Recommendations for Broad Scale Monitoring to Evaluate the Effects of Hatchery Supplementation on the Fitness of Natural Salmon and Steelhead Populations

Final Draft Report of the Ad Hoc Supplementation Monitoring and Evaluation Workgroup*

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Introduction and Background

Hatchery supplementation (e.g., Cuenco et al. 1993) is a management strategy which has been widely adopted as a means to help conserve and rebuild depressed salmon populations within the Columbia basin. The Regional Assessment of Supplementation Project report (RASP 1992) provides a useful working definition for supplementation:

> *Supplementation is the use of artificial propagation in an attempt to maintain or increase natural production, while maintaining the long-term fitness of the target population and keeping the ecological and genetic impacts on non-target populations within specified biological limits.*

The objectives and management protocols of a supplementation hatchery contrast with those of a traditional hatchery program whose objective is solely to provide additional fish for harvest in commercial, sport and/or tribal fisheries. Reflecting their contrasting objectives, the two types of program typically differ significantly in their protocols for broodstock management and juvenile rearing. The fish stock in a harvest augmentation programs is typically kept separate from the natural population - only adults which return to the hatchery, which are predominantly of hatchery origin, are collected for spawning (segregated broodstock management). In contrast, in a supplementation program, broodstock (typically of both natural and hatchery origin) is collected from among adults returning for natural spawning (integrated broodstock management). Progeny of the hatchery-spawned fish in both types of program are reared to a juvenile life-stage, typically the (pre-)smolt stage. Juveniles in harvest augmentation programs are then released back, in many cases directly from the hatchery, into the river whose fishery is to be augmented. The fish are expected to continue their life cycle in parallel with the natural population – migrating to the marine environment where they rear, and return as mature adults. In contrast, juveniles from a supplementation hatchery are, ideally, transferred to an acclimation facility within the spawning area of their river of origin. The fish are retained in the acclimation facility for a certain period prior to (volitional) release, to reinforce the imprinting process and increase the rate of return as mature adults to the spawning area. Because of the high rate of spawning success and egg-to-juvenile survival in a hatchery setting relative to the natural environment, the number of juveniles produced per artificially spawned fish will exceed that of a fish spawning naturally. If survival of the hatchery origin fish during the juvenile to adult life stages is sufficiently similar to that of natural origin fish, a hatchery program can result in a large increase in the total number of adults produced from a given number of spawners. In a harvest augmentation program, an increased number of adults will therefore be available for the fishery; there is no intention that the fish escape to join the natural spawning population, although some straying can be expected to occur. In a supplementation program, the primary goal is to increase total adult abundance in the river of release, to support natural production, and secondarily, in some cases, to support harvest (Cuenco et al. 1993).

Empirical evidence from supplementation programs does generally support the expectation of an increase in adult escapement while the program is active. For example, in a review of reports for which sufficient monitoring data were available, greater adult-to-adult survival for hatchery-spawned versus naturally spawning fish was commonly found, though there were some exceptions (Waples et al. 2007). However, even when an anticipated abundance boost is achieved from the infusion of supplementation hatchery fish, it remains uncertain that the action will yield a sustained increase in natural population abundance over subsequent generations. Indeed, despite the expectation of short-term demographic benefits, considerable controversy exists regarding possible negative effects that hatchery supplementation may have on long-term fitness and viability of natural populations (ISAB 2002, Myers et al. 2004, Brannon et al. 2004).

It is evident from empirical data that harvest augmentation hatchery programs can have deleterious effects on natural populations – studies have shown that the number of salmon smolts released from these programs has been negatively correlated with the productivity or abundance of associated natural populations (e.g., Levin et al. 2001, Nickelson 2003, Chilcote 2003, Hoekstra et al. 2007). In addition, reviews of published studies and reports which compared natural reproductive success of hatchery origin versus natural origin adults, indicated that hatchery origin fish generally produced fewer offspring (Berejikian and Ford 2004, Waples et al. 2007, Araki et al. 2008). However, the majority of hatchery programs reviewed in these studies were harvest augmentation programs, which used out-of-basin and/or segregated broodstock management, creating a hatchery stock which might reasonably be expected to be less fit. There are currently few cases of consistently managed supplementation programs, and associated unsupplemented reference populations, for which reliable data sets for abundance and productivity are available and have been analyzed to make a robust assessment of the long-term effects of supplementation (see Appendix B).

Additionally, the most direct test of supplementation on a population would involve an analysis of abundance and productivity trends in both treatment and reference populations for some period following cessation of supplementation. However, until recently supplementation has been continuous in essentially all programs, and such comparisons with a post-supplementation period are not yet possible. Exceptionally, the study plan for the Idaho Supplementation Study (ISS) project called for cessation of supplementation in treatment streams, which was indeed enacted in 2007. Monitoring to measure production and productivity is scheduled to continue in these streams for an additional 5 years (Bowles and Leitzinger 1991, Lutch et al. 2005), presenting the opportunity to perform such Before-During-After assessments as data accumulates. Also, Before-After comparisons are occurring as part of on-going long-term studies of supplementation of Hood Canal summer chum (Thom Johnson, WDFW, personal communication) and Hood Canal steelhead (Barry Berejikian, NWFSC, NOAA-Fisheries, personal communication).

With continued and improved monitoring over the coming years, population trend analyses in supplemented and reference populations to discern long-term effects on natural population fitness will become increasing reliable. In the meantime, however, fisheries managers remain in need of relevant information on which to base decisions regarding use of supplementation as a mitigation and/or conservation action. It is therefore useful to engage in monitoring and evaluation studies which provide shorter-term, complementary information on productivity differences which could be attributable to hatchery versus natural rearing. One such approach is to use genetic parentage analysis to evaluate within generations, the relative reproductive success (RRS) of hatchery and natural origin fish in supplemented populations. Recent developments in molecular genetics techniques provide a means to accomplish these analyses. An RRS study requires the trapping of (nearly) all in-migrating adults destined for the spawning grounds within a stream/river, collection of tissue samples, identification of each adult as being of hatchery versus natural origin (based on a tag, mark, or scale analysis), and similar trapping and sampling of the progeny (recruits) of these adults either at the juvenile stage or as returning adults. DNA analysis is performed on the tissue samples for a series of molecular markers. The resultant genotyping permits identification of the progeny produced by each individual broodfish. Data from these parentage analyses are then used to calculate number (and variance) of recruits per natural spawner (R/S) of hatchery origin versus wild origin. The ratio of these R/S values then provides a measure of relative reproductive success (RRS):

$$\text{RRS} = \frac{R/S_{(\text{hatchery})}}{R/S_{(\text{wild})}}$$

RRS values which are consistently close to 1.0 in studies conducted over multiple broodyears and/or across multiple populations would infer that natural reproductive success of the supplementation fish was similar to that of natural origin fish within broodyears tested. On the other hand, RRS values which are consistently and appreciably below 1.0 would indicate that hatchery rearing was associated with a loss of productivity for supplementation fish spawning under natural conditions. The latter result carries with it the implication that successive generations of supplementation, while they may provide a temporary boost to population abundance, might progressively depress population fitness, with the possibility that the loss in fitness could place the population at a greater risk of extinction than it faced prior to initiation of the hatchery program.

Berejikian and Ford (2004) and Araki et al. (2008) reviewed the limited number of available reports on RRS studies of hatchery-reared salmonids. Results indicated that hatchery stocks of non-local origin consistently demonstrated low productivity relative to wild fish (RRS<<1). Local hatchery stocks performed substantially better than non-local stocks, but nonetheless, generally demonstrated lower productivity than wild fish. A general conclusion as to the effects of supplementation, however, could not be made as the number of studies using local stocks was limited, and the analyses were subject to confounding effects of environmental and genetic factors. Exceptionally, Araki et al. (2007), were able to design their comparison to test only genetic effects, and observed a significant loss in productivity associated with hatchery rearing.

In light of the widespread use of supplementation across the Columbia basin and of the controversy related to the potential for deleterious long-term effects, the Northwest Power Planning and Conservation Council (NPCC) requested that the Independent Science Advisory Board (ISAB) review the benefits and risks of supplementation. In particular, the NPCC asked the ISAB to investigate the validity of the assumption that a supplementation hatchery program can be used effectively as a short-term means to rebuild abundance without having a persistent negative effect on natural population fitness and viability. The ISAB concluded that the assumption remains incompletely tested and requires an experimental design that directly compares supplemented and reference populations – populations which have had little or no hatchery influence (ISAB 2003). The ISRP/ISAB: "Monitoring and Evaluation of Supplementation Projects" Report 2005-15 re-affirmed the importance of this approach, and proposed that an inter-agency group be called together to establish the basic design for a basin level evaluation.

In response to the recommendation in the ISRP/ISAB report (2005-15), the *Ad Hoc* Supplementation Work Group (AHSWG) convened in two successive workshop: 1) to identify opportunities for coordination among supplementation monitoring programs (Galbreath et al. 2006), and 2) to discuss the goals, technical requirements and challenges of performing a large-scale hatchery experiment (Galbreath et al. 2007). Discussion continued within a smaller working group, with the objective to elaborate the present report. In this report, the AHSWG provides 1) a review the ISAB/RP 2005-15 recommendations, 2) a summary of the outcomes of the two supplementation monitoring workshops, 3) a description of how a basin-wide hatchery evaluation fits within the monitoring and evaluation (M&E) framework recently proposed by the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP), and 4) the AHSWG's recommendations for a coordinated Columbia basin-wide plan for evaluating the effects of hatcheries on natural salmon populations.

I. Monitoring and Evaluation of Supplementation Projects - ISAB/ISRP 2005-15

In the Monitoring and Evaluation of Supplementation Projects report (2005-15), the ISRP and ISAB review the nature of the demographic, genetic and ecological risks that could be associated with supplementation. In view of these risks, they re-emphasize the need that the suitability and efficacy of all hatchery programs be assessed relative to the two standards for use of supplementation identified in the RASP report (1992): 1) "intervention should be required to conserve a population", and 2) "supplementation should not reduce the long-term fitness of the target population and should keep the ecological and genetic impacts on non-target populations within specified limits".

The report follows with a general description of the challenges to collecting the kind and amount of monitoring data that would be needed to quantify effects of supplementation on population abundance and productivity within individual programs and across multiple programs. The report provides ideas and recommendations for development of a coordinated basin-wide evaluation of supplementation, including:

- “The number of locations that need to be monitored needs to be determined as an overall Columbia River basin experiment”
- “there are several possible designs for a large scale, basin-wide experiment: … treatment-control; before-after treatment control, or within system detailed life-stage monitoring and genetic sampling”
- The chosen design(s) should:
    - “Determine which projects to include in a basin-wide evaluation”
    - “Establish defined protocols for selected projects”
    - “Establish more reference locations”
- they suggest that a workshop “to execute a cooperative management experiment”, … “towards selection of designs within the Columbia Basin that utilize data on population demographics and recruitment to assess the effectiveness and impact of supplementation”.

