treatment of the Clearwater spawning areas, and may be supplemented by an individual-based version that will allow stronger ties to physical habitat (e.g., water quality, contaminants), simulation of population genetics, and possibly consideration of climate-change effects. Such a modeling approach would be capable of addressing the question of whether a reintroduction effort could sustain two genetically distinct populations or separate spawning aggregates of the larger extant population given the degree of inter-breeding that is present under the present-day passage systems.

Gaps (15c): Improvements in the available data sets on adult and juvenile abundance are outlined under the status section of Monitoring Question (1a) and gaps section of Monitoring Question (1c). The modeling effort described under this Objective would benefit greatly from collaboration through the Life Cycle Modeling initiative being carried out under the Adaptive Management Implementation Plan.

Monitoring Question (15d): Is a collection and/or passage system feasible with survival levels necessary to sustain a population?

Construction of the Hells Canyon Complex initially included passage of anadromous fish including fall Chinook salmon with the hope of sustaining the natural production that was occurring upstream of the Complex. Although passage of adults using traps at the base of the dams and hauling them upstream of the dams was successful, efforts to pass juvenile fish through the large impoundment created by Brownlee Reservoir and collect them near Brownlee Dam were not. This failure ultimately led to discontinuing the passage effort and creating the present-day blockage at the Hells Canyon Complex. Dams upstream of the Hells Canyon Complex associated with other potential reaches do not have passage systems.

Approach (15d): The approach for this question would be to evaluate the adult trapping system associated with the Hells Canyon Dam to determine what components would be necessary to support a reintroduction program. The ability to sort adult fish at the trap and evaluate PIT tags and/or other marks would be a necessity. The approach to assessing the feasibility of a passage system for juvenile fish is more complex. A complete review/evaluation of juvenile passage options relative to current technology and what has been learned about juvenile passage through reservoirs since initial efforts in Brownlee Reservoir is necessary. Evaluation of reservoirs associated with other potential reservoirs in this same context would be necessary. Behavioral studies using radio-tag or hydroacoustic technologies would be necessary to identify potential passage routes and evaluate ranges of potential collection efficiencies of passage options based on similar passage systems at other locations (possibly in combination with studies described under Monitoring Question 15b).

Analysis (15d): Estimation of passage efficiencies could be incorporated into the multi-stage life-cycle model to evaluate the feasibility of passage relative to sustaining a population (Monitoring Question 14c). Following evaluation of passage options and life-cycle models, determinations of feasibility could be determined. If passage options were determined to be feasible, then a second phase of evaluation would be necessary to incorporate broader considerations and evaluations of passage/reintroduction relative to legal, economic, and social feasibility questions. A third phase, if determined feasible, would be engineering design and possible construction of prototypes to begin to test collection efficiencies and feasibility.

Status (15d): A literature review of passage options that could have application to the Hells Canyon Complex was conducted by the Idaho Power Company and is included in the application to relicense the Hells Canyon Complex. An evaluation and conceptual design for modification of the Hells Canyon Dam adult fish trap was also included as part of the relicensing application. Modifications of the adult trap are included as part of the Protection, Mitigation, and Enhancement measures to be implemented by the Idaho Power Company upon license issuance. This facility modification will proceed as part of the existing hatchery program for broodstock collection, even if it is not used for passage purposes. No specific funding or plans are in place to support behavioral and passage studies of juvenile fall Chinook salmon within blocked habitats upstream of Hells Canyon Dam.

Gaps (15d): Funding or specific plans to conduct juvenile fall Chinook salmon behavior or further passage options evaluations have not been identified.

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Temperature in the Lower Snake River during Fall Chinook Salmon Egg Incubation, Fry Emergence, Shoreline Rearing, and Early Seaward Migration

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Introduction

Temperature in the lower Snake River salmon during fall Chinook salmon egg incubation, fry emergence and shoreline rearing in riverine habitat, and during early seaward migration in Lower Granite Reservoir was an important consideration during the writing of the recovery plan. This file report briefly addresses three sets of questions asked during that process.

1. What is the average water temperature in the mainstem Snake River (a. below Hells Canyon Dam to the Salmon River and b. Salmon River to Lower Granite Res) during egg incubation? What temperature(s) triggers emergence timing from the gravel to shoreline riverine areas?

2. What temperature triggers dispersal from these areas to Lower Granite Reservoir? Our example in the plan says peak dispersal from upper and lower reaches of the Snake River into Lower Granite Reservoir were May 28 and June 4, respectively, in 1995 (Connor et al. 2002). Do we have anything more recent? What is the relationship between these migration dates and temperature? Are the fish leaving the reaches before temperature becomes a concern? How do operations at Hells Canyon Complex contribute to these temperatures and dispersal timing?

3. What are the average temperatures when juvenile fall Chinook pass Lower Granite Dam? We say that in 2011 the median date for passage of juveniles from the Hells Canyon-Salmon River reach was June 16 (Connor et al. 2012). What was the temperature in mid-June? Again, are the fish getting out before temperature becomes a big concern?

After providing a brief description of the influence of operation of the Hells Canyon Complex of dams on temperature in the Snake River upper and lower reaches and Lower Granite Reservoir, this report focuses on answering the above three sets of questions. Tables and figures are attached after the text before the acknowledgements section.

Hells Canyon Complex and Temperatures Downstream

Water stored in Brownlee Reservoir passes rapidly through Oxbow and Hells Canyon reservoirs that have little storage capacity, thus the temperature of water released at Brownlee Dam is the primary determinant of temperature in the tailrace of Hells Canyon Dam. As has been pointed out in the recovery plan, the Snake River upper reach extends from Hells Canyon Dam to the Salmon River mouth. The majority of flow through the upper reach is provided by releases of water from Hells Canyon Dam; hence the water temperature in that reach is determined almost solely by the temperature of the water released from Brownlee Dam. Discharge downstream of the Salmon River mouth in the Snake River lower Reach is also dominated by outflow from Hells Canyon Dam. For example in brood year 1993 (fall of 1993 through spring of 1994) discharge from Hells Canyon Dam made up 69%, 66%, 70%, and 46% of the flow volume in the lower reach during immigrations, spawning, and early and late incubation (Nelle and Connor 1996). Therefore, temperature in the lower reach is also affected by operation of the Hells Canyon Complex of Dams but not to the extent observed in the upper reach.

The thermal structure in Brownlee Reservoir is principally determined by the amount of inflow and spring flood control operations. In a high inflow year, with a corresponding flood control draft, the average reservoir temperature will be warmer in late summer and fall than it will be in a low inflow year. During a high flow year, the reservoir is re-filled with warmer inflowing water, whereas during a low flow year, the reservoir retains more of the cold water stored over the winter. Thus, in a high flow year, the hypolimnetic water is warmer than in a low flow year. In a high flow year, Brownlee Reservoir is also significantly drafted in late summer and early fall in preparation for the stable fall Chinook salmon spawning flow program. In low flow years, the reservoir is drafted less in preparation for these flows. The extent of the fall drawdown influences the temperature of the discharge from Hells Canyon Dam. In a high flow year, much of the warm water collected during the summer months is evacuated early and the cooler fall inflows has a greater influence on downstream water temperatures. In low flow years, much of the warmer summer water is retained and delays the effect of the cooler inflows. Thus in high flow years, salmonid spawning temperatures are cooler than in low flow years, as a reflection of reservoir draft.

Brownlee Dam passes water over the spillways during spring months in some years and through the turbine intakes year round. The turbine intakes draw water generally from the epilimnion and metalimnion of the reservoir. The elevation of the intake channel to the powerhouse dictates the elevation of the metalimnion and establishes the hypolimnion deeper than the intakes to the power house. Drawing water from this level in the reservoir typically allows for outflows to be cooler than the inflowing water from generally mid-March to mid-September. Brownlee Reservoir is dimictic mixing during the spring and late fall and stratifying in the summer and winter. Summer stratification usually occurs in late April to early May and is typically very strong, with much colder hypolimnetic waters than the epilimnion, whereas thermal differences in the winter are less structured, with colder water near the surface but much of the reservoir volume is uniform in temperature. Around mid-September, inflowing water begins to cool, but outflowing water from Brownlee is still reflective of the large thermal mass in the epilimnion. Thus water temperatures in the discharge generally exceed the inflowing water temperature until late fall. During the winter months, inflowing water and surface waters in the reservoir are typically colder than the deeper waters. Thus water temperature in the discharge during winter months is typically warmer than the inflows. In the spring, the influence of the warming inflowing water is delayed because of the large cold mass of water in the reservoir. The warming inflow water begins to flow over the colder deep water and accelerates the thermal stratification. Thus, water passed through the turbines during summer is cooler than reservoir surface temperatures and water passed through the turbines in the winter is warmer than reservoir surface water, with periods during these transitions where these conditions switch. The ability to manage these thermal dynamics of the reservoir and temperature of the discharge with operations of the reservoir alone would be difficult because of the many variables that influence the thermal structure. In some conditions, the ability to increase or decrease discharge volume could change the thermal characteristics of the outflow. Similarly, the ability to draft or fill the reservoir under certain thermal conditions or time periods could alter temperatures in the outflow.

Question Set 1: Temperature, Incubation, and Fry Emergence

Temperature is warmer from October through January during spawning and incubation in the upper reach than in the lower reach (Figure 1). Water temperature is similar between the two reaches from February until roughly the third week of April depending on year, after which the upper reach becomes warmer than the lower reach through emergence (Figure 1).

Compared to mean temperature during incubation, the initial temperature at fertilization is a more powerful indicator of habitat suitability for fry production along the lower Snake River. Geist et al. (2006) fertilized Lyons Ferry Hatchery fall Chinook salmon eggs and then assigned them to replicated, starting temperature treatments (13.0^{o}C, 15.0^{o}C, 16.0^{o}C, 16.5^{o}C, and 17.0^{o}C). Dissolved oxygen in the 13.0^{o}C and 17.0^{o}C treatment replicates was held at saturation, whereas the remaining three treatment replicates were subdivided and held at oxygen levels of 4 mg/L, 6 mg/L, 8 mg/L and saturation. The apparatus that produced each temperature treatment was programmed to drop the temperature by approximately 0.2^{o}C/d for 40 d, while increasing the dissolved oxygen level by 2 mg/L/d starting 16 d post fertilization. The 40-d temperatures were selected to bound the1991–2003 interannual mean thermal regime in the Snake River upper reach, and the 4 mg/L oxygen treatment represented the lowest level observed at a spawning site along the upper reach. After 40 days, the temperatures were equilibrated among the treatments to match the 2001 drought year temperatures. Mean (± SD) survival from fertilization to emergence calculated across the three coolest temperature treatments and the corresponding oxygen treatments was 92.7 ± 4.7% compared to 93.1 ± 1.4% for fish in the 16.5^{o}C treatment and 1.7 ± 1.6% for fish in the 17.0^{o}C treatment. Geist et al. (2006) concluded that exposure to water temperatures up to 16.5^{o}C will not have deleterious effects on survival or growth from egg to emergence if temperatures decline at a rate of 0.2^{o}C/d or more after spawning and dissolved oxygen levels remain above 4 mg/L.

The results of Geist et al. (2006) support rephrasing part of Question Set 1 as such "What percentage the eggs fertilized in the Snake River upper and lower reaches are fertilized at initial temperatures above 16.5^{o}C?" Answering that question requires information on time of spawning and temperature. Redd count data collected along the Snake River upper and lower reaches (see Groves et al. 2013 for details) provide the best available science on spawn timing. The first date of spawning in a given year was estimated here by subtracting 7 days from the flight date when redds were first counted in each reach. For example, the first redds counted during 1991 in the lower reach were counted on a flight made on 28-Oct. Thus, 21-Oct was assigned as the start date for the "first spawning interval redds were constructed" (Table 1). The end date for that interval was equal to the flight date of 28-Oct minus 1, which resulted in a survey interval duration of 6 days (Table 1). The same steps were taken to establish the second and third survey intervals and to populate Tables 2 and 3. Together the three intervals covered contiguous periods of time (e.g., 1991 lower reach; first interval 21-Oct to 27-Oct; second interval 28-Oct to 3-Nov; third interval 4-Nov to 10-Nov; Tables 1–3). After defining the intervals, the tables were populated with interval mean, interval minimum daily mean, and interval maximum daily mean temperatures. The temperatures in Table 1 were then compared to the 16.5^{o}C threshold for high survival from fertilization to emergence established by Geist et al. (2006).