II. <u>Supplementation Monitoring and Evaluation Workshops</u>

Acting on the recommendation of the ISAB and ISRP, CRITFC and NOAA-Fisheries (Northwest Fisheries Science Center) took the initiative to contact representatives from fisheries organizations working in the Columbia basin (tribal, state, federal agencies, power companies, universities and private consultants), and organized two *Ad Hoc* Supplementation Monitoring and Evaluation Workshops. The first was held on April 6-7 2006 (Galbreath et al. 2006), and the second on February 14-15, 2007 (Galbreath et al. 2007). The key observations and recommendations from these workshops are:

- A Columbia basinwide evaluation of hatchery effects should combine two approaches:
    - basic monitoring of annual population abundance and productivity in essentially all salmon/steelhead populations, supplemented and non-supplemented streams, across the Columbia basin, and
    - intensive monitoring to estimate RRS of hatchery-origin and natural-origin salmon/steelhead in a subset of supplemented streams.
- Assessment of long-term effects of hatchery programs is best achieved through comparisons of trends in population abundance and productivity in supplemented versus non-supplemented (‘reference’) populations. However, because of the multitude of natural factors which vary within and between populations and years, these assessments require relatively long data sets from multiple populations. While such long-term data sets do exist for some hatchery influenced populations, the data were not necessarily acquired using similar techniques, such that lack of standardization in data between populations introduces additional error to the analyses. Additionally, monitoring of non-supplemented streams is currently not widespread, and where it does occur is often performed at a lower intensity than in supplemented streams. As noted by the ISRP and ISAB (2005), increased and more rigorous monitoring of reference populations is needed. Currently, inferences can be made as to possible effects of

supplementation. However, more definitive answers backed with statistical rigor will require additional time for data to accumulate.

- In the meantime, to provide managers complementary information on hatchery effects, RRS studies should be enacted within different supplemented populations, to estimate recruits-per-spawner data for hatchery origin versus natural origin adults. It is understood that RRS studies only test for effects which are observable within a single generation or two, and that these studies cannot provide information on effects which are more subtle, but which may accumulate over time. Nonetheless, RRS studies can be more effectively controlled than population trend analyses, they can provide information in a much shorter time frame, and they can quickly present "red flags" in cases where effects are relatively large. The pedigree analyses performed in these RRS studies can also provide information important for estimating:
    - effective population size
    - individual variance for measures of reproductive success
    - correlation between these two productivity measures
    - correlation between these productivity measures and other phenotypic traits.
    - insight on possible causes behind any observed reductions in productivity of hatchery reared fish and their natural progeny when combined with detailed behavioral and ecological monitoring
- Greater coordination among entities currently monitoring supplemented and non-supplemented streams is needed. For an effective assessment, monitoring protocols must be standardized within and between supplemented and reference populations.
- Results from multiple RRS studies should be analyzed together using a covariate such as proportionate natural influence (PNI), to account for the relative intensity of hatchery influence among mixed hatchery-natural populations. PNI is calculated as:

$$\text{PNI} = \frac{\text{pNOB}}{\text{pNOB} + \text{pHOS}}$$

  where, pNOB is the proportion of broodstock composed of natural origin adults, and pHOS is the proportion of hatchery origin adults among the natural spawning population each year (Busack et al. 2006).
- Several different supplementation projects which include intensive hatchery and population monitoring are underway within the Columbia basin, e.g., the Idaho Supplementation Study (ISS), the Yakima-Klickitat Fisheries Project (YKFP), the Grande Ronde Chinook and Steelhead Life History Project, the current monitoring on the Wenatchee River supplementation project, and the M&E framework being implemented in the Mid-Upper PUD hatchery programs. Results from these projects should generally be adequate for answering the finer scale effects they were designed to test. The Workshop participants strongly support maintenance of these efforts.

A small working group of 11 persons, the *Ad Hoc* Supplementation Work Group (AHSWG – see Galbreath et al. 2007), was identified from amongst the workshop participants. The AHSWG was given the task to elaborate a framework for a basinwide analytical design to assess effects of supplementation on natural abundance and productivity. Notably, this group included several persons active within the Hatchery Subgroup of the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP), a group working on similar issues related to M&E of hatchery programs.

III Consistency with the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP)

Created in 2003, CSMEP is a multi-agency effort designed to develop a coordinated regional monitoring and evaluation program for fish populations in the Columbia basin. In light of the broad focus and complexity of the task, project participants were subdivided among several work groups, including: Status and Trends, Harvest, Hydrosystem, Habitat, Hatcheries, and Integration. As a test case to refine design methods and analytical tools, CSMEP initially focused their plans on M&E of spring/summer (stream-type) Chinook salmon populations in the Snake River Basin Evolutionary Significant Unit (ESU), which were summarized in the Snake River Basin Pilot Report (Marmorek et al. 2007a and b). The Status and Trends plan in this report describes a coordinated system of standardized monitoring actions to be conducted on each stream/river, involving counting and sampling of adults at in-river weirs and/or during spawning surveys. The objective of the monitoring is to gather basic population measures with which to estimate the four Viable Salmonid Population (VSP) parameters: abundance, productivity, spatial structure, and diversity (McElhaney et al. 2000), for each population with known levels accuracy and precision. The M&E plan presented in the Hatcheries section of the report describes the monitoring needed to determine the distribution and RRS of hatchery origin adults in target and non-target spring Chinook populations. Because these questions are not necessarily site-specific, but of general relevance to use of hatcheries as a class of management actions, the subgroup expanded their plan to encompass stream-type Chinook salmon across the Columbia River Basin above Bonneville Dam. The hatchery section specifically recommended: 1) incorporation into the basic plan recommended by the Status and Trends group, of monitoring to quantify rates of straying of hatchery (harvest augmentation and supplementation) origin fish to non-target streams, primarily through systematic screening of carcasses for coded wire tags, and 2) initiation of six similarly designed RRS studies to provide measures of relative productivity of hatchery and natural origin adults within supplemented streams – the streams to be systematically selected from across a range of supplementation intensities (PNI values). These designs proposed by CSMEP have in large part been incorporated into the recommendations of the AHSWG described below.

IV **AHSWG Review and Recommendations**

As proposed in the Monitoring and Evaluation of Supplementation Projects memo (ISRP and ISAB 2005-15), the AHSWG has focused its efforts on designing recommendations for monitoring which will help predict the magnitude of change to abundance and productivity in supplemented natural populations that can be attributable to hatchery influence. Building off the previous Supplementation M&E Workshops and the work of CSMEP, the AHSWG provides the following comments and recommendations for M&E of supplementation programs, which will enable a regional assessment of supplementation effects on natural salmon/steelhead populations:

1. Standardize protocols for M&E of salmon/steelhead populations in the basin, and organize these actions within a regional, multi-tiered Framework (Appendix A).
2. Adopt a two-pronged approach to Effectiveness Monitoring of salmon/steelhead populations, for measuring change in long-term population fitness associated with supplementation.
    - A. Continue and expand ongoing monitoring of basic VSP parameters in supplemented and non-supplemented (reference) streams, and coordinate analysis of population trends. In addition, cease supplementation in several long-term projects to permit measurement of population effects post-supplementation.
    - B. Continue and expand Relative Reproductive Success (RRS) studies.
3. Maintain the momentum from current CSMEP and AHSWG efforts, through formation and funding of an interagency technical working group to provide continued basinwide assessment.

Recommendation 1. Standardize protocols for M&E of salmon/steelhead populations in the basin, and organize these actions within a regional, multi-tiered Framework (Appendix A).

Monitoring and Evaluation of hatchery programs is generally conducted on a project-by-project basis across the Columbia River basin. However, there can be wide variation between projects in the choice of metrics, methodologies and protocols for monitoring activities, providing data on population parameters of varying nature and reliability. This lack of coordination and standardization confounds analyses which would utilize information from across projects, and complicates our ability to make a reliable regional assessment of the efficacy and effects of the hatchery programs. The AHSWG proposes adoption of standardized methodologies for M&E of salmon and steelhead populations, as described by CSMEP in Marmorek (2007a and b). The AHSWG also proposes reorganization of current and proposed hatchery M&E efforts into a coordinated multi-tiered framework. This framework categorizes activities into three levels of increasing intensity: Compliance and Implementation Monitoring, Hatchery Effectiveness Monitoring, and Uncertainties Research. Compliance and Implementation Monitoring involves annual monitoring of hatchery production measures and basic VSP information on affected populations. As the data obtained from these monitoring activities are used to regulate hatchery operations, Compliance and Implementation

Monitoring should be viewed as integral to basic hatchery operation and maintenance. Hatchery Effectiveness Monitoring involves an increased level of monitoring which provides data to break down the basic VSP measures into their component parts. At the program-specific scale, the increased detail permits improved evaluation of whether a program is complying with its defined management guidelines and goals, and at a regional scale will permit collective analysis of trends across populations. For both Compliance and Implementation Monitoring and Hatchery Effectiveness Monitoring, it is critical that monitoring protocols be standardized across programs, to reduce error in analyses for effects on VSP parameters performed with data collected from multiple programs. Uncertainties Research involves relatively complex designs to test hypotheses about effects of particular hatchery operations. Because of the need for controlled conditions and intensive data collection, this sort of M&E is typically conducted at a small project-specific scale. An expanded description of this Framework for Regional M&E is provided in Appendix A.

Of note, organization of monitoring efforts is becoming less agency specific. Design of current M&E efforts increasingly requires coordination amongst fisheries management agencies, as well as local salmon recovery boards, subbasin planning groups, etc.

Recommendation 2. Adopt a two-pronged approach to monitoring the effects of supplementation on the VSP parameters of abundance, productivity, spatial structure and diversity, for measuring changes in long-term population fitness.

A) First priority for this approach is to continue, to standardize, and to expand as needed the current monitoring of basic VSP parameters in supplemented and non-supplemented (reference) streams, and to coordinate analyses of population trends. In addition, supplementation in several long-term projects should be ceased, so as to permit measurement of effects during a post-supplementation period.

Methodologies to acquire the data needed to answer questions surrounding long-term effects of hatchery programs on natural population fitness generally fall into the Effectiveness Monitoring tier within the monitoring framework (Appendix A). While designs to collectively analyze these data into a comprehensive regional assessment of the effects of hatcheries are not difficult to conceive, there exist numerous logistical challenges to enacting a design with sufficient statistical validity within the complex and often conflictual realities of Columbia River fisheries management.

Designs to assess hatchery effects primarily involve analysis of trends in population parameters of abundance and productivity across time. Population abundance is estimated through direct and/or indirect measures of adult escapement, redd counts, and juvenile abundance. Productivity can be measured through recruits per spawner estimates (for both juvenile and/or adult recruits) and redd number and density. Logistical constraints to obtaining reliable data for estimating these parameters, however, can be considerable, and use of monitoring methodologies of decreased consistency, introduces an increased amount of error into the trend analyses. Even without measurement error, the trend analyses are complicated by confounding effects of variation related to natural environmental fluctuation in stream characteristics (temperature, flow, etc.), as well as that related to human activities – activities which affect decreases in stream productivity, as well as restoration activities which improve productivity. This variation occurs both within and between populations, and within and between years. Similarly, changes in hatchery management over the time period monitored can compromise the legitimacy of assignment the population to one particular hatchery program category or another within an analysis. To factor out the effect introduced by these multiple sources of variation and error, analytical designs to discern differences in trends in hatchery influenced populations will require judicious selection of a subset of populations for which the data are sufficiently reliable and can be standardized among populations. Additionally, these data sets will necessarily have to cover many years (multiple generations).

Analyses may take any of several approaches to determine population trends and relate differences in trend to effects of hatchery intervention. These approaches include comparisons within populations of data Before, During and/or After a period of hatchery influence (intentional supplementation or unintentional straying), paired Treatment-Reference comparisons, or analyses for correlations in data from several affected populations across a gradient of treatment intensity (e.g., PNI). A regional assessment of the effects of hatcheries will involve comparison of results from multiple analyses using a variety of these analytical approaches, each design being chosen according to how it best fits a subset of the available data sets. Characteristics of these various design options are described in greater detail in Appendix B.

Included with Appendix B is a preliminary assessment of abundance and productivity trends for ESA-listed spring Chinook populations in the Columbia basin. Beyond illustrating the type of comparisons that can be performed with time series data for abundance and productivity, the assessment illustrates how variation in data reliability, and variation in environmental and hatchery management influences increase the difficulty of interpreting analytical results.

As the first step to developing appropriate designs for trend analyses in Columbia River salmon/steelhead populations, we established a definitive list of these populations within the basin (Table 1 and Figures 1-3). The populations are organized by stock/species and information for each was added relative to the category of hatchery influence, and the type and history of monitoring data available. The table is an expansion of the list populations indentified by the Interior Columbia River Basin Technical Recovery Team (ICRBTRT) for ESUs listed under the Endangered Species Act, and includes populations in unlisted ESUs. Within the table each population is identified as being one which is, or is not, recommended by the AHSWG for inclusion in trend analyses. The choice for the recommendation is based on the following criteria:

- A relatively continuous time series of abundance data already exists for the population, preferably including data for several years prior to hatchery stocking for those populations in which a supplementation program was initiated.

- The data also include estimates of the proportions of hatchery origin and natural origin fish, both on the spawning grounds and within the hatchery broodstock for supplemented populations.

Table 1. Salmon and steelhead populations within the Columbia basin upstream of Bonnevillle Dam, and downstream from Chief Joseph and Hell's Canyon Dams. Note: blank cells within the table represent instances where data is unavailable, or occasionally where data exists but was not collected in time for the current draft of the report.

ESU	MPG	Stream/Population Name	ICTRT label	Run	Type of hatchery influence	Years of abundance data	10-year Average: Natural abundance / R(adults)/S	10-year Average: Minimum proportion wild	10-year Average: Proportion wild	10-year Average: PNI	Populations recommended for trend analyses
SPRING (stream-type) CHINOOK											
Central Columbia Spring Chinook											
		Wind River			HA						no
		Little White Salmon River			HA						no
		(Big) White Salmon River			HA						no
		Hood River			Supp (reintroduced)	1992-2007	__ / 0.25	0	0.29	0	no
		Klickitat River			Supp						
		Deschutes River (Warm Springs R.)			reference	1975-present		0.9	>90%	n/a	YES
		Deschutes River mainstem			HA						no
		John Day River									
		John Day mainstem		spring	Reference	1959-2007		0.98	0.99	n/a	YES
		Middle Fork - John Day		spring	Reference	1959-2007		0.98	0.99	n/a	YES
		North Fork - John Day		spring	Reference	1959-2007		0.98	0.99	n/a	YES
		Granite Creek		spring	Reference	1959-2007		0.98	0.99	n/a	YES
		Umatilla River		spring	Supp (reintroduced)	1989-2007		0	0.04		no
		Walla Walla River/Touchet River									
Snake River Spring-Summer Chinook ESU (SRSS ESU)											
	Lower Snake										
		Tucannon River	SNTUC		Supp	1979-2006		0.01	0.49	0.6	YES

Asotin Creek	SNASO		extirpated						
Grande Ronde River									
Wenaha River	GRWEN	Spring	Ref	1964-2007	376 / 0.74	0.85	0.95	n/a	YES
Lostine River	GRLOS	Spring	HA and Supp	1959-2007	276 / 0.78	0.28	0.68	0.8	YES
Minam River	GRMIN	Spring	Ref	1954-2007	337 / 1.02	0.87	0.96	n/a	YES
Catherine Creek	GRCAT	Spring	HA and Supp	1955-2007	107 / 0.89	0.34	0.71	0.8	YES
Grande Ronde River upper mainstem	GRUMA	Spring	HA and Supp	1955-2007	38 / 0.42	0.04	0.77	0.8	YES
Lookinglass Creek	GRLOO	Spring	Supp						YES
Imnaha River									YES
Imnaha River mainstem	IRMAI	Spring/Summer	Supp	1949-2007	380 / 0.79	0.2	0.35	0.4	YES
Big Sheep Creek	IRBSH	Spring	Supp	1964-2007	4 / 0.29	0	0.62		YES
Dry Clearwater (lower)									
Lapwai/Big Canyon Creeks	CRLAP		(reintroduced)						no
Potlatch River	CRPOT		(reintroduced)						no
Lawyer Creek	SCLAW		(reintroduced)						no
Upper S. Fork Clearwater	SCUMA		(reintroduced)						no
Wet Clearwater (upper)									
Lower N. Fork Clearwater	NCLMA		HA (reintroduced)						no
Upper N. Fork Clearwater	NCUMA		(reintroduced)						no
Lolo Creek	CRLOL		Supp (reintroduced)						no
Middle Fork Clearwater			SUPP (reintroduced)						no
Lochsa R	CRLOC		Supp (reintroduced)						no
Selway - Meadow Creek	SEMEA		(reintroduced)						no
Selway - Moose Creek	SEMOO		(reintroduced)						no
Upper Selway River	SEUMA		(reintroduced)						no
South Fork Clearwater			Supp (reintroduced)						no

	South Fork Clearwater		Supp (reintroduced)					no
	South Fork Clearwater		HA (reintroduced)					no
S Fk (and lower) Salmon River								
	Slate Creek		Reference					no
	Little Salmon River	SRLSR	HA				n/a	no
	South Fork Salmon River mainstem	SFMAI	HA and Supp	1958-2003	0.36	0.61	0.2	YES
	Secesh River	SFSEC	Reference	1957-2005	0.91	0.96	n/a	YES
	East Fork South Fork Salmon River (Johnson Creek)	SFEFS	HA and Supp	1957-2003	0.62	0.9	0.8	YES
Middle Fk Salmon River								
	Middle Fork Salmon River below Indian Creek	MFLMA	Reference				n/a	
	Big Creek	MFBIG	Reference	1957-2004	1	1	n/a	YES
	Camas Creek	MFCAM	Reference	1963-2003	1	1	n/a	YES
	Loon Creek	MFLOO	Reference	1957-2004	1	1	n/a	YES
	Middle Fork Salmon River above Indian Creek	MFUMA	Reference				n/a	YES
	Sulphur Creek	MFSUL	Reference	1957-2003	1	1	n/a	YES
	Bear Valley Creek	MFBEA	Reference	1960-2003	1	1	n/a	YES
	Marsh Creek	MFMAR	Reference	1957-2003	0.99	1	n/a	YES
Upper Salmon River								
	North Fork Salmon River	SRNFS	Reference					
	Lemhi River	SRLEM	Reference	1957-2003	1	1	n/a	YES
	Salmon River lower mainstem below Redfish Lake	SRLMA	HA	1957-2005	1	1	n/a	YES
	Salmon River upper mainstem above Redfish Lake	SRUMA	HA and Supp	1962-2005	0.5	0.75	0.4	YES
	Pahsimeroi River	SRPAH	Supp	1986-2005	0	0.58	0.2	YES
	East Fork Salmon River	SREFS	Reference	1960-2005	0.45	0.92	n/a	YES

Yankee Fork	SRYFS	HA	1961-2003		1	1	n/a	YES
Valley Creek	SRVAL	Reference	1957-2003		1	1	n/a	YES
Panther Creek	SRPAN	Reference					n/a	
Chamberlain Creek	SRCHA	Reference	1985-2003		1	1	n/a	YES
Mid-Columbia Spring Chinook ESU								
(Yakima)								
Upper Yakima River/Cle Elum River		Supp						
Naches River/American River		Reference					n/a	
Upper-Columbia Spring Chinook ESU								
Wenatchee-Methow								
Wenatchee River (Icicle River)	UCWEN	HA	1960-2007	2 / 0.05	0	0.02	0	no
Wenatchee River (Chiwawa River)	UCWEN	Supp	1960-2007	456 / 1.58	0.18	0.48	0.4	YES
Entiat River	UCENT	Supp	1960-2007	142 / 1.59	0.37	0.69	0	YES
Methow River	UCMET	HA and Supp	1960-2007	419 / 2.28	0.08	0.52	0.2	YES
Okanogan River/Similkameen River	UCOKA	extinct						
<u>FALL (ocean-type) CHINOOK</u>								
Deschutes River Summer/Fall								
Deschutes River								
Central Columbia Fall Chinook								
Umatilla River		Supp						
Yakima River		Supp						
Mid-Columbia Summer/Fall Chinook								
Columbia River								
Wells Program		HA	n/a	n/a	n/a	n/a	n/a	no
Turtle Rock Program		HA	n/a	n/a	n/a	n/a	n/a	no
Wenatchee River		Supp	1960-2007	7,968 /	0.51	0.83	0.8	YES

					1.79				
Methow River			Supp	1960-2007	1,590 / 2.72	0.25	0.71	0.7	YES
Okanogan River/Similkameen River			Supp	1960-2007	1,924 / 2.08	0.3	0.45	0.5	YES
Snake River Fall Chinook ESU									
Snake River Fall Chinook ESU									
Lower Mainstem (Extant)			HA					n/a	
Lower Mainstem (Extant)			HA					n/a	
Lower Mainstem (Extant)			HA					n/a	
Lower Mainstem (Extant)			Supp						
Marsing Reach									
Salmon Falls									

<u>STEELHEAD</u>

Central Columbia									
Wind River									
Little White Salmon									
White Salmon River	MCWSA-s	winter	HA					n/a	
Hood River		summer	Supp						
Hood River		winter	Supp						
Fifteenmile Cr	MCFIF-s	winter	Reference	1985-2007	703 / 1.82	1	1		YES
Klickitat River	MCKLI-s	summer	HA					n/a	
Klickitat River	MCKLI	winter	Reference						
Deschutes - Westside	DRWST-s	summer	Reference	1980-2007	456 / 1.05	0.57	0.74		YES
Deschutes - Eastside	DREST-s	summer	reference	1990-2007	1599 / 1.89	0.43	0.62	n/a	YES
Crooked River	DRCRO-s		Extinct						
Rock Creek	MCROC-s								
John Day - Lower Mainstem	JDLMT-s		Reference	1965-2007	1800 / 2.99	0.82	0.9	n/a	YES
John Day - Upper Mainstem	JDUMA-s		Reference	1965-2007	524 / 2.14	0.87	0.92	n/a	YES