Survival from fertilization to fry emergence was probably low in the Snake River lower reach in the drought year 2001 through some portion of the second survey interval, and in 2014 during the first survey interval redds were constructed (Table 1). Observations of temperatures above 16.5^{o}C were more common and possibly more detrimental to survival from fertilization to emergence in the Snake River upper reach than in the Snake River lower reach. Temperature above 16.5^{o}C were observed during the first survey interval redds were counted in the upper reach in 1994, 1996, 1999–2001, 2003–2007, 2010–2012, and 2014 (Table 1). Temperatures above 16.5^{o}C were observed during the second survey interval in the upper reach in 2001 and 2005 and during the third survey interval in 2001 (Tables 2 and 3). This simple assessment points to temperature during spawning as a factor for fry loss, but it did not quantify the extent of that loss.

The first step to quantifying fry loss due to warm temperatures was to calculate the cumulative percentage of the total annual redd count made in each reach by interval (Tables 1–3). In the lower reach during 2001, the first 0.5% of the all redds that were eventually counted were counted when temperature remained between 17.4^{o}C and 18.3^{o}C (Table 1) during the first survey interval when redds construction was observed. No new redds were constructed during the second spawning interval when the maximum temperature observed was also above 16.5^{o}C (Table 2). Thus, estimated fry loss due to temperature in the lower reach during 2001 was 0.5% (Tables 1 and 2). Estimating fry loss was not as simple in the lower reach during 2014 when 2.6% of all the redds that were eventually counted were counted between a nonlethal temperature of 14.1^{o}C and a lethal temperature of 17.0^{o}C (Table 1). To estimate fry loss in that instance, a method that used the data Table 1 was applied as shown below by example where 13 is the interval duration.

	Date	Daily estimates of cumulative (%) redd counts			Mean daily temperature
Interval start date ==>	10/13/2014	2.6% / (13+1)	=	0.2%	17.0
	10/14/2014	2.6% / (13+1) + 0.2%	=	0.4%	16.6
	10/15/2014	2.6% / (13+1) + 0.4%	=	0.6%	16.2
	10/16/2014	2.6% / (13+1) + 0.6%	=	0.7%	15.8
	10/17/2014	2.6% / (13+1) + 0.7%	=	0.9%	15.6
	10/18/2014	2.6% / (13+1) + 0.9%	=	1.1%	15.7
	10/19/2014	2.6% / (13+1) + 1.1%	=	1.3%	15.7
	10/20/2014	2.6% / (13+1) + 1.3%	=	1.5%	15.6
	10/21/2014	2.6% / (13+1) + 1.5%	=	1.7%	15.4
	10/22/2014	2.6% / (13+1) + 1.7%	=	1.9%	15.2
	10/23/2014	2.6% / (13+1) + 1.9%	=	2.0%	15.0
	10/24/2014	2.6% / (13+1) + 2.0%	=	2.2%	14.6
	10/25/2014	2.6% / (13+1) + 2.2%	=	2.4%	14.5
Interval end date ==>	10/26/2014	From (Table 1)		2.6%	14.1

That method allocates the cumulative percentage of redds constructed during the interval across the individual days within the interval, and then compares those daily cumulative percentages to temperature on those individual days. Fry loss due to warm water temperatures in the lower reach during 2014 was estimated to be 0.4% of the total fry production in that reach and year. The same method was then applied to data collected in the upper reach. Annual fry loss in the upper reach due to exposure to temperatures above 16.5^{o}C averaged (± SD) 2.0 ± 2.3% and ranged from 0.2% to 7.3% (Table 4).

With respect to the second question in Question Set 1, fry emergence is not triggered by a daily mean temperature threshold. Development of fall Chinook eggs and the timing of fry emergence primarily proceed according to the accrual of temperature units (Wallach 1901). For example, 10 temperature units would accrue if average temperature was 10^{o}C the first 24 h after fertilization and cumulative temperature units would be 20 if temperature remained at 10^{o}C during the following 24 h. In the lower and upper reaches of the Snake River, it takes just over 1,000 cumulative temperature units for fry to emergence (Connor et al. 2003a). The nature of the thermal regime (e.g., Figure 1) insures that the fry emerge at temperatures well above freezing and well below annual maxima. That conclusion was confirmed with empirical data as follows.

On average, and during 13 years of the 1994–2013 time period when both reaches were beach seined, the median date of fry (≤ 45-mm fork length; Connor et al. 2002) presence along the shorelines (i.e., the best available science on emergence timing) was earlier in the Snake River upper reach compared to the lower reach (Table 5). During the other 6 years, the median dates of fry emergence timing were identical (Table 5). Under the thermal regimes observed in the two reaches there is little difference in the water temperature experienced by fry in those two reaches (Table 5).

Question Set 2: Temperature and Dispersal into Lower Granite Reservoir

Timing of temperature-related parr (≥ 45-mm fork length; Connor et al. 2002) dispersal from the shorelines of the Snake River lower and upper reaches into Lower Granite Reservoir can be assessed by using beach seine data to calculate the median date of parr presence. Time of dispersal becomes earlier as the median catch date becomes earlier and vice versa. Connor et al. (2013) evaluated the factors affecting the median date of parr presence by analyzing data collected jointly on fish in the Snake River upper and lower reaches. They reported the results for the following model fitted from data collected by beach seining during 1992–2011 (R^2 = 0.64; N = 20; P < 0.0007):

$\log_e$ Annual median day of capture = 5.164 - 7.003 * CPUE - 0.012 * Max°C + 0.031 * Flow;

where CPUE was annual mean catch per unit effort used to represent relative abundance during shoreline rearing, Max°C was the annual maximum spring temperature, and Flow was the annual mean spring flow.

The r^2 value for a bivariate regression model fitted from annual mean CPUE to predict the annual median day of parr capture was roughly five times higher than the r^2 values for the maximum spring river temperature and mean spring river flow partial regression models (0.46 versus 0.07 and 0.10) suggesting that competition for food and space was a stronger factor for dispersal timing into the reservoir from the two reaches compared to the factors flow and temperature. Annual median day of capture was inversely proportional to annual maximum spring river temperature indicating that fish began downstream dispersal earlier during warm springs compared to cool springs, but there was no evidence for a temperature trigger per se. Annual median day of capture was directly proportional to annual mean spring river flow suggesting that fish began downstream later in high flow years compared to low flow years, seining efficiency was low early and high late during high flow years, or a combination of those two explanations.

The results in the preceding paragraph provided some evidence for temperature-related dispersal, but do not answer the question "Are the fish leaving the reaches before temperature becomes a concern?" To answer that question; the peak, first, and last dates of parr presence were tabulated with the mean daily temperatures on that peak and the seasonal mean and maximum daily mean temperatures during rearing (Table 6). Here, the peak date represented the point in time when downstream dispersal into the reservoir exceeded recruitment to the shorelines of the two reaches, and the last date of parr presence defined the point in time when shoreline rearing was complete and all survivors had entered the reservoir.

The work of Geist et al. (2010) with natural-origin fall Chinook salmon juveniles transferred from the upper reach to a laboratory was used in part to evaluate the suitability of temperature for growth. They found that growth in both fork length and weight increased as temperature increased from 14.0^{o}C to 20.0^{o}C and declined slightly up to a temperature of 22.0^{o}C. The work of Yankee (2006) conducted with juvenile Lyons Ferry Hatchery fall Chinook salmon, was also used to evaluate the suitability of temperature for growth, but also to address physiological development, and survival. He observed severely reduced growth and large physiological responses in blood plasma indicative of acute stress, cellular damage, and impaired nutrition in fish reared in a 24.0^{o}C treatment that started at approximately 14.0^{o}C and then gradually increased over 3 weeks to 24.0^{o}C where it was held for an additional 3 weeks. He also documented 100%mortality several hours after temperature exceeded 26.0^{o}C in a 28.0^{o}C treatment that also started at 14.0^{o}C and was increased over time as described for the 24.0^{o}C treatment. The combined work of Yankee (2006) and Geist et al. (2010) showed that: (1) exposure of juvenile fall Chinook salmon to a naturally increasing thermal regime of 14.0^{o}C to 20.0^{o}C does not raise large concerns relevant to growth, physiological development, and survival; (2) exposure to 24.0^{o}C can have severe growth and physiological consequences, and (3) temperatures above 26.0^{o}C are almost instantaneously lethal even if the fish are gradually acclimated to warm water.

The above three temperature criteria were then compared to the temperatures experienced by parr in the Snake River lower and upper reaches (Table 6). That comparison suggested that temperature was not a concern at the peak of parr presence in the upper and lower reaches (Table 6). Maximum temperature at the end of shoreline rearing, however, did exceed 20.0^{o}C in the lower reach during 6 of 19 years, and in the upper reach during 1 of 19 years (Table 6). In all of those cases, temperature did not exceed the 24.0^{o}C benchmark for severely reduced growth and retarded physiological development, or the 26.0^{o}C for direct mortality. The results on growth were particularly important because a high rate of parr growth in the upper reach is a large factor for parr-to-smolt survival (Connor et al. 2012).

Question Set 3: Temperature and passage through Lower Granite Reservoir

During summer, cold water from Dworshak Reservoir (11–16ºC) moves underneath the warmer water from Brownlee Reservoir and the lower Snake River tributaries (20–23ºC) at the confluence of the lower Snake and Clearwater rivers to create large variations in both vertical and cross-channel temperature distributions (Figure 2; Cook et al. 2006). The temperature distributions change as water is mixed and moves downstream; however, strong vertical gradients persist. Tiffan et al. (2009) fitted juvenile fall Chinook salmon with temperature sensing radio tags and found that the majority of the subyearlings maintained average body temperatures that differed from average vertical profile temperatures during most of the time they were tracked in the reservoir. The mean proportion of the time subyearlings were tracked within the 16–20°C temperature range was larger than the proportion of time this range was available, which confirmed temperature selection opposed to random use. The subyearlings also selected a depth and temperature combination that allowed them to increase their exposure to temperatures of 16-20ºC when temperatures <16 and >20ºC were available at lower and higher positions in the water column. Those results confirmed that juvenile fall Chinook salmon are capable of "behavioral thermoregulation."

Constant recording of temperature throughout Lower Granite Reservoir to explicitly document annual temperature regimes in three dimensions would be labor intensive, so managers rely on a water quality monitor installed in the tailrace of Lower Granite Dam that reports the mean temperature of the reservoir water after it is mixed by the turbines (CBR 2015). A 2000 decision by the State of Idaho to deny waivers for exceeding dissolved gas levels above 110% in the tailrace of Dworshak Dam affected the implementation of summer flow augmentation. To avoid exceeding that "gas cap," the maximum volume of water that could be released from Dworshak Dam was reduced to approximately 397 m^3/s/d (14,000 ft^3/s/d). Thus in some years, the full 1.2 million acre feet of stored water in Dworshak Reservoir available for summer flow augmentation could not be released by the end of August. Managers subsequently extended the flow augmentation period from August 31 through the first two weeks of September. For that reason, analyses were restricted here to the years 2000–2013.

Connor et al. (2014) reported daily estimates of passage abundance for natural-origin fall Chinook salmon at Lower Granite Dam during 2000–2013. Annual daily mean tailrace temperatures were plotted against those estimates and compared here to the temperature criteria established for Question Set 2 (Figures 3–16). In most years, daily passage decreased after temperature approached 20.0^{o}C. The 20.0^{o}C temperature threshold was not exceeded in 2000, 2002, 2004, 2005, and 2008–2012. Temperature in 2001 ranged from 20.2–20.8^{o}C between 6 and 7 July and was 20.1^{o}C from 9 to 11 September that year (Figure 4). Temperature averaged 20.1^{o}C on 30 August 2003 (Figure 6). On 1 July 2006 temperature averaged 20.3^{o}C and ranged from 20.1^{o}C to 20.6^{o}C between 1 and 7 July that year (Figure 9). Temperature averaged 20.1^{o}C on 5 July 2007 (Figure 10). Temperature averaged 20.1^{o}C on 22 August 2013 and between 20.1^{o}C to 20.4^{o}C between 19 and 22 September that year (Figure 16).