John Day - North Fork	JDNFJ-s		Reference	1965-2007	1740 / 2.41	0.87	0.92	n/a	YES
John Day - Middle Fork	JDMFJ-s		Reference	1965-2007	756 / 2.45	0.87	0.92	n/a	YES
John Day - South Fork	JDSFJ-s		Reference	1965-2007	259 / 2.06	0.87	0.92	n/a	YES
Willow Creek	MCWIL-s								
Umatilla River	MCUMA-s	summer	Supp	1967-2007	1472 / 1.50	0.41	0.64		
Touchet River	WWTOU-s	summer	HA					n/a	
Walla Walla River	WWMAI-s	summer	HA	1993-2005	650 / 1.34	0.95	0.98	n/a	
Satus Creek	YRSAT-s			1985-2004		0.87	0.94		
Toppenish Creek	YRTOP-s			1985-2004		0.87	0.94		
Naches River	YRNAC-s			1985-2004		0.87	0.94		
Upper Yakima	YRUMA-s			1985-2004		0.87	0.94		
Snake River									
Lower Snake									
Tucannon River	SNTUC-s	summer	Supp						
Asotin Creek	SNASO-s	summer	Reference						
Clearwater									
Lower Clearwater	CRLMA-s	summer	HA					n/a	
South Fork	CRSFC-s	summer	HA and Supp						
Lolo Creek	CRLOL-s	summer	Supp						
Lochsa River	CRLOC-s	summer							
Selway River	CRSEL-s	summer							
Salmon River									
Little Salmon	SRLSR-s	summer	HA					n/a	
South Fork	SFMAI-s	summer	Reference					n/a	
Secesh River	SFSEC-s	summer	Reference					n/a	
Chamberlain Creek	SRCHA-s	summer	Reference					n/a	
Big, Camas, and Loon	MFBIG-s	summer	Reference					n/a	
Upper Middle Fork	MFUMA-s	summer	Reference					n/a	
North Fork	SRNFS-s	summer	Reference					n/a	
Lemhi River	SRLEM-s	summer	HA					n/a	
Pahsimeroi River	SRPAH-s	summer	HA					n/a	
East Fork	SREFS-s	summer	HA and Supp						
Upper Mainstem	SRUMA-s	summer	HA					n/a	
Hell's Canyon									

	Hell's Canyon	SNHCT-s	summer	HA					n/a	
Grande Ronde										
	Lower Grande Ronde	GRLMT-s	summer	Reference and HA					n/a	
	Joseph Creek	GRJOS-s	summer	Reference	1970-2007	2132 / 2.62	1	1		YES
	Wallowa River	GRWAL-s	summer	HA					n/a	
	Upper Grande Ronde	GRUMA-s	summer	Reference	1967-2007	1226 / 2.29	0.54	0.84		YES
	Imnaha River	IRMMT-s	summer	Supp	1982-2007	__ / 1.51				YES
Upper Columbia										
	Wenatchee	UCWEN-s		supp	1986-2006	774 / 0.97	0.11	0.39	0.4	YES
	Entiat	UCENT-s		supp/ref	1986-2006	108 / 0.52	0.09	0.21	n/a	YES
	Methow	UCMET-s		supp	1986-2006	394 / 0.33	0.02	0.12	0.1	YES
	Okanogan	UCOKA-s		supp	1986-2006	116 / 0.17	0.01	0.07	0.1	YES

The AHSWG concurs with recommendations of CSMEP that informed fisheries management in the region requires monitoring following standardized protocols, to obtain estimates of basic VSP parameters:

- Abundance –absolute counts of total adult escapement at in-river weirs/traps, with at least one weir per Major Population Group (MPG); and where no weirs exist, estimates based on expansion of annual redd counts – multiple (3x) surveys surveys (aerial or walking), at least one of which should cover the entire spawning area
- Productivity - sampling of adults at weirs or as carcasses during multiple (3x) spawning ground surveys, at least one of which should cover the entire spawning area, to obtain information on hatchery of origin, sex ratio, and age structure – which is used in combination with abundance information to estimate productivity; adults should be identified to sex, and sampled for marks and tags, for scales (or, dorsal fin ray or some other structure to obtain age information), and for tissue when DNA analyses are envisioned
- Spatial structure – use of spawning ground survey data from multiple (3x) spawning ground surveys, at least one of which should cover the entire spawning area, to estimate redd number and redd density per geographic area within the subbasin
- Diversity – estimation of adult characteristics, e.g., run-timing, spawn-timing, size, sex-ratio, age structure, and morphometric measures

The AHSWG also recommends that supplementation programs be experimentally ceased in multiple populations. As discussed in the Introduction, the most direct test of the long-term effects of supplementation will involve analyses of population time series which include data during post-supplementation periods, preferably extending over at least 12 years (three generations).

Criteria which would make a supplemented population an attractive choice for cessation, and subsequent inclusion in a Before-After type of analysis include:

- Supplementation has been implemented over several generations already.
- Monitoring has been performed relatively consistently over the period of supplementation, providing a reliable data set against which post-supplementation information may be compared.
- Freshwater spawning and rearing habitat is adequate to support a natural population, and measures of natural productivity are relatively high, such that it is reasonable to believe the non-supplemented natural population could be self-sustainable.

From among the supplemented populations listed in Table1, a subset meeting the above criteria are identified in Table 2 as potential candidates for having their supplementation programs discontinued (at least temporarily).

Table 2. Candidate salmon/steelhead populations for cessation of supplementation.

Species/ Stock	Population or subpopulation	Years of abundance data	Generations of supp.	10-year Average: Average PNI	10-year Average: Average population size	Natural $R_{(adults)}/S$	Rationale
SPRING (stream-type) CHINOOK							
	Imnaha River mainstem (IRMAI)	1949-2007	5	0.35	380	0.79	Long-term supplementation program with good time series so possible to monitor effects; also a good candidate for a viable natural population.
	South Fork Salmon River mainstem (SFMAI)	1992-2007	2+				Supplementation ceased in 2007. Long-term supplementation program with good time series so possible to monitor effects; also a good candidate for a viable natural population.
	Salmon River upper mainstem (SRUMA)	1989-2007	2+	0.43			Supplementation ceased in 2007. As above. PNI value for section above Sawtooth weir only.
	Pahsimeroi River (SRPAH)	1986-2007	2+	0.17	390		Supplementation ceased in 2007. As above. Average population for 1997 - 2007
	Crooked River (CRSFC)	1989-2007	2+				Supplementation ceased in 2007. Long-term supplementation program with good time series so possible to monitor effects. BUT, a questionable candidate for a viable natural population; supplementation ceased in 2007.
	Wenatchee River above Tumwater Dam (UCWEN)	1960-2007	4+	0.38	1337	1.58	Population is well monitored; good candidate for viable population.
	Entiat River (UCENT)	1960-2007	4+	0	226	1.59	As above, but involves a harvest augmentation hatchery program that has already been terminated.

	Methow River (UCMET)	1960-2007	3+	0.21	2030	2.28	As above, although previous harvest augmentation hatchery program terminated, while supplementation continues
FALL (ocean-type) CHINOOK							
							Snake River fall Chinook generally meets criteria, BUT this population has been recommended for continuation of RRS study.
STEELHEAD							
	Wenatchee River (UCWEN-s)	1978-2007	10+	0.43	2274	0.97	Steelhead RRS studies are consistent in finding low RRS; likely explanation for low productivity of natural UC steelhead is past hatchery impacts
	Wenatchee River above Tumwater Dam (UCWEN-s)	1998-2007	10+	0.43	1511	0.97	As above, but maintain production for some harvest and exclude all hatchery fish above Tumwater as experiment. Would require population monitoring above and below Tumwater.
	Entiat River (UCENT-s)	1978-2007	8	n/a	559	0.52	In theory, this is already being done in the Entiat, but stray rates from other areas and difficult in monitoring are making this an ineffective experiment. Planned hatchery improvements should result in reduced straying and improve population monitoring.
	Methow River (UCMET-s)	1977-2007	10+	0.14	4045	0.33	Would be a very dramatic experiment since population is currently >90% hatchery fish. Population is almost certainly highly impacted by past hatchery practices. Easily monitored.

While supplementation was recently halted in the four ISS spring/summer (stream-type) Chinook populations in Table 2, we recommend cessation of supplementation in an additional one or two stream-type Chinook populations in different parts of the basin, in several steelhead populations, and in at least one ocean-type Chinook population. Identification from among the candidates, which specific programs would be recommended for termination, however, is a management/policy decision which will require consideration of numerous factors, and concurrence from multiple concerned management agencies.

While Implementation and Compliance Monitoring, and Effectiveness Monitoring (at the regional scale) will permit enacting the recommended analyses in relative population abundance and productivity, it will not permit elucidation of mechanisms behind observed differences. To do so, more intensive and finer scaled population and habitat monitoring will be required for a subset of populations.

Scientifically sound and robust Effectiveness Monitoring (at the project scale) via intensively monitored programs are already ongoing or proposed in the basin, including: the ISS, YKFP, Northeast Oregon Hatchery, Johnson Creek, Wenatchee River supplementation project, and Mid-Upper Columbia hatchery programs. Some of research questions these studies are addressing include:

- Are there impacts of the hatchery program on non-target taxa of concern (NTTOC) – in-terms of abundance and productivity of the non-target population(s), competition for food and habitat resources, etc.
- Does hatchery rearing affect changes in behavioral and physical characteristics of the natural population – e.g., juvenile characteristics: growth rate, age and size at smoltification; adult characteristics: age, size and morphometrics at time of return, run-timing, spawn timing, jack rate, fecundity, sex-ratio, etc.

The AHSWG strongly recommends continued support for these ongoing programs.

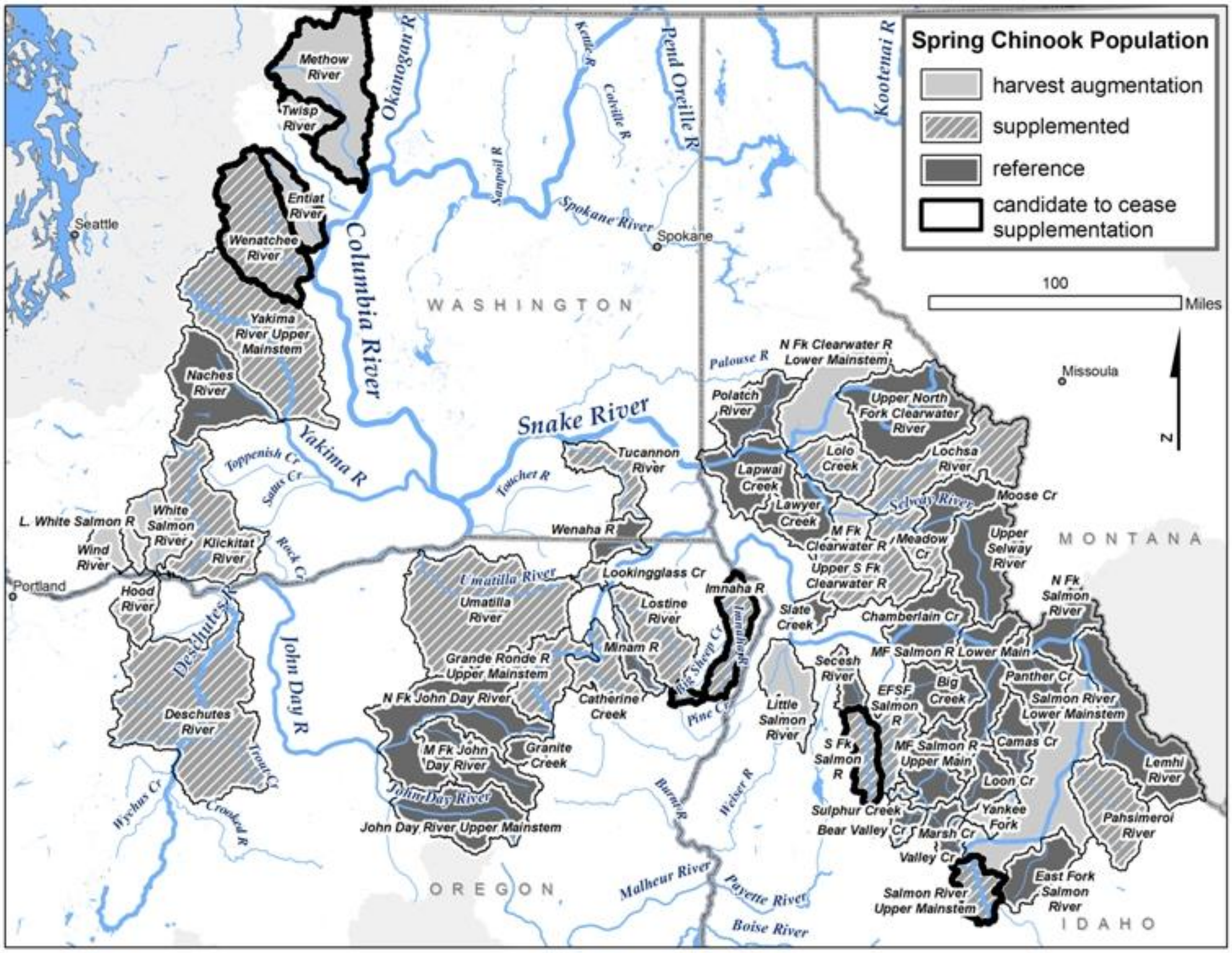


Figure 1. Potential supplemented and reference Spring Chinook salmon populations for long-term monitoring. Candidates for experimental cessation of supplementation are also illustrated.

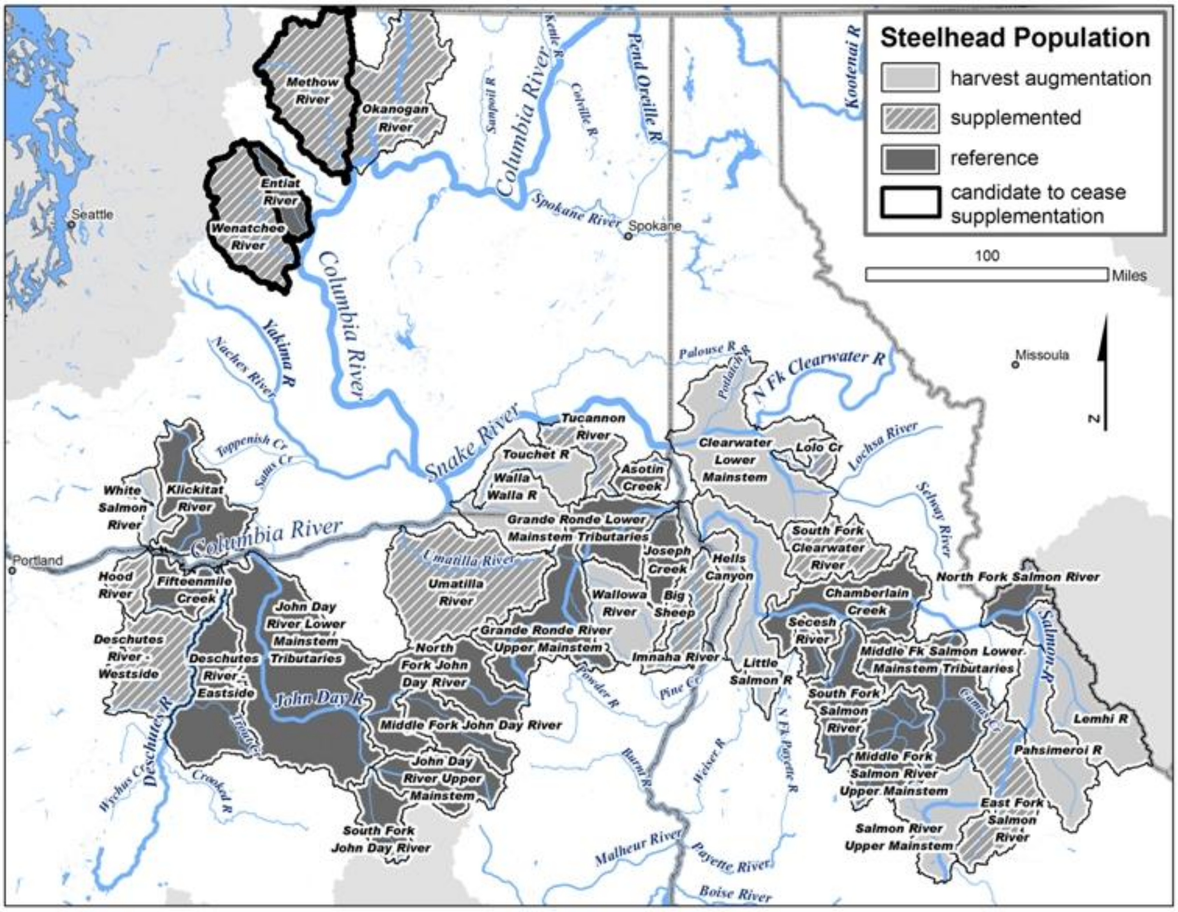


Figure 2. Potential supplemented and reference steelhead populations for long-term monitoring. Candidates for experimental cessation of supplementation are also illustrated.

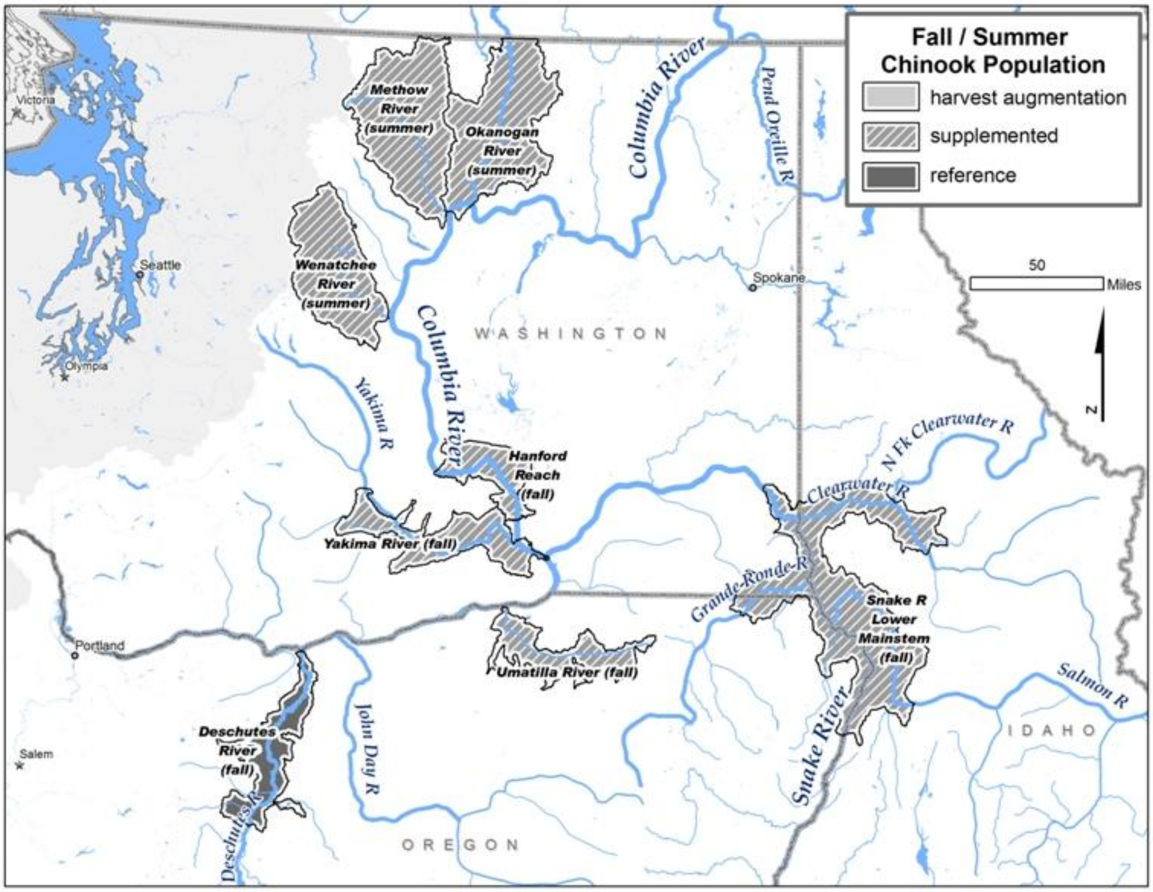


Figure 3. Potential supplemented and reference fall/summer Chinook salmon populations for long-term monitoring. Note the lack of many existing reference populations.

B) Continue and expand Relative Reproductive Success (RRS) studies.

To complement monitoring of population abundance and productivity for long-term trend analyses, we recommend continued support of current RRS studies of supplemented populations. Beyond the RRS projects which are currently ongoing in the basin, CSMEP recommended that the number of spring Chinook RRS studies be expanded to at least six (Marmorek et al. 2007a and b). We concur, and recommend further expansion to include, a) a total of at least six RRS studies of steelhead populations, b) three RRS studies of reintroduced anadromous salmonid populations, and c) support for the RRS study recently initiated on Snake River fall Chinook, and addition of a study on another ocean-type population, e.g. Wenatchee River summer Chinook. As recommended by CSMEP (Marmorek et al. 2007a and b), the spring Chinook and steelhead populations the choice of the populations within species for RRS study should include ones from across the basin, and across the range (low to high) of PNI values. As described above, using PNI as a covariate in an analysis will permit determination whether differences in productivity are apparent only beyond a certain intensity of supplementation.