Given that juvenile fall Chinook salmon are capable of behavioral thermoregulation; the above results do not raise concerns relevant to growth, physiological development, and survival reductions directly linked to temperature. Parr-to-smolt survival, however, decreases as the passage season becomes later (Connor et al. 2003b, 2012; Smith et al. 2003). Temperature-related predation is likely the source of late-season mortality——and as such—predation is a large concern.

Tables and Figures

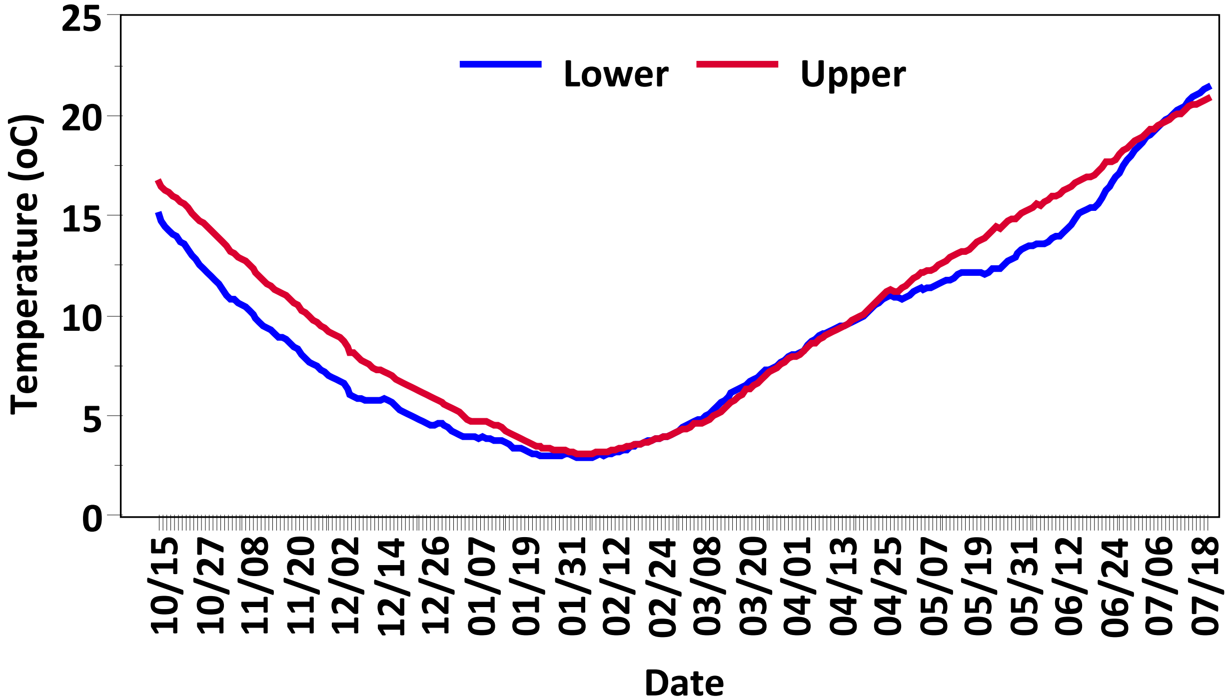

Figure 1.—Twenty-year mean daily water temperature in the Snake River upper and lower reaches during spawning, fry emergence and shoreline rearing, brood years 1994 to 2013. Water temperature in this and all figures and tables were collected using reach-specific thermographs by the Idaho Power Company.

Table 1.—Information mean daily temperature (^oC) and cumulative (%) redd counts in the Snake River upper and lower reaches during the first survey interval, 1991–2014. The first survey interval was established based on the flight date when redds were first counted minus 7 (i.e., start date) and the flight date minus 1 (End date). Temperatures above 16.5^oC are given underlined in bold.

	Lower reach							Upper reach						
				Temperature							Temperature			
Year	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count	Start date	End date	Interval duration (d)	Mean	Min	Max	Cumulative (%) redd count
1991	21-Oct	27-Oct	6	14.0	13.1	15.0	5.0	4-Nov	10-Nov	6	12.6	12.3	12.9	9.1
1992	29-Oct	4-Nov	6	12.8	11.9	13.4	6.9	29-Oct	4-Nov	6	14.7	13.9	15.3	12.5
1993	18-Oct	24-Oct	6	14.1	13.3	15.1	4.3	25-Oct	31-Oct	6	14.2	13.7	14.7	35.7
1994	25-Oct	31-Oct	6	13.0	11.7	13.7	4.5	17-Oct	23-Oct	6	16.1	15.4	**16.8**	2.9
1995	23-Oct	29-Oct	6	11.5	10.7	11.9	7.7	16-Oct	22-Oct	6	15.3	14.6	16.1	14.3
1996	21-Oct	27-Oct	6	11.7	11.1	12.1	22.7	14-Oct	20-Oct	6	16.0	15.3	**16.8**	4.1
1997	13-Oct	19-Oct	6	14.5	13.7	15.0	3.4	20-Oct	26-Oct	6	13.3	12.6	13.8	40.0
1998	19-Oct	25-Oct	6	12.4	12.1	13.1	42.3	19-Oct	25-Oct	6	14.6	14.2	15.1	15.6
1999	11-Oct	17-Oct	6	15.5	14.5	16.2	4.2	11-Oct	17-Oct	6	16.5	15.6	**17.1**	1.3
2000	16-Oct	22-Oct	6	13.8	13.2	14.1	2.9	2-Oct	8-Oct	6	**17.1**	**16.7**	**17.4**	0.5
2001	2-Oct	8-Oct	6	**18.3**	**17.4**	**19.3**	0.5	2-Oct	8-Oct	6	**19.0**	**18.4**	**19.8**	2.7
2002	14-Oct	20-Oct	6	13.8	13.4	14.0	2.9	14-Oct	20-Oct	6	15.3	14.9	15.6	3.8
2003	20-Oct	26-Oct	6	15.0	13.9	15.6	5.9	13-Oct	19-Oct	6	**17.6**	**17.2**	**18.1**	0.7
2004	11-Oct	17-Oct	6	15.8	15.6	16.0	0.2	18-Oct	24-Oct	6	**16.8**	16.2	**17.4**	7.4
2005	11-Oct	17-Oct	6	14.9	14.8	15.1	0.3	11-Oct	17-Oct	6	**16.8**	**16.6**	**17.1**	1.1
2006	16-Oct	22-Oct	6	14.0	13.2	15.0	4.4	16-Oct	22-Oct	6	16.1	15.6	**16.6**	5.3
2007	23-Oct	29-Oct	6	11.8	11.0	12.6	12.1	8-Oct	14-Oct	6	**17.1**	16.5	**17.6**	0.2
2008	13-Oct	19-Oct	6	13.6	13.2	14.6	3.7	13-Oct	19-Oct	6	16.1	16.0	16.5	0.8
2009	12-Oct	18-Oct	6	13.7	13.0	14.3	2.4	12-Oct	18-Oct	6	15.9	15.5	16.5	0.5
2010	18-Oct	1-Nov	14	13.5	12.4	14.6	4.0	18-Oct	1-Nov	14	16.1	15.0	**16.9**	2.5
2011	17-Oct	30-Oct	13	13.9	12.4	15.2	1.2	17-Oct	30-Oct	13	15.6	14.4	**17.1**	2.4
2012	15-Oct	28-Oct	13	13.7	11.8	15.8	5.2	15-Oct	28-Oct	13	16.0	14.5	**17.6**	1.4
2013	14-Oct	27-Oct	13	12.9	12.0	14.1	4.7	14-Oct	27-Oct	13	15.5	14.6	16.5	4.9
2014	13-Oct	26-Oct	13	15.5	14.1	**17.0**	2.6	13-Oct	26-Oct	13	**17.6**	**16.6**	**18.7**	1.3
Mean ± SE							6.4 ± 1.8							7.1 ± 2.1

Table 2.—Information mean daily temperature (^{o}C) and cumulative (%) redd counts in the Snake River upper and lower reaches during the second survey interval, 1991–2014. Temperatures above 16.5^{o}C are given underlined in bold.

	Lower reach							Upper reach						
Year	Start date	End date	Interval duration (d)	Temperature Mean	Temperature Min	Temperature Max	Cumulative (%) redd count	Start date	End date	Interval duration (d)	Temperature Mean	Temperature Min	Temperature Max	Cumulative (%) redd count
1991	28-Oct	3-Nov	6	11.4	10.2	12.6	10.0	11-Nov	18-Nov	7	11.6	11.1	12.1	40.9
1992	6-Nov	15-Nov	9	10.9	10.2	11.7	48.3	6-Nov	15-Nov	9	12.8	12.1	13.7	37.5
1993	25-Oct	31-Oct	6	12.0	11.4	12.9	32.6	1-Nov	7-Nov	6	13.1	12.4	13.7	71.4
1994	31-Oct	5-Nov	5	11.2	10.5	11.7	36.4	25-Oct	30-Oct	5	14.9	14.3	15.2	11.4
1995	30-Oct	4-Nov	5	9.4	8.5	10.4	92.3	23-Oct	29-Oct	6	13.9	13.3	14.2	42.9
1996	28-Oct	3-Nov	6	10.8	10.2	11.2	50.0	21-Oct	27-Oct	6	14.6	13.9	14.9	46.9
1997	20-Oct	26-Oct	6	11.9	11.0	12.6	31.0	27-Oct	2-Nov	6	12.2	11.7	12.6	75.0
1998	26-Oct	1-Nov	6	11.6	11.0	12.1	73.1	26-Oct	1-Nov	6	13.5	13.0	13.9	47.7
1999	18-Oct	24-Oct	6	13.2	12.8	13.8	22.9	18-Oct	24-Oct	6	14.9	14.7	15.2	15.6
2000	23-Oct	29-Oct	6	12.2	11.8	12.5	8.7	9-Oct	15-Oct	6	15.8	15.5	16.4	2.7
2001	8-Oct	14-Oct	6	16.0	15.1	**<u>17.4</u>**	0.5	8-Oct	14-Oct	6	17.4	16.8	**<u>18.4</u>**	2.7
2002	21-Oct	27-Oct	6	12.6	11.6	13.5	17.4	21-Oct	27-Oct	6	14.3	13.6	15.0	26.6
2003	27-Oct	2-Nov	6	12.7	10.6	14.3	21.7	20-Oct	26-Oct	6	**<u>16.8</u>**	16.1	**<u>17.3</u>**	7.6
2004	18-Oct	24-Oct	6	14.4	13.4	15.2	8.4	25-Oct	31-Oct	6	15.5	14.9	15.9	33.4
2005	18-Oct	23-Oct	5	14.8	14.4	15.0	14.7	18-Oct	23-Oct	5	16.3	16.0	**<u>16.6</u>**	11.8
2006	23-Oct	6-Nov	14	11.3	9.5	13.0	56.4	23-Oct	6-Nov	14	14.1	13.1	15.5	38.2
2007	30-Oct	6-Nov	7	10.5	10.1	11.4	52.6	15-Oct	22-Oct	7	15.7	15.3	16.4	4.1
2008	20-Oct	26-Oct	6	12.8	12.3	13.5	22.0	20-Oct	26-Oct	6	15.2	14.9	15.9	15.4
2009	19-Oct	25-Oct	6	13.2	12.5	13.8	10.2	19-Oct	25-Oct	6	14.9	14.5	15.4	8.6
2010	2-Nov	15-Nov	13	11.4	10.1	12.4	46.4	2-Nov	15-Nov	13	13.9	12.7	15.0	60.9
2011	31-Oct	13-Nov	13	10.3	9.3	12.4	34.0	31-Oct	13-Nov	13	12.5	11.3	14.3	67.8
2012	29-Oct	11-Nov	13	11.6	9.8	12.4	50.3	29-Oct	11-Nov	13	13.8	12.3	14.6	78.3
2013	28-Oct	10-Nov	13	10.5	9.4	11.8	66.9	28-Oct	10-Nov	13	13.1	12.1	14.4	87.6
2014	27-Oct	9-Nov	13	13.1	11.9	13.9	36.2	27-Oct	9-Nov	13	15.5	14.4	16.3	70.3
Mean ± SE							35.1 ± 4.7							37.7 ± 5.5

Table 3.—Information mean daily temperature (^oC) and cumulative (%) redd counts in the Snake River upper and lower reaches during the third survey interval, 1991–2014 interval. Temperatures above 16.5^oC are given underlined in bold.