In addition to providing species-specific information, RRS studies of steelhead will be particularly informative to fisheries managers in light of the logistical difficulties inherent in obtaining reliable population abundance and productivity information on steelhead populations and the resultant lack of reliability of trend analyses for this species - high winter-spring flows make efforts to keep in-stream wires/traps operational, to count redds, and to survey carcasses very difficult, if not impossible.

Our recommendations also include study of three previously extirpated populations – populations which were subsequently reintroduced through hatchery stocking. Reintroduced populations in the Columbia basin include all coho populations upstream of Bonneville Dam, and several different spring Chinook populations, e.g., hood River, Umatilla River, those in the Clearwater River system, etc. (Phillips et al. 2000, Everett et al. 2006, Bosch et al. 2007, ISRP 2007, Narum et al. 2007). The reintroductions were initiated by successive years of acclimation and release of smolts derived from out-of-basin hatchery stocks. As adults returned from these initial stockings, a portion were used as hatchery broodstock to produce smolts, with which the stream was supplemented in addition to the out-of-basin smolts. The remaining portion of returning adults were allowed to escape upstream for natural spawning. In one or two of these projects, stocking of out-of-basin smolts has already been phased out, and supplementation of the new natural populations continues using only local broodstock. RRS studies of these populations will provide quantified measures of productivity during this period of renaturalization, which could be analyzed for an increasing trend, and compared to levels observed in natural reference populations.

Sampling and analysis in each of the recommended RRS projects described above should be conducted annually for up to 12 years. This will permit accumulation of adult return data for successive broodyears. Additionally, we recommend the studies be designed so that it is possible to determine if any fitness differences between wild and hatchery origin fish are due to genetic versus environmental causes. For example, this could be accomplished by comparisons of RRS of hatchery-spawned fish with hatchery-origin versus natural-origin parents, as described by Araki et al. (2007b) in their study of Hood River steelhead. Similarly, estimation of RRS of naturally spawning fish with natural-origin parents, but with grandparents of different origin would permit attribution of any differences to genetic effects, though this will require collection of adult data for at least two full generations.

In designing RRS studies, we believe the following factors should be considered:

- Relative fitness should be measured at the population or large spawning aggregate scale if possible, in order to be confident that the results are applicable at the population scale. If such studies are logistically not possible, smaller scales studies should be considered.
- Factors to be considered in evaluating study designs should include:
    - Ability to sample the large majority of the potential spawning population
    - Ability to collect covariate data on potential parents
    - Ability to collect adequate samples of juvenile and adult progeny

    - Size of the potential spawning population – must be large enough for adequate statistical power but small enough to be logistically feasible for parentage analysis (spawning population sizes between 200 and 2000 are ideal; analysis of larger populations will become easier as technology improves)
    - In order to maximize power to estimate relative fitness, the ratio of hatchery to wild fish in the spawning population should not be too extreme (roughly 50:50 is ideal).
- Trade-offs between studies of large, populations that do not control for all potentially confounding effects versus studies of smaller populations which can be better controlled but might be less representative, studies should be carefully considered.
- Relative fitness should be based on productivity assessments of progeny at juvenile and adult life stages, in order to better assess where differences in fitness are occurring (e.g., fry, smolt, and adult stages)
- Relative fitness studies should be designed such that inferences about genetic versus environmental effects of fitness differences can be made.
- In order to determine potential causes if fitness differences are observed, data on characteristics of the spawning populations under study should be collected, including (where it is logistically feasible):
    - Number of spawning adults
    - Number of juveniles produced
    - Individual run and spawn timing
    - Sex
    - Morphology (length, weight, possibly a photograph)
    - Freshwater and saltwater age
    - Hatchery versus wild origin (and if possible specific hatchery origin)
    - Redd characteristics
        - Morphology
        - Depth
        - Water velocity
        - Water temperature
    - Egg voidance
    - Spawning behavior
    - Spawning location

Table 3 (and illustrated in Figures 4 and 5) provides a list of supplemented populations (grouped by species/stock) with ongoing RRS studies, and other populations which we propose as candidates for study. The criteria which make RRS studies of these populations useful include:

- The populations are supplemented by ‘modern’ programs that generally follow currently accepted best practices for supplementation (e.g., use of local broodstock, incorporation of natural origin adults in the broodstock, release of juveniles within natural spawning areas following a period of local acclimation, etc.)

- An adult trap which can capture (near) 100% of the in-migrating adults already exists, or one could be cost-effectively installed and operated
- Trapping of juveniles already occurs, or could be feasibly implemented
- These populations have at least reasonably good time series of data for abundance and productivity, and their history of supplementation is well documented and understood.

Table 3. Supplemented populations with an ongoing relative reproductive success (RRS) study, or is a candidate for an RRS study. (MPG and ESU designations as defined by the ICRBTRT; HA = harvest augmentation; Supp = supplementation; n/a = not applicable; blank cells indicates that data is unavailable)

Supplemented Natural Populations

Population	Subbasin	Life history segment	Ongoing RRS study	Generations of supp.	10-year Average PNI	10-year Average Pop. Size
SPRING (stream-type) CHINOOK						
Upper Yakima River	Yakima River	Adult-to-fry	no	1		
Chiwawa River	Wenatchee River	adult-to-parr/smolt/adult	yes	4	0.57	717
White River	Wenatchee River	adult-to-parr/smolt/adult	yes	4	n/a	75
Twisp River	Methow River	adult-to-smolt	no	3	0.5	220
Chewuch River	Methow River	adult-to-smolt	no	3	0.28	552
upper Methow River	Methow River	adult-to-smolt	no	3	0.10	1284
Tucannon River	Lower Snake	adult-to-smolt	no		0.64	
Pahsimeroi River	Salmon River	adult-to-smolt/adult	yes	2+	0.17	
Salmon River upper mainstem above Redfish Lake	Salmon River		no	2+	0.43	
East Fork South Fork Salmon River (Johnson Creek)	Salmon River	adult-to-smolt/adult	no		0.79	
Catherine Creek	Grand Ronde River	adult-to-parr-smolt-adult	yes	1	0.75	107
Lostine River	Grand Ronde River	adult-to-parr-smolt-adult	yes	1	0.75	276
upper Grande Ronde	Grand Ronde River	adult-to-parr-smolt-adult	no	1	0.77	38

FALL (ocean-type) CHINOOK							
	Snake River						
	Wenatchee River						
STEELHEAD							
	Kalama River		lifetime	yes	1		
	Hood River (winter run)	Central Columbia	lifetime	yes	1		
	Hood River (summer run)	Central Columbia	lifetime	yes	1		
	Wenatchee	Wenatchee	adult-parr and lifetime	no		0.43	774
-	Little Sheep Creek	Imnaha River	adult-to-parr-smolt-adult	no	4	-	-

Supplemented Reintroduced Populations

Population	Subbasin	Life history segment	Ongoing RRS Study
SPRING (stream-type) CHINOOK			
West Fork Hood River	Central Columbia	adult-to-adult	no
Umatilla River	Central Columbia	adult-to-smolt	no
Newsome Creek	Clearwater River	adult-to-smolt	no
Red River	Clearwater River	adult-to-smolt	no
Crooked River	Clearwater River	adult-to-smolt	no
Clear Creek	Clearwater River	adult-to-smolt	no
Lookingglass Creek	Grande Ronde River	adult-to-smolt/adult	no
COHO			
Upper Yakima River	Mid-Columbia	adult-to-smolt	no
Upper Wenatchee River	Mid-Columbia	adult-to-smolt	no
Twisp River (Methow River)	Mid-Columbia	adult-to-smolt	no
STEELHEAD			

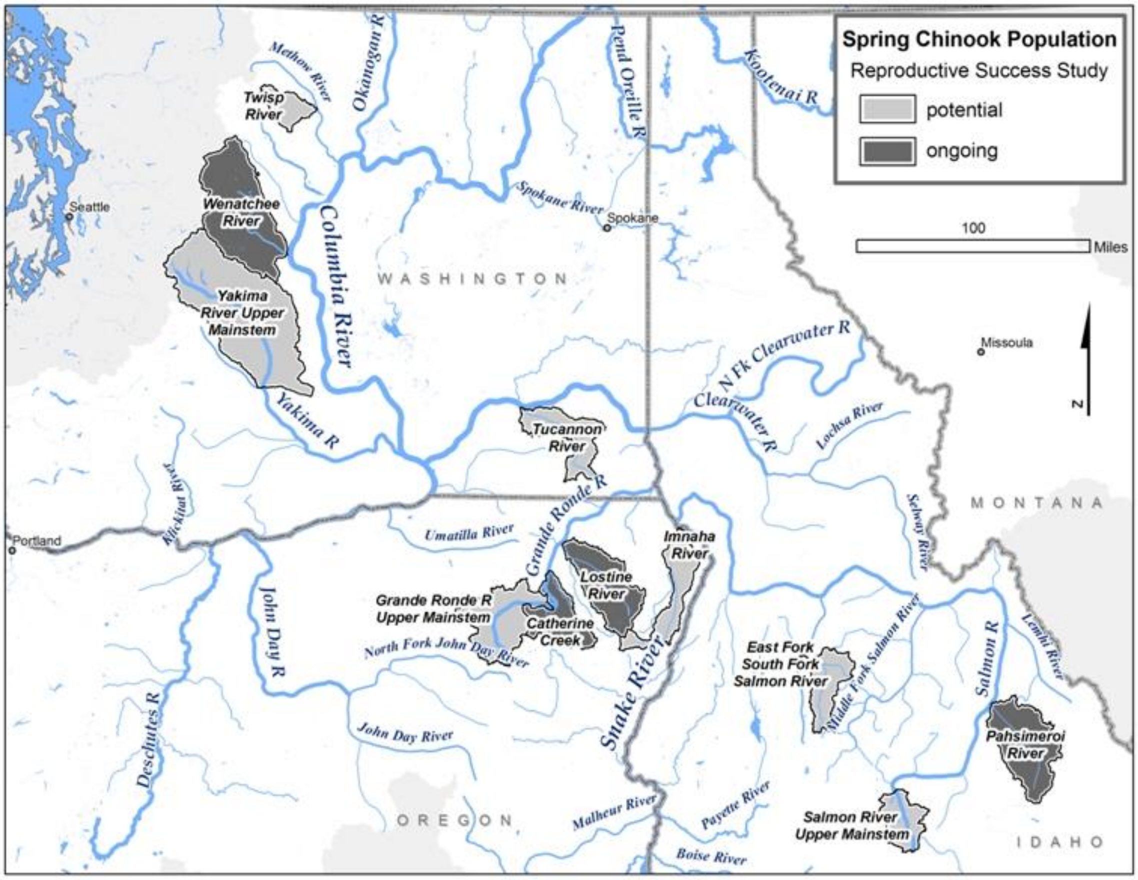


Figure 4. Ongoing and potential RRS studies of Spring Chinook salmon.