	Lower reach							Upper reach						
	Start	End	Interval	Temperature			Cumulative (%)	Start	End	Interval	Temperature			Cumulative (%)
Year	date	date	duration (d)	Mean	Min	Max	redd count	date	date	duration (d)	Mean	Min	Max	redd count
1991	4-Nov	10-Nov	6	10.0	9.5	10.3	50.0	19-Nov	24-Nov	5	10.2	9.6	10.8	72.7
1992	16-Nov	26-Nov	10	9.0	7.4	10.0	93.1	16-Nov	26-Nov	10	11.1	9.8	12.0	68.8
1993	1-Nov	7-Nov	6	10.7	9.9	11.2	50.0	8-Nov	14-Nov	6	11.6	11.0	12.1	100.0
1994	6-Nov	13-Nov	7	10.0	9.4	10.4	40.9	31-Oct	5-Nov	5	13.6	12.9	14.1	42.9
1995	5-Nov	12-Nov	7	8.4	8.0	8.7	100.0	30-Oct	4-Nov	5	12.3	11.6	13.0	67.9
1996	4-Nov	11-Nov	7	9.5	9.0	10.1	95.5	28-Oct	3-Nov	6	13.5	12.9	13.8	81.6
1997	27-Oct	2-Nov	6	10.6	9.9	11.0	34.5	3-Nov	9-Nov	6	11.5	11.2	11.6	85.0
1998	2-Nov	9-Nov	7	10.2	9.6	10.9	92.3	2-Nov	9-Nov	7	12.2	11.6	12.9	75.2
1999	25-Oct	3-Nov	9	12.0	11.1	12.8	43.8	25-Oct	3-Nov	9	13.7	12.7	14.5	46.7
2000	30-Oct	5-Nov	6	11.1	10.6	11.7	42.0	16-Oct	22-Oct	6	15.3	14.6	15.5	11.3
2001	15-Oct	21-Oct	6	14.5	14.2	15.2	2.4	15-Oct	21-Oct	6	16.3	15.9	**16.8**	2.7
2002	28-Oct	3-Nov	6	10.1	9.0	11.7	47.5	28-Oct	3-Nov	6	12.2	11.4	13.7	61.7
2003	3-Nov	12-Nov	9	9.5	8.9	10.7	58.5	27-Oct	2-Nov	6	15.1	14.0	16.4	33.6
2004	25-Oct	31-Oct	6	12.5	11.8	13.0	31.9	1-Nov	7-Nov	6	14.0	13.6	14.5	82.9
2005	24-Oct	30-Oct	6	13.7	12.9	14.3	38.3	24-Oct	30-Oct	6	15.5	15.1	15.9	33.5
2006	7-Nov	12-Nov	5	9.9	9.2	11.1	58.1	7-Nov	12-Nov	5	12.4	12.0	13.2	86.4
2007	7-Nov	12-Nov	5	9.7	9.3	10.0	72.8	23-Oct	29-Oct	6	14.5	14.1	15.2	25.9
2008	27-Oct	2-Nov	6	11.8	11.6	12.3	56.0	27-Oct	2-Nov	6	14.1	13.9	14.5	68.5
2009	26-Oct	1-Nov	6	11.3	10.7	12.3	40.7	26-Oct	1-Nov	6	13.5	13.0	14.4	64.4
2010	16-Nov	28-Nov	12	8.0	6.3	10.1	83.1	16-Nov	28-Nov	12	10.9	9.6	12.6	88.6
2011	14-Nov	20-Nov	6	8.6	8.0	9.2	89.6	14-Nov	20-Nov	6	10.7	10.0	11.3	93.6
2012	12-Nov	25-Nov	13	9.1	8.2	9.6	100.0	12-Nov	25-Nov	13	11.3	10.5	12.2	97.5
2013	11-Nov	26-Nov	15	8.3	6.6	9.5	100.0	11-Nov	26-Nov	15	10.8	9.5	12.0	98.7
2014	10-Nov	23-Nov	13	8.4	7.2	11.5	99.3	10-Nov	23-Nov	13	11.8	10.3	14.2	96.4
Mean ± SE							63.3 ± 5.7							66.1 ± 5.8

Table 4.—Estimated fry loss associated with temperatures above 16.5°C in the Snake River upper reach during years of the period 1991–2014 when temperature did exceed 16.5°C at the onset of spawning. Abbreviations: %, estimated daily cumulative (%) redd count; °C, mean daily temperature. Continued on next page.

	1994		1996		1999		2000		2001		2003		2004	
Date	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C
2-Oct							0.1	17.4	0.1	19.8				
3-Oct							0.1	17.3	0.3	19.5				
4-Oct							0.2	17.4	0.4	19.2				
5-Oct							0.3	17.3	0.5	18.9				
6-Oct							0.4	17.1	0.7	18.7				
7-Oct							0.4	16.8	0.8	18.5				
8-Oct							0.5	16.7	0.9	18.4				
9-Oct								16.4	1.1	18.0				
10-Oct								16.1	1.2	17.4				
11-Oct					0.2	16.8		15.9	1.4	17.1				
12-Oct					0.4	17.0		15.8	1.5	16.9				
13-Oct					0.6	17.1		15.6	1.6	16.8	0.5	18.1		
14-Oct			0.6	16.8	0.7	16.9		15.6	1.8	17.2	1.1	18.0		
15-Oct			1.2	16.5	0.9	16.1		15.5	1.9	16.8	1.6	17.4		
16-Oct			1.8	16.2	1.1	15.8			2.0	16.6	2.2	17.2		
17-Oct	0.4	16.8	2.3	16.0	1.3	15.6			2.2	16.4	2.7	17.3		
18-Oct	0.8	16.7	2.9	15.7					2.3	16.0	3.3	17.5	1.1	17.4
19-Oct	1.2	16.3	3.5	15.7					2.4	15.9	3.8	17.4	2.1	17.0
20-Oct	1.7	16.3	4.1	15.3					2.6	16.1	4.3	17.3	3.2	17.0
21-Oct	2.1	16.0							2.7	16.0	4.9	17.3	4.2	17.0
22-Oct	2.5	15.5									5.4	17.2	5.3	16.7
23-Oct	2.9	15.4									6.0	17.0	6.3	16.3
24-Oct											6.5	16.5	7.4	16.2
25-Oct											7.1	16.1		
26-Oct											7.6	16.1		
Loss (%)	0.8		0.6		0.7		0.5		2.0		6.0		5.3	

Table 4.—(Continued)

	2005		2006		2007		2010		2011		2012		2014	
Date	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C	%	°C
8-Oct					0.0	17.6								
9-Oct					0.1	17.5								
10-Oct					0.1	17.2								
11-Oct	0.9	17.1			0.1	17.0								
12-Oct	1.8	16.9			0.1	16.9								
13-Oct	2.7	16.8			0.2	16.7							0.1	18.7
14-Oct	3.6	16.8			0.2	16.5							0.2	18.4
15-Oct	4.5	16.7									0.1	17.6	0.3	18.2
16-Oct	5.4	16.6	0.8	16.6							0.2	17.4	0.4	18.0
17-Oct	6.4	16.6	1.5	16.4					0.2	17.1	0.3	16.9	0.5	17.9
18-Oct	7.3	16.6	2.3	16.2			0.2	16.9	0.3	16.9	0.4	16.8	0.6	17.9
19-Oct	8.2	16.4	3.0	16.1			0.3	16.7	0.5	16.7	0.5	16.7	0.7	17.8
20-Oct	9.1	16.3	3.8	16.0			0.5	16.7	0.7	16.5	0.6	16.7	0.7	17.6
21-Oct	10.0	16.3	4.5	15.7			0.7	16.7	0.9	16.3	0.7	16.3	0.8	17.5
22-Oct	10.9	16.1	5.3	15.6			0.8	16.7	1.0	15.9	0.8	15.9	0.9	17.2
23-Oct	11.8	16.0					1.0	16.6	1.2	15.7	0.9	15.5	1.0	17.0
24-Oct							1.2	16.4	1.4	15.5	1.0	15.3	1.1	17.0
25-Oct							1.3	15.9	1.5	15.0	1.1	15.1	1.2	16.8
26-Oct							1.5	15.8	1.7	14.7	1.2	14.8	1.3	16.6
27-Oct							1.7	15.8	1.9	14.7	1.3	14.6		
28-Oct							1.8	15.7	2.1	14.4	1.4	14.5		
29-Oct							2.0	15.5	2.2	14.5				
30-Oct							2.2	15.2	2.4	14.4				
31-Oct							2.3	15.2						
1-Nov							2.5	15.0						
Loss (%)	7.3		0.8		0.2		1.0		0.5		0.6		1.3	

Table 5.—Date of fry presence along the Snake River upper and lower reaches, and mean water temperature (^oC) on those dates, 1995–2013.

		Date of fry presence			Mean water temperature		
Year	Reach	First	Median	Last	First	Median	Last
1995	Lower	02-Apr	30-Apr	04-Jun	8.5	10.7	13.2
1996	Lower	15-Apr	06-May	24-Jun	8.5	10.7	13.9
1997	Lower	20-Apr	04-May	29-Jun	9.8	11.7	18.2
1998	Lower	12-Apr	26-Apr	14-Jun	9.6	10.7	15.5
1999	Lower	04-Apr	02-May	27-Jun	8.5	10.6	15.4
2000	Lower	03-Apr	10-Apr	05-Jun	9.3	10.3	14.8
2001	Lower	01-Apr	06-May	03-Jun	7.8	11.4	14.9
2002	Lower	31-Mar	05-May	16-Jun	6.8	11.0	16.2
2003	Lower	23-Mar	20-Apr	22-Jun	7.6	10.1	15.6
2004	Lower	22-Mar	03-May	07-Jun	7.4	12.8	15.2
2005	Lower	27-Mar	17-Apr	05-Jun	6.8	10.0	13.8
2006	Lower	26-Mar	14-May	11-Jun	6.8	13.1	14.9
2007	Lower	25-Mar	29-Apr	03-Jun	8.6	12.9	16.7
2008	Lower	24-Mar	28-Apr	16-Jun	6.8	9.9	13.8
2009	Lower	22-Mar	26-Apr	14-Jun	6.2	10.0	14.9
2010	Lower	21-Mar	25-Apr	20-Jun	7.5	9.9	14.2
2011	Lower	27-Mar	08-May	10-Jul	7.7	11.3	16.8
2012	Lower	26-Mar	07-May	11-Jun	7.0	11.3	12.6
2013	Lower	24-Mar	28-Apr	16-Jun	5.5	11.6	16.1
Mean ± SD		30-Mar ± 9 d	30-Apr ± 8 d	15-Jun ± 10 d	7.7± 1.2	11.1± 1.0	15.1± 1.4
1995	Upper	02-Apr	23-Apr	21-May	8.2	10.1	14.0
1996	Upper	15-Apr	29-Apr	06-May	10.7	12.0	12.7
1997	Upper	20-Apr	20-Apr	20-Apr	9.9	9.9	9.9
1998	Upper	12-Apr	19-Apr	10-May	9.3	9.7	13.9
1999	Upper	04-Apr	02-May	23-May	8.9	11.3	15.8
2000	Upper	03-Apr	10-Apr	15-May	9.1	10.3	13.9
2001	Upper	01-Apr	29-Apr	20-May	7.4	9.9	12.5
2002	Upper	31-Mar	21-Apr	02-Jun	6.1	10.3	14.3
2003	Upper	23-Mar	13-Apr	25-May	7.2	9.8	13.7
2004	Upper	22-Mar	19-Apr	24-May	6.7	11.4	14.0
2005	Upper	27-Mar	17-Apr	15-May	6.6	9.0	12.7
2006	Upper	26-Mar	16-Apr	21-May	6.2	9.6	14.9
2007	Upper	25-Mar	22-Apr	03-Jun	7.5	10.8	15.9
2008	Upper	31-Mar	28-Apr	26-May	7.2	10.0	13.6
2009	Upper	22-Mar	19-Apr	17-May	5.1	8.9	13.8
2010	Upper	21-Mar	25-Apr	06-Jun	7.2	10.5	14.0
2011	Upper	27-Mar	08-May	12-Jun	7.4	11.2	15.0
2012	Upper	26-Mar	30-Apr	18-Jun	6.9	12.8	16.7
2013	Upper	24-Mar	21-Apr	26-May	4.8	9.9	14.0
Mean ± SD		30-Mar ± 8 d	23-Apr ± 7 d	23-May ± 13 d	7.5± 2.0	10.4± 2.3	14.0± 3.1

Table 6.—Dates of parr presence along the Snake River upper and lower reaches (see Connor et al. 2002) including and temperature (^oC) on the peak of rearing, and mean and maximum temperature over the rearing period, 1995–2013.

		Date of parr presence			Mean water temperature		
Year	Reach	Peak	First	Last	On Peak	Mean	Max
1995	Lower	07-Jun	05-Apr	06-Jul	11.6	12.2	16.8
1996	Lower	29-May	17-Apr	18-Jul	12.8	13.3	20.4
1997	Lower	13-Jun	22-Apr	16-Jul	13.5	14.0	19.8
1998	Lower	26-May	14-Apr	08-Jul	12.4	13.6	19.6
1999	Lower	16-Jun	06-Apr	15-Jul	14.3	12.7	19.8
2000	Lower	10-May	05-Apr	29-Jun	12.0	13.5	19.4
2001	Lower	22-May	04-Apr	27-Jun	13.9	13.0	19.8
2002	Lower	29-May	02-Apr	16-Jul	13.3	13.3	22.3
2003	Lower	21-May	25-Mar	02-Jul	11.5	12.1	19.4
2004	Lower	19-May	01-Apr	30-Jun	12.9	13.1	19.7
2005	Lower	11-May	29-Mar	05-Jul	11.1	12.7	19.7
2006	Lower	16-May	11-Apr	27-Jun	13.2	13.2	19.5
2007	Lower	08-May	27-Mar	03-Jul	11.9	13.3	20.5
2008	Lower	14-May	27-Mar	17-Jul	10.5	12.0	19.9
2009	Lower	19-May	08-Apr	07-Jul	12.6	13.0	20.3
2010	Lower	18-May	30-Mar	20-Jul	13.0	12.9	20.6
2011	Lower	27-May	30-Mar	13-Jul	11.6	11.9	17.9
2012	Lower	13-Jun	11-Apr	11-Jul	13.1	13.3	20.7
2013	Lower	08-May	27-Mar	26-Jun	12.9	12.0	17.2
Mean ± SD		24-May ± 12 d	04-Apr ± 8 d	08-Jul ± 8 d	12.5 ± 1.0	12.9 ± 0.6	19.6 ± 1.3
1995	Upper	01-Jun	13-Apr	22-Jun	16.0	13.2	17.0
1996	Upper	24-May	19-Apr	21-Jun	13.8	14.2	18.1
1997	Upper	29-May	24-Apr	20-Jun	15.0	14.3	17.1
1998	Upper	12-May	16-Apr	06-Jul	14.5	14.4	19.1
1999	Upper	26-May	15-Apr	02-Jul	14.0	14.7	19.5
2000	Upper	27-Apr	07-Apr	16-Jun	12.9	13.7	17.2
2001	Upper	03-May	06-Apr	14-Jun	8.9	11.9	16.1
2002	Upper	25-Apr	12-Apr	03-Jul	10.8	13.5	18.8
2003	Upper	08-May	27-Mar	26-Jun	11.7	12.6	18.5
2004	Upper	07-May	02-Apr	25-Jun	13.2	13.7	18.0
2005	Upper	05-May	31-Mar	23-Jun	11.2	12.3	17.1
2006	Upper	18-May	31-Mar	29-Jun	14.5	13.8	19.0
2007	Upper	03-May	05-Apr	05-Jul	11.9	14.0	19.6
2008	Upper	16-May	11-Apr	18-Jul	12.8	14.1	20.0
2009	Upper	14-May	02-Apr	18-Jun	13.0	12.8	18.5
2010	Upper	13-May	01-Apr	22-Jul	12.0	13.7	20.3
2011	Upper	17-May	07-Apr	07-Jul	12.6	13.3	19.0
2012	Upper	11-May	20-Apr	29-Jun	13.0	14.5	18.5
2013	Upper	02-May	18-Apr	27-Jun	11.0	13.8	17.5
Mean ± SD		12-May ± 10d	09-Apr ± 8 d	29-Jun ± 10d	12.8 ± 3.0	13.6 ± 2.9	18.4 ± 3.9

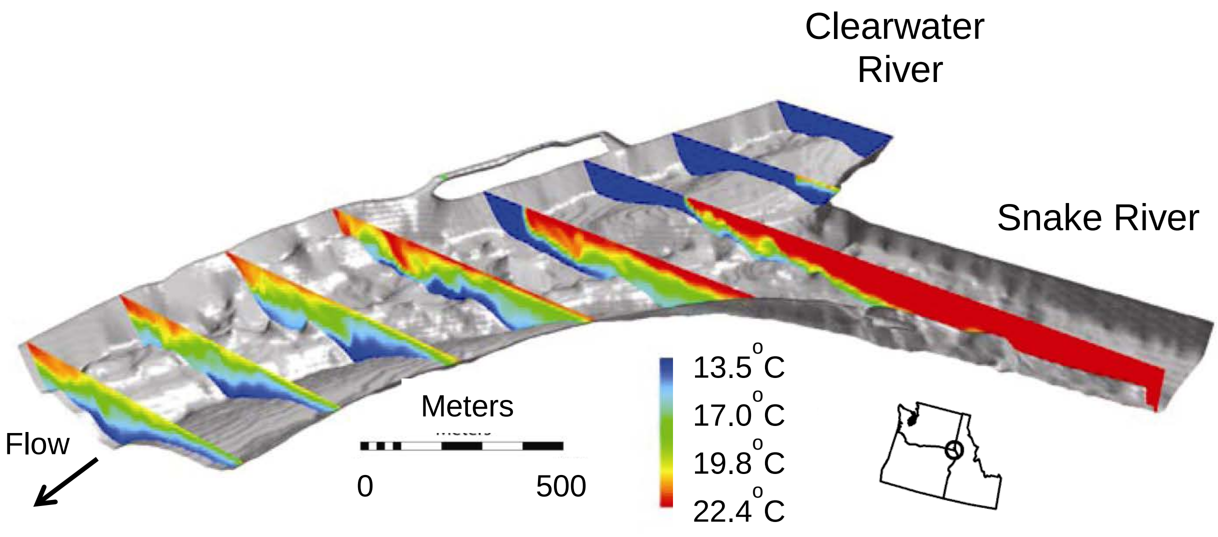

Figure 2.—Thermal layering modeled in Lower Granite Reservoir at the confluence of the Snake and Clearwater rivers during the implementation of summer flow augmentation (Cook et al. 2006).

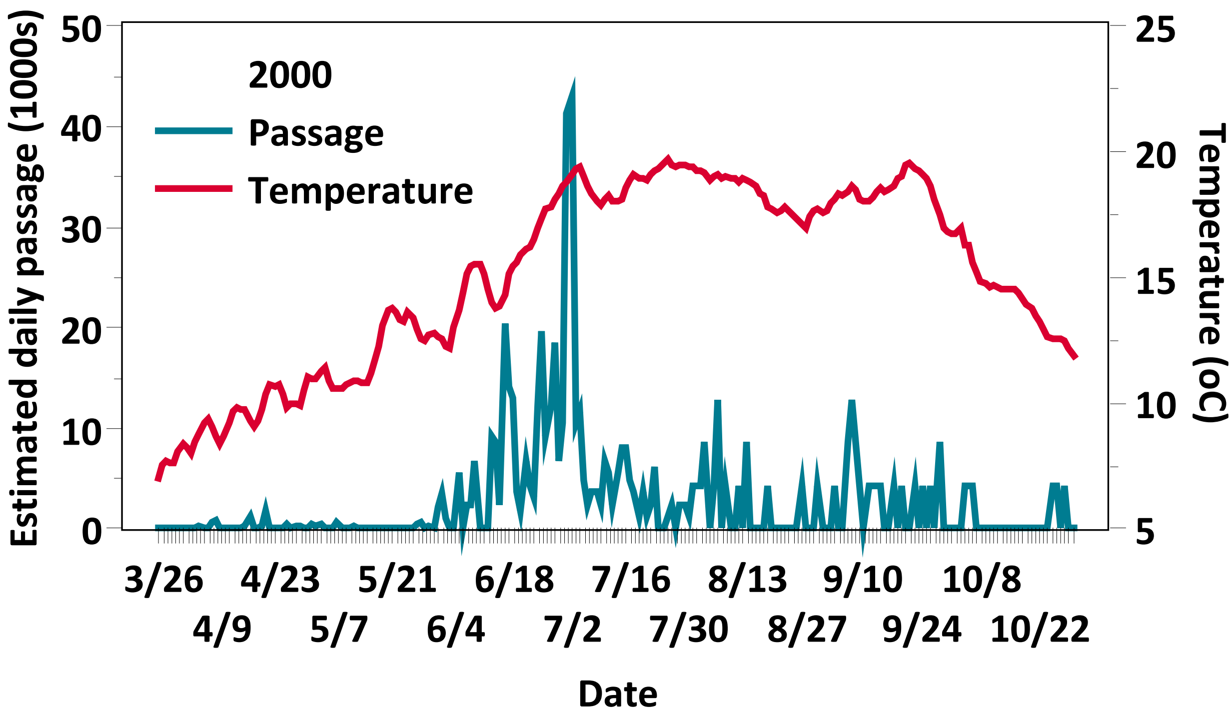

Figure 3.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2000.

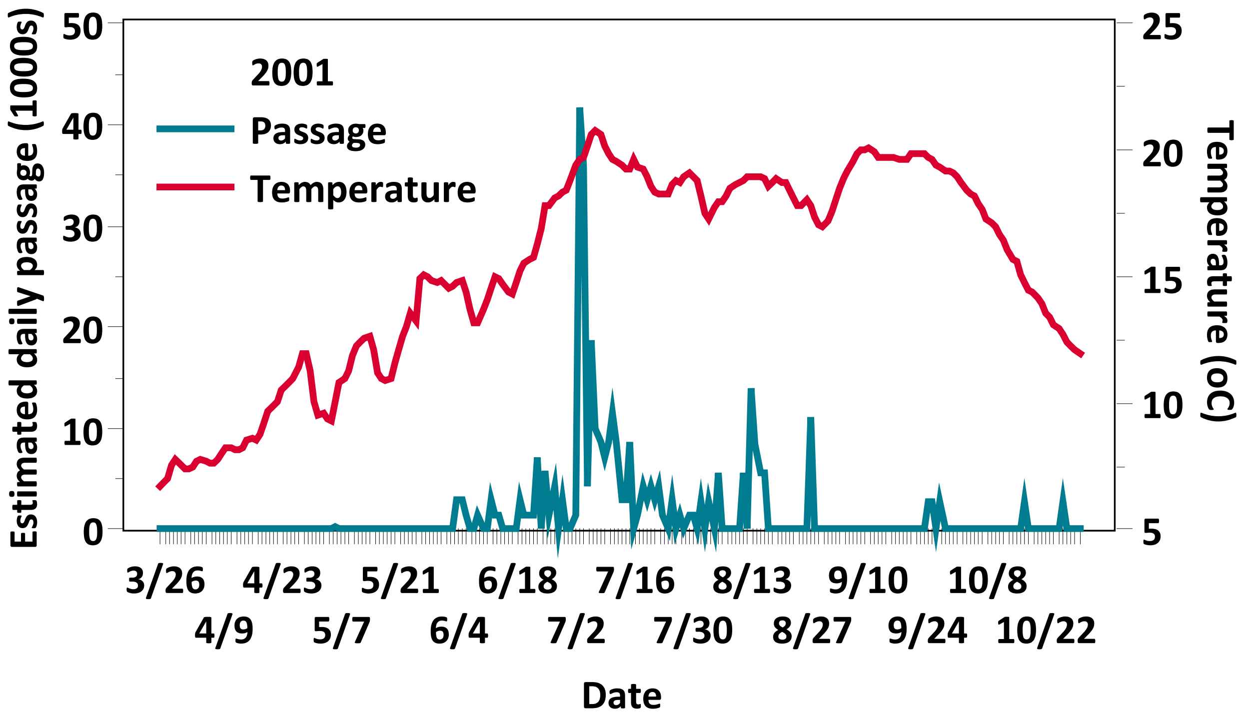

Figure 4.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2001.