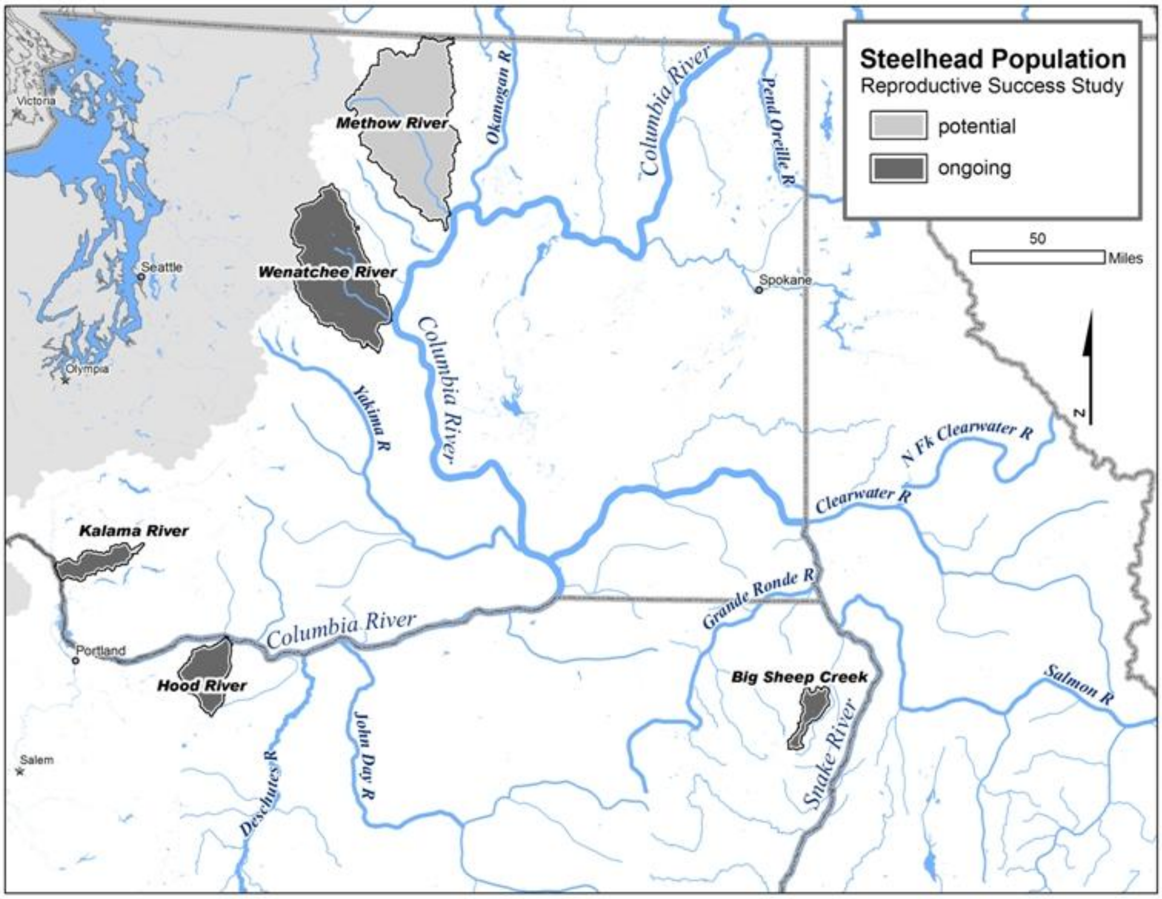


Figure 5. Ongoing and potential RRS studies of steelhead.

<u>Recommendation 3</u>. Maintain the momentum from current CSMEP and AHSWG efforts, through formation of an interagency technical working group.

We recommend that an interagency working group be created to coordinate data analysis of the monitoring projects identified to provide information for these regional analyses. Whether this group is created utilizing an existing forum (e.g., CBFWA, CSMEP, RIST, etc.) or a new one, the essential point is that a formally recognized forum is necessary to a) regularly communicate information and research, monitoring, and evaluation results among managers, b) develop and implement large scale study designs, and c) continue to work to standardize data collection and analysis, and communicate results of these analyses to managers and policy makers.

<u>Summary</u>

As described by the ISRP and ISAB (2005-15), improved information on effects of artificial production programs is needed both to update the guidelines for use of supplementation described in the NPCC Fish and Wildlife Program, and to aid in the three step reviews of specific hatchery projects funded, or proposed for funding, under the Program. Implementation of the AHSWG recommendations will establish a common framework for individual hatchery program M&E, and define the type and scale of monitoring needed to provide the data and assessments of the effects of hatchery supplementation. With this information, managers will be able to use a cost-benefit approach to design of supplementation projects – one which weighs the advantage of the nearer-term demographic increases expected of supplementation against the potential of longer-term genetic and demographic risks to the natural population. The information may also be valuable for designing additional strategies, which deviate from current hatchery practices to ensure that programs can fulfill the social and legal mandates for harvest mitigation and conservation. Decisions on hatchery use will also need to consider expected changes to conditions of freshwater habitat, and for survival through the hydrosystem, and estuary and ocean rearing over the coming years. This process of deciding if, how and when to apply hatcheries will require considerable policy, management and legal input in addition to the scientific input.

References

Araki, H. B. A. Berejikian, M. J. Ford and M. S. Blouin. 2008 *in press*. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications.

Araki, H., B. Cooper and M. S. Blouin. 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. Science 318:100-103.

Berejikian, B. A. and M. J. Ford. 2004. Review of relative fitness of hatchery and natural salmon. NOAA-Technical Memorandum NMFS-NWFSC-61. Seattle, Washington. (http://www.nwfsc.noaa.gov/assets/25/6011_02012005_154209_fitnesstm61final.pdf).

Bosch, W. J., T. H. Newsome, J. L. Dunnigan , J. D. Hubble, D. Neeley, et al. 2007. Evaluating the Feasibility of Reestablishing a Coho Salmon Population in the Yakima River, Washington. North American Journal of Fisheries Management 27: 198–214.

Bowles, E., and E. Leitzinger. 1991. Salmon supplementation studies in Idaho rivers (Idaho supplementation studies). Idaho Department of Fish and Game experimental design, Project Number 89-098, to the Bonneville Power Administration, Portland, Oregon. http://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=01466-1

Brannon, E. L., D. F. Amend, M. A. Cronin, J. E. Lanna, S. LaPatra, W. J. McNeil, R. E. Noble, C. E. Smith, A. J. Talbot, G. A. Wedemeyer, and H. Westers. 2004a. The controversy about salmon hatcheries. Fisheries 29(9):12–31.

Busack, C, P. Hulett, T. Pearsons, J. Tipping and J. B. Scott, Jr. 2006. Chapter 3 Artificial production. *in* J. B. Scott, Jr. and W. T. Gill, editors. *Oncorhynchus mykiss*: Assessment of Washington State's anadromous populations and programs. Washington Department of Fish and Wildlife, Olympia, Washington. (http://wdfw.wa.gov/fish/papers/steelhead/)

Chilcote, M. W. 2003. Relationship between natural productivity and the frequency of wild fish in mixed spawning populations of wild and hatchery steelhead. Canadian Journal of Fisheries and Aquatic Sciences 60:1057-1067.

CSMEP 2004. (www.cbfwa.org/csmep/web/documents/meetings/2004_0701/ESSArevisedTableC1June28.doc)

Cuenco, M. L., T. W. H. Backman, and P. R. Mundy. 1993. The use of supplementation to aid in natural stock restoration. Pages 269-293 *in* J. G. Cloud and G. H. Thorgaard, editors. Genetic conservation of salmonid fishes. Plenum Press, New York.

Everett, S., C. Beasley, R. Johnson, C. L. Davenport and R. Larson. 2006. Nez Perce tribal hatchery Project; Coho salmon master plan, Clearwater River Basin. 2003-2004 Annual Report, Project No. 198335000, 134 electronic pages, (BPA Report DOE/BP-00004035-1) (http://pisces.bpa.gov/release/documents/documentviewer.aspx?pub=A00004035-1.pdf)

Everhart, W. H. and W. D. Youngs. 1992. Principles of fishery science. Cornell University Press, Ithaca, New York.
Galbreath, P. F., P. B. Roger and M. J. Ford. 2006. Report of the Supplementation Monitoring and Evaluation Workshop – April 6-7, 2006, Columbia River Inter-Tribal Fish Commission, Portland OR (http://www.cbfwa.org/csmep/web/documents/general/Documents/Supplementation%20M&E%20Workshop%20I%20Report.pdf).
Galbreath, P. F., P. B. Roger and M. J. Ford. 2007. Meeting Summary - Supplementation Monitoring and Evaluation Workshop II - February 14-15, 2007. NOAA, Portland OR (http://www.cbfwa.org/csmep/web/documents/general/Documents/Supp%20M&E%20Workshop%20II%20Summary.pdf).
Goodman, D. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. Canadian Journal of Fisheries and Aquatic Science. 62:1-16.
Hoekstra, J. M., K. K. Bartz, M. H. Ruckelshaus, J. M. Moslemi and T. K. Harms. 2007. Quantitative threat analysis for management of an imperiled species-Chinook salmon (*Oncorhynchus tshawytscha*). Ecological Applications, 17:2061-2073.(http://www.nwfsc.noaa.gov/publications/displayallinfo.cfm?docmetadataid=6605)
ISAB. 2002. Hatchery surpluses in the Pacific Northwest. Fisheries 27(12):16-27.
ISAB. 2003. A Review of Salmon and Steelhead Supplementation (ISAB 2003-3; http://www.nwcouncil.org/library/isab/isab2003-3.htm).
ISRP and ISAB. 2005. Monitoring and Evaluation of Supplementation Projects. ISRP&ISAB Report 2005-15. Northwest Power and Conservation Council, Portland, Oregon. (http://www.nwcouncil.org/library/isrp/isrpisab2005-15.pdf)
Kucera, P. A. and R. W. Orme. 2007. Chinook salmon (*Oncorhynchus tshawytscha*) adult escapement monitoring in Lake Creek and Secesh River, Idaho in 2006. Annual report submitted to the Bonneville Power Administration. Bonneville Power Administration, Portland, OR.
Lutch, J., J. Lockhart, C. Beasley, K. Steinhorst, and D. Venditti. 2005. An updated study design and statistical analysis of Idaho supplementation studies. Scientific findings report to the Bonneville Power Administration, Project Numbers 1989-098-00, 1989-098-01, 1989-098-02, and 1989-098-03, Portland, Oregon. http://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=P102750
Levin, P. S., R. W. Zabel and J. G. Williams. 2001. The road to extinction is paved with good intentions: negative association of fish hatcheries and threatened salmon. Proceedings of the Royal Society of London B 268:1153-1159.
Marmorek, D. R., M. Porter, D. Pickard and K. Wieckowski (editors). 2007a. Snake River Basin Pilot Study: Volume 1. Prepared by ESSA Technologies Ltd., Vancouver, B.C. on behalf of the Columbia Basin Fish and Wildlife Authority, Portland, OR. 2007. Collaborative Systemwide Monitoring and Evaluation Project (CSMEP) Snake Basin Pilot Report. Prepared by ESSA Technologies Ltd., Vancouver, B.C. on behalf of the Columbia Basin Fish and Wildlife Authority, Portland, OR. 47 pp. (http://www.cbfwa.org/csmep/web/documents/general/Documents/Volume%201%20FINAL.pdf)
Marmorek, D. R., M. Porter, D. Pickard and K. Wieckowski. 2007b. Collaborative Systemwide Monitoring and Evaluation Project (CSMEP) Snake River Basin Pilot Study: Volume 2. Prepared by ESSA Technologies Ltd., Vancouver, B.C. on behalf of the Columbia Basin Fish and Wildlife Authority, Portland, OR. 216 pp. (http://www.cbfwa.org/csmep/web/documents/general/Documents/volume%202_Draft_FINAL.pdf)
McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmon populations and the recovery of evolutionarily significant units U.S. Department of Commerce, NOAA Technical Memo, NMFS-NWFSC-42, 156. (http://www.nwfsc.noaa.gov/assets/25/5561_06162004_143739_tm42.pdf)
Myers, R. A., S. A. Levin, R. Lande, F. C. James, W. W. Murdoch and R. T. Paine. 2004. Hatcheries and endangered salmon. Policy Forum. Science 303:1980.
Narum, S. R., W. D. Arnsberg, A. J. Talbot and M. S. Powell. 2007. Reproductive isolation following reintroduction of Chinook salmon with alternative life histories. Conservation Genetics 8:1123-1132.
Nickelson, T. 2003. The influence of hatchery coho salmon (*Oncorhynchus kisutch*) on the productivity of wild coho salmon populations in Oregon coastal basins. Canadian Journal of Fisheries and Aquatic Sciences 60:1050-1056.