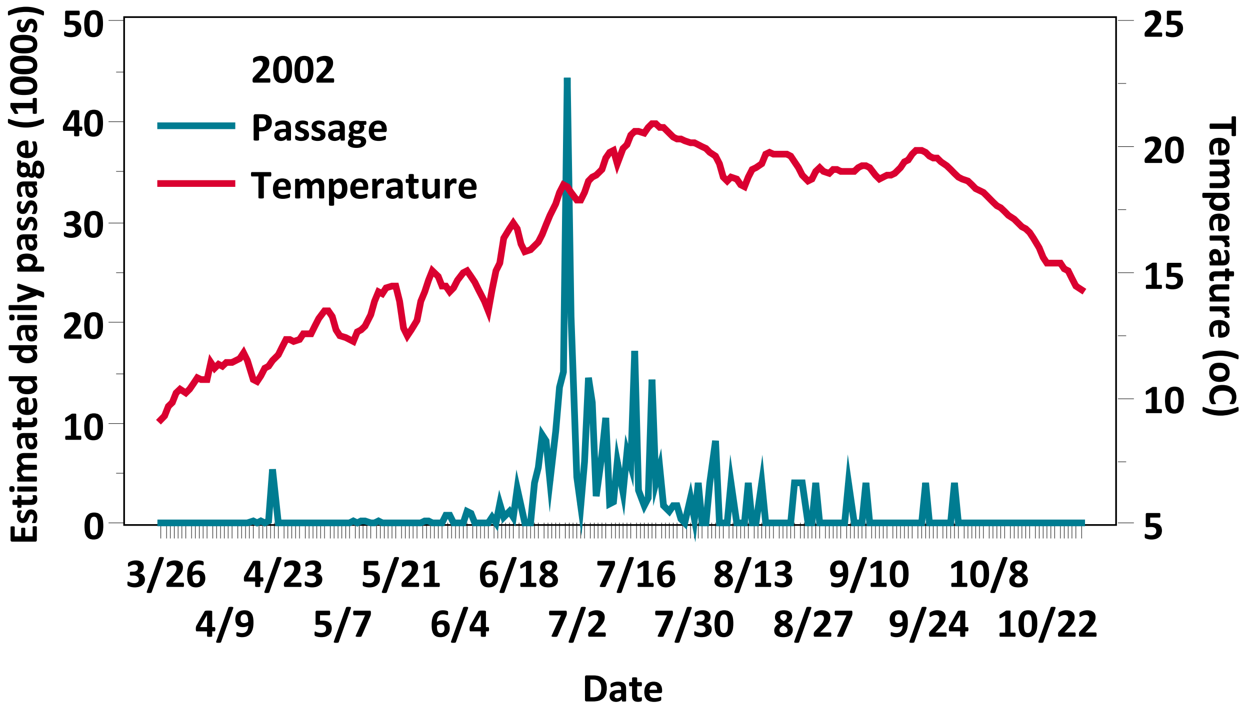

Figure 5.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2002.

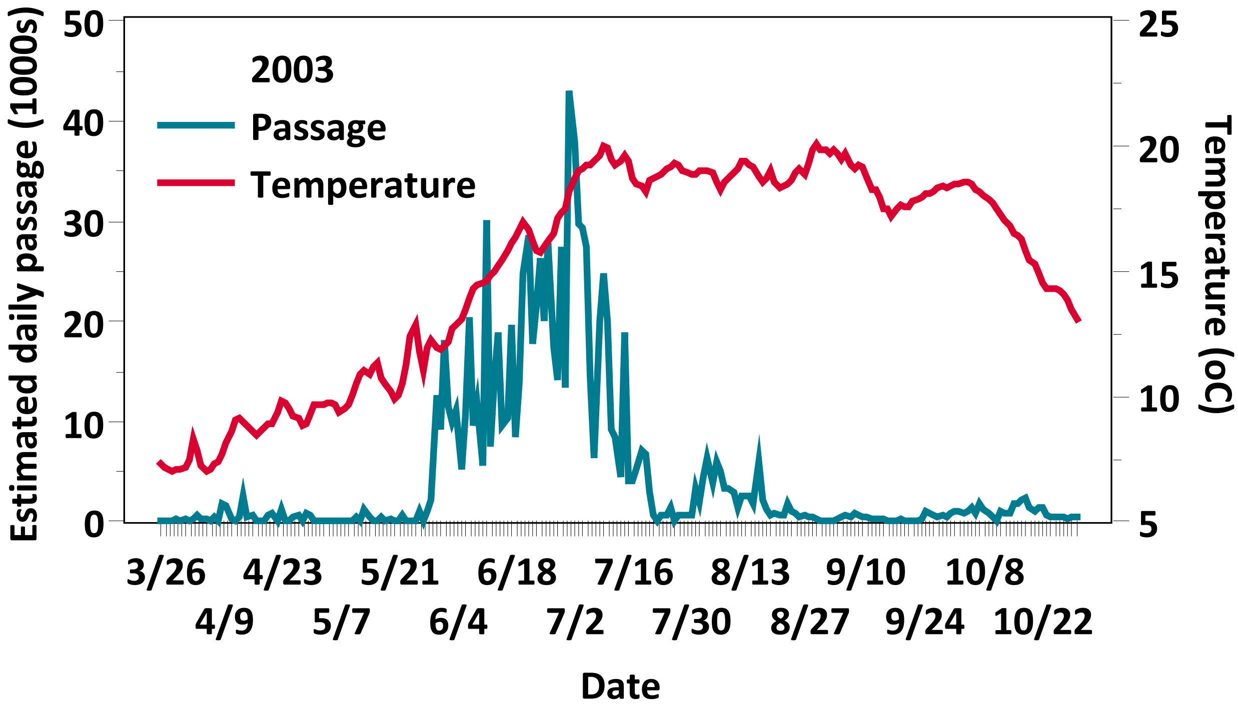

Figure 6.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2003.

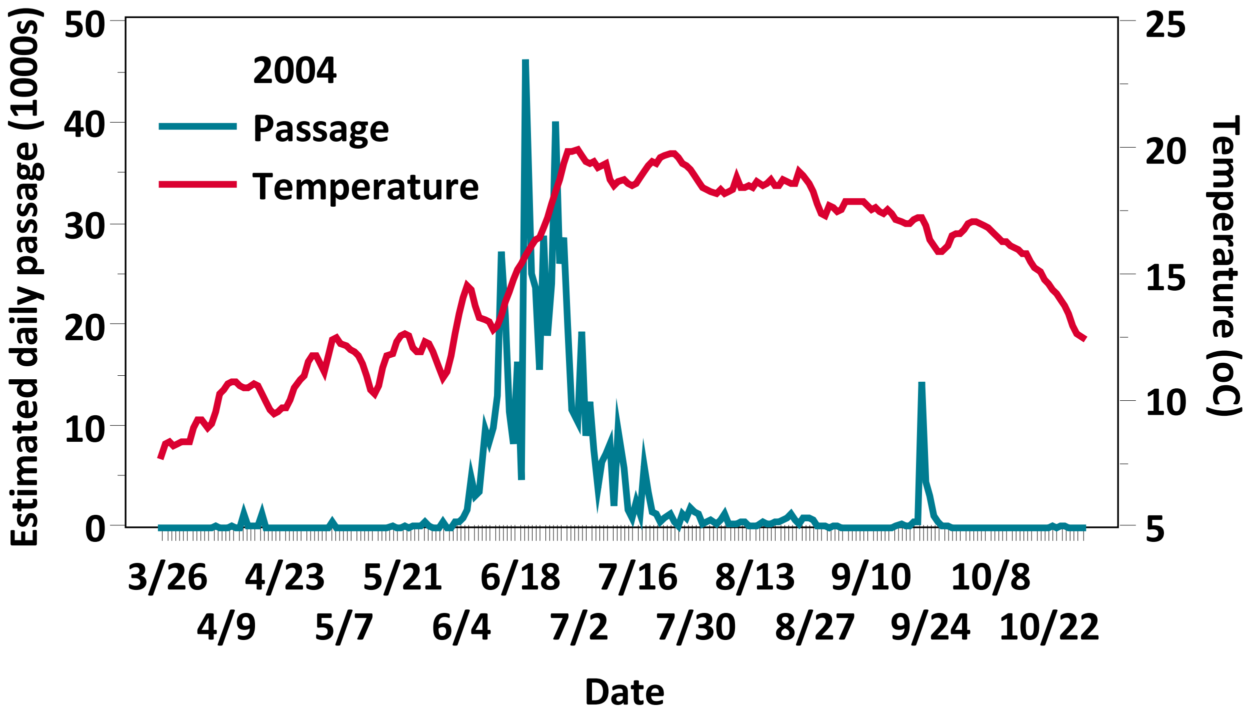

Figure 7.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2004.

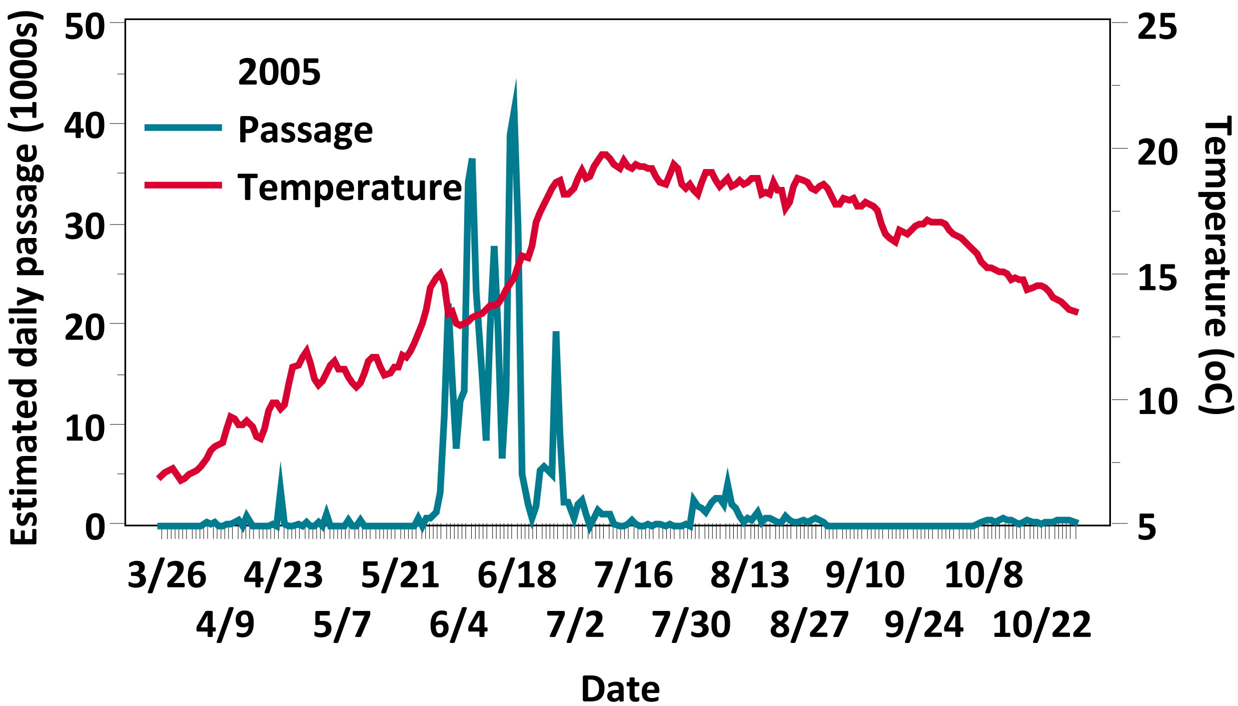

Figure 8.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2005.

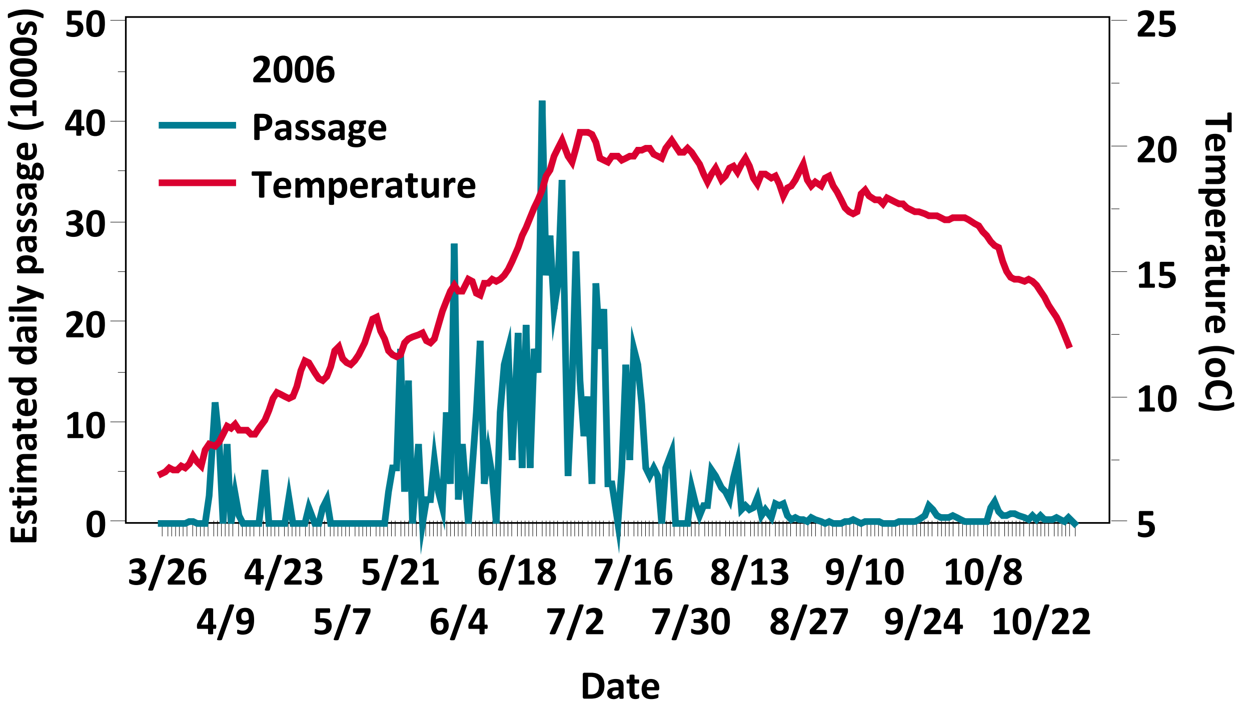

Figure 9.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2006.

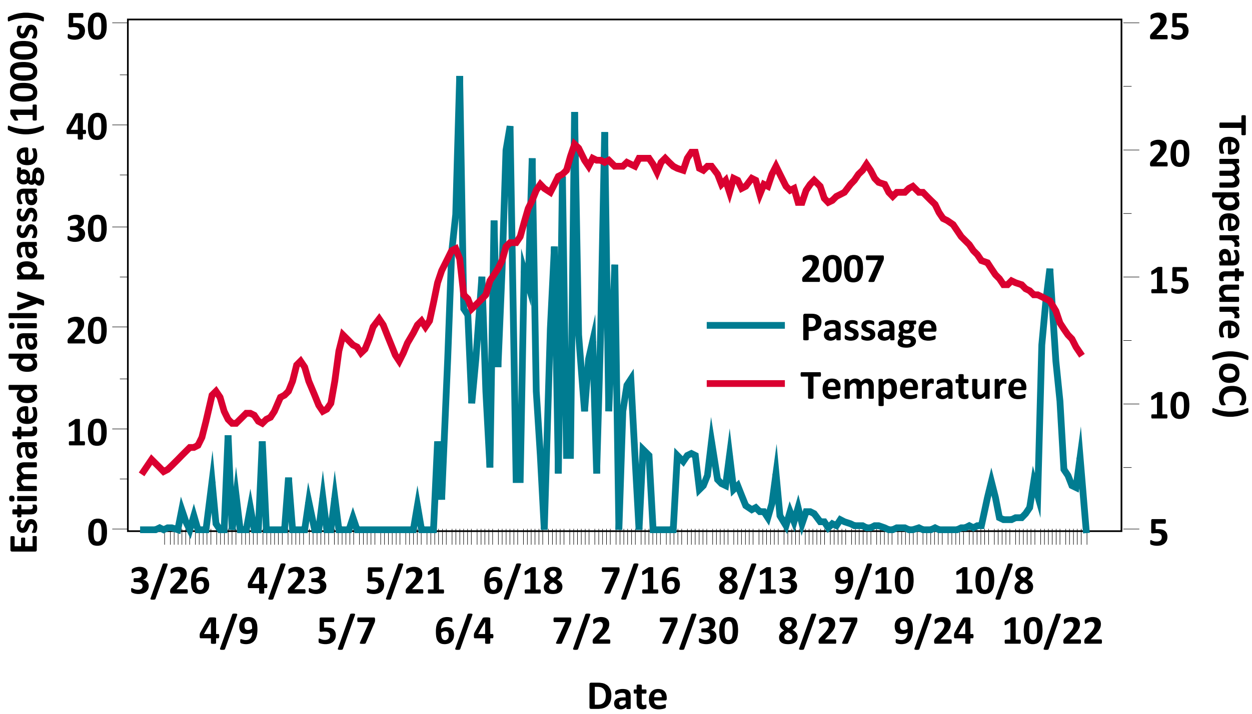

Figure10.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2007.

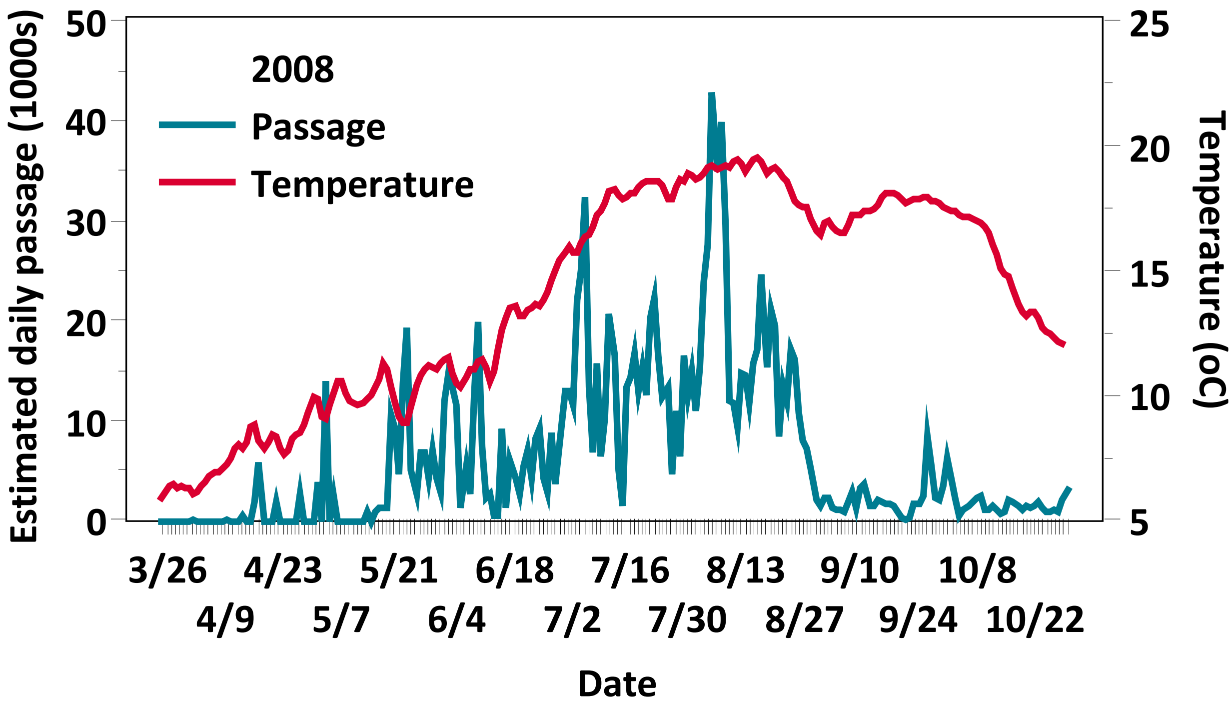

Figure11.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2008.

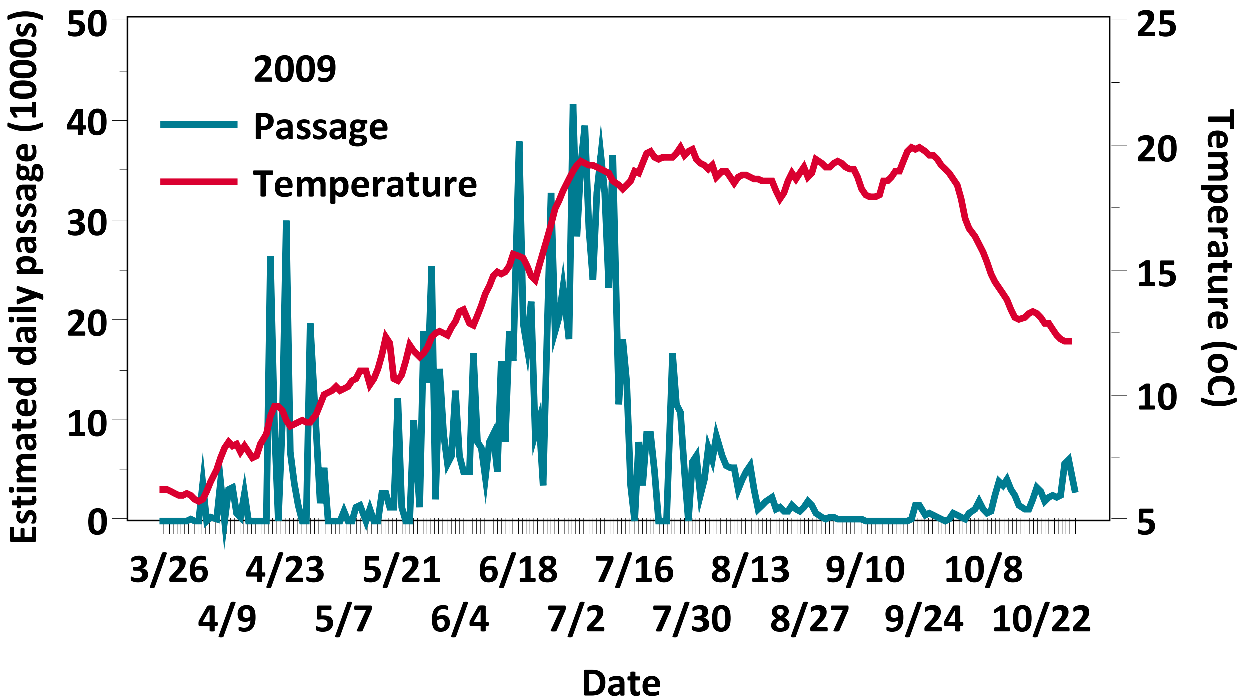

Figure12.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2009.

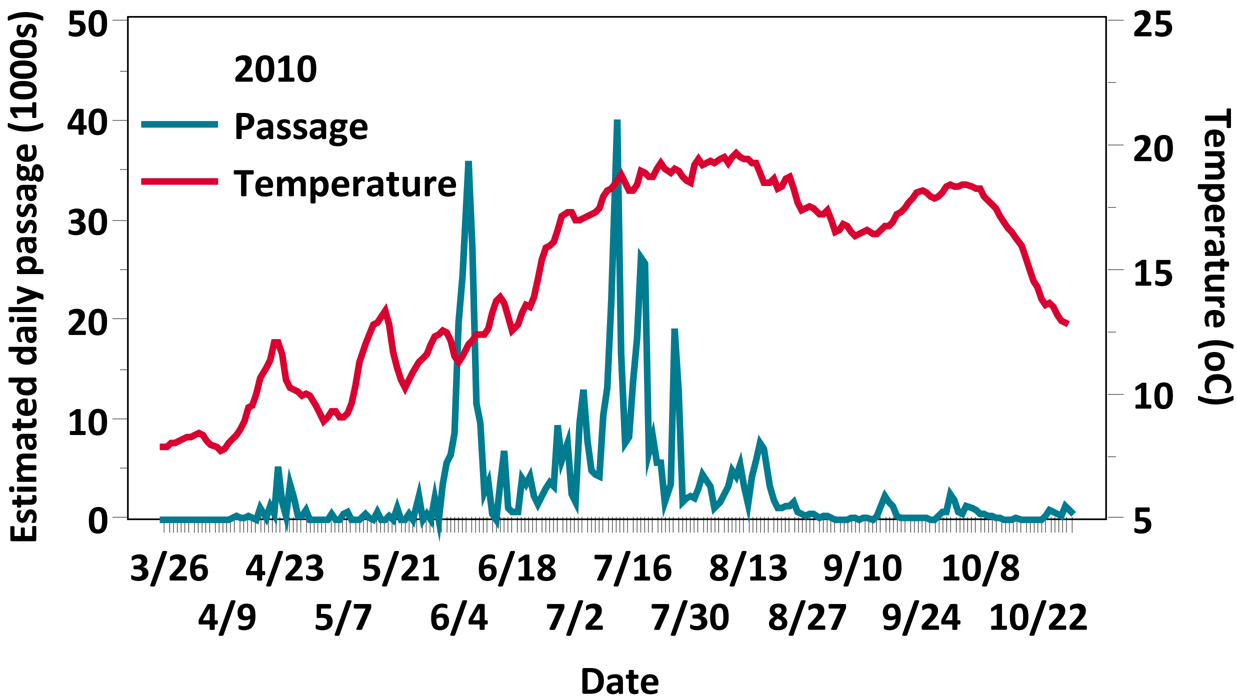

Figure13.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2010.

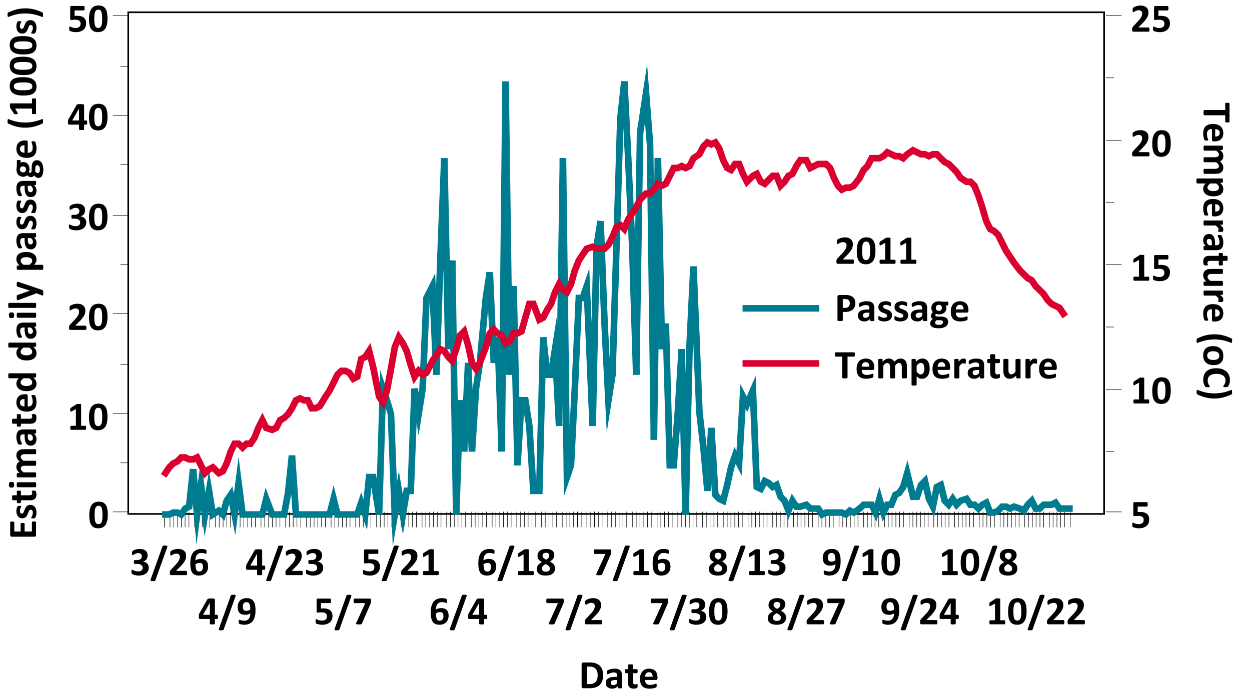

Figure14.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2011.

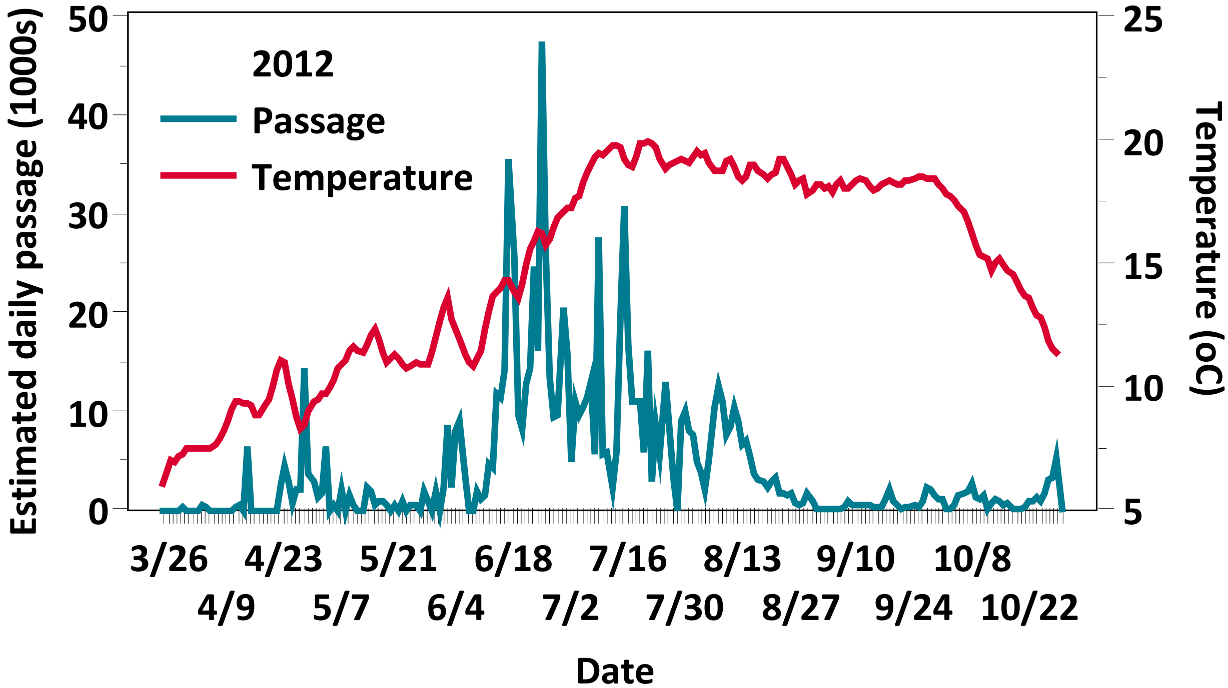

Figure15.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2012.

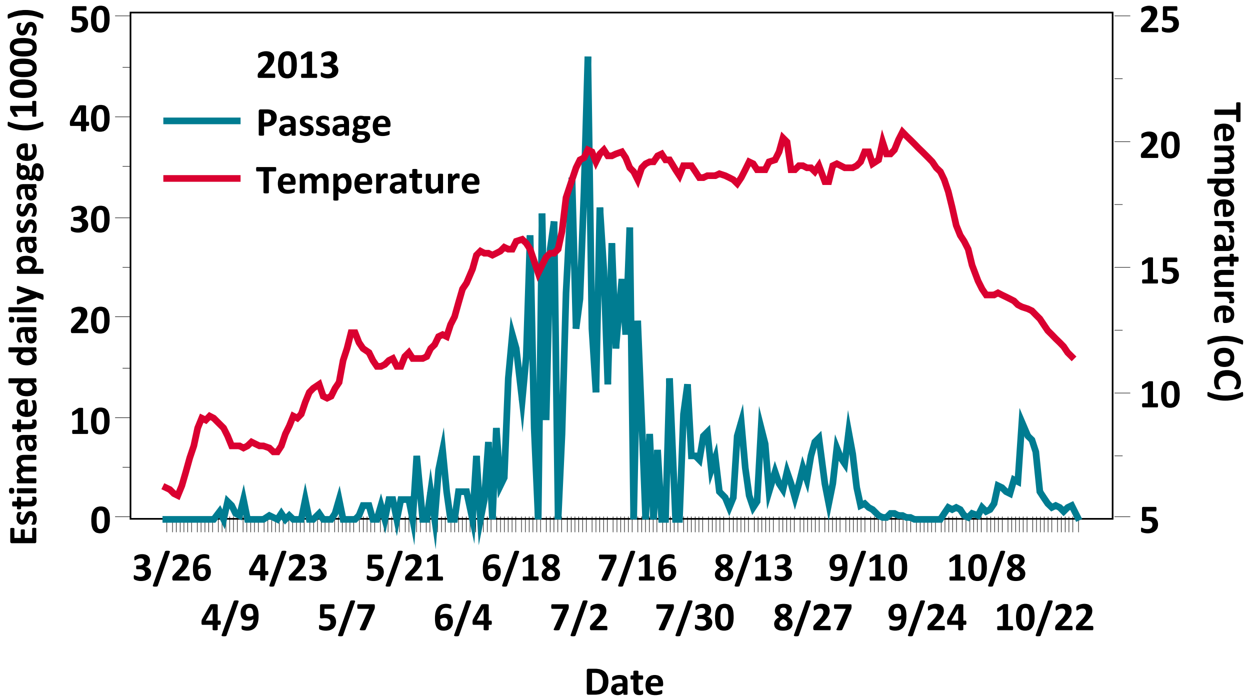

Figure16.—Estimated daily passage abundance of natural-origin fall Chinook salmon smolts (Connor et al. 2014) plotted against daily mean temperature measured in the tailrace of Lower Granite Dam (CBR 2015) during 2013.

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Jim Chandler provided invaluable insight to the influence of the Hells Canyon Complex of Dams on temperature. Phillip Groves was the principal investigator during temperature data collection and redd surveys along the lower Snake River. Funding for this report was provided under project 199102900 funded by the Bonneville Power Administration.

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