NPCC (Northwest Power and Conservation Council). 2006b. *Draft* Guidance for Developing Monitoring and Evaluation as a Program Element of the Fish and Wildlife Program. (NPCC Document 2006-4). Portland, Oregon. http://www.nwcouncil.org/library/2006/draftme.htm).

Parnell, I., D. Marmorek, and M. Porter 2004. Revised Table C1 Structure and Definitions for Data Descriptors (Columns) and Performance Measures (Rows) to Guide Development of the CSMEP Inventory Database and Data Input system. Prepared for the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP). Based on Discussions at the June 17 CSMEP Meeting. ESSA Technologies Ltd., Vancouver, B.C., Canada. (www.cbfwa.org/csmep/web/documents/meetings/2004_0701/ESSArevisedTableC1June28.doc***)***

Phillips, J. L., J. Ory and A. Talbot. 2000. Anadromous salmonid recovery in the Umatilla River basin: A case study. Journal of the American Water Resources Association 36:1287-1308.

RASP (Regional Assessment of Supplementation Project). 1992. Supplementation in the Columbia Basin. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Summary Report Series, Final Report, Project 85-62, Portland, Oregon (http://pisces.bpa.gov/release/documents/documentviewer.aspx?pub=P01830-11.pdf).

Steinhorst, R. K. 2000. Confidence intervals for escapement estimates derived from stratified samples. Report to Idaho Fish and Game for project K818.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. U.S. Forest Service, Intermountain Research Station, General Technical Report INT-GTR-307, Odgen, Utah.

Waples, R. S., M. J. Ford, and D. Schmitt. 2007. Empirical results of salmon supplementation in the Northeast Pacific: A preliminary assessment. pp. 383-403 *in* T. M. Bert, editor. Ecological and Genetic Implications of Aquaculture Activities (Reviews: Methods & Technologies in Fish Biology & Fisheries, Vol. 6). Springer-Verlag, New York.

Appendix A

Framework for Integrated Hatchery Research, Monitoring and Evaluation

Monitoring of hatchery programs to assess the effects that they have on population and ESU productivity, involves only a portion of the breadth of activities required for comprehensive monitoring and evaluation (M&E) of how hatcheries are operated in the region. The Northwest Power and Conservation Council (NPCC 2006) has called for integration of individual hatchery evaluation programs into a regional evaluation plan. Presented here is a standardized science-based framework for cost effectively implementing hatchery research, monitoring, and evaluation projects that are compatible with a larger regional program. Ideally this framework will provide generalized guidance (i.e. limitation levels or balance points) on aspects of hatchery programs to maximize benefits to natural production and abundance, and to minimize effects on natural population productivity and long-term fitness. Assessment of long-term and short-term application of integrated supplementation/mitigation programs, as well as segregated harvest augmentation programs are addressed here.

This framework is structured to describe three categories of research, monitoring, and evaluation associated with hatchery programs; 1) Implementation and Compliance Monitoring, 2) Hatchery Effectiveness Monitoring, at both project and regional scales, and 3) Uncertainty Research. Basic monitoring and evaluation activities/projects that address Implementation and Compliance Monitoring should be conducted on all hatchery programs. An increased intensity of M&E activities/projects that address Hatchery Effectiveness Monitoring (both regionally and locally) will be conducted on a subset programs, and yet a further increase of M&E activities/projects to address Uncertainty Research would involve a limited set of research projects.

This approach utilizes a common set of standardized performance measures (Table A1) as established by the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP). Adoption of this suite of performance measures and definitions across multiple study designs, will facilitate coordinated analysis of findings from regional monitoring and evaluation efforts aimed at addressing management questions and critical uncertainties associated with supplementation and ESA listed stock status/recovery. The list of performance measures is sufficiently inclusive to populate numerous models to guide the implementation and operation of supplementation programs. For example, Goodman (2005) developed a model (Figure A1) that describes how hatchery operations could be adaptively managed to optimize benefits to natural populations and minimize the risks of artificial propagation. Table A2 lists the variables/parameters of Goodman’s model, defines the variables, and shows how they might be derived from the performance measures.

Table A1. Standardized performance measures and definitions for status and trends and hatchery effectiveness monitoring. Modified from Parnell et al. (2004).

Performance Measure		Definition (some definitions remain specific to Snake Basin and need to modified for Columbia Basin application)
Abundance	Adult Escapement to Tributary	Number of adults (including jacks) that have escaped to a certain point (i.e. - mouth of stream). Population based measure. Calculated with mark recapture methods from weir data adjusted for redds located downstream of weirs and in tributaries, and maximum net upstream approach for DIDSON and underwater video monitoring. Provides total escapement and wild only escapement. [Assumes tributary harvest is accounted for]. Uses TRT population definition where available.
	Fish per Redd	Number of fish divided by the total number of redds. Applied by: The population estimate at a weir site, minus broodstock and mortalities and harvest, divided by the total number of redds located upstream of the weir.
	Female Spawner per Redd	Number of female spawners divided by the total number of redds above weir. Applied in 2 ways: 1) The population estimate at a weir site multiplied by the weir derived proportion of females, minus the number of female prespawn mortalities, divided by the total number of redds located upstream of the weir, and 2) DIDSON application calculated as in 1 above but with proportion females from carcass recoveries. Correct for miss-sexed fish at weir for 1 above.
	Index of Spawner Abundance - redd counts	Counts of redds in spawning areas in index area (trend), extensive areas, and supplemental areas. Reported ad redds & redds/km.
	Spawner Abundance	Estimated number of total spawners on the spawning ground. Calculated as the number of fish that return to an adult monitoring site, minus broodstock removals and weir mortalities and harvest if any, subtracts the number of female prespawning mortalities and expanded for redds located below weirs. Calculated in two ways: 1) total spawner abundance, and 2) wild spawner abundance which multiplies by the proportion of natural origin (wild) fish. Calculations include jack salmon.
	Hatchery Fraction	Percent of fish on the spawning ground that originated from a hatchery. Applied in two ways: 1) Number of hatchery carcasses divided by the total number of known origin carcasses sampled. Uses carcasses above and below weirs, 2) Uses weir data to determine number of fish released above weir and calculate as in 1 above, and 3) Use 2 above and carcasses above and below weir.
	Ocean/Mainstem Harvest	
	Harvest Abundance in Tributary	Number of fish caught in tributary fisheries (tribal, sport, or commercial) by hatchery and natural origin.
	Index of Juvenile Abundance (Density)	Parr abundance estimates using underwater survey methodology are made at pre-established transects. Densities (number per 100 m2) are recorded using protocol described in Thurow (1994). Hanken & Reeves estimator.
	Juvenile Emigrant Abundance	Gauss software is used to estimate emigration estimates. Estimates are given for parr pre-smolts, smolts and the entire migration year. Calculations are completed using the Bailey Method and bootstrapping for 95% CIs. Gauss program developed by the University of Idaho (Steinhorst 2000) Gauss (Aptech Systems, Maple Valley, Washington)

	Smolts	Smolt estimates, which result from juvenile emigrant trapping and PIT tagging, are derived by estimating the proportion of the total juvenile abundance estimate at the tributary comprised of each juvenile life stage (parr, presmolt, smolt) that survive to LGD (or other common point in mainstem). It is calculated by multiplying the life stage specific abundance estimate (with standard error) by the life stage specific survival estimate to LGD (with standard error). The standard error around the smolt equivalent estimate is calculated using the following formula; where X = life stage specific juvenile abundance estimate and Y = life stage specific juvenile survival estimate: $Var(X \cdot Y) = E(X)^2 \cdot Var(Y) + E(Y)^2 \cdot Var(X) + Var(X) \cdot Var(Y)$
	Run Prediction	This will not be in the raw or summarized performance database.

Survival – Productivity	Smolt-to-Adult Return Rate	The number of adult returns from a given brood year returning to a point (stream mouth, weir) divided by the number of smolts that left this point 1-5 years prior. Calculated for wild and hatchery origin conventional and captive brood fish separately. Adult data applied in two ways: 1) SAR estimate to stream using Population estimate to stream, 2) adult PIT tag SAR estimate to escapement monitoring site (weirs, LGR), and 3) SAR estimate with harvest. Accounts for all harvest below stream. *Smolt-to-adult return rates* are generated for four performance periods; tributary to tributary, tributary to LGD, LGD to LGD, and LGD to tributary. *LGD to LGD* SAR estimates are calculated by dividing the number of PIT tagged adults returning to LGD by the estimated number of PIT tagged juveniles at LGD. Variances around the point estimates are calculated as described above. *Tributary to tributary SAR* estimates for natural and hatchery origin fish are calculated using PIT tag technology as well as direct counts of fish returning to the drainage. PIT tag SAR estimates are calculated by dividing the number of PIT tag adults returning to the tributary (by life stage and origin type) by the number of PIT tagged juvenile fish migrating from the tributary (by life stage and origin type). Overall PIT tag SAR estimates for natural fish are then calculated by averaging the individual life stage specific SAR's. Direct counts are calculated by dividing the estimated number of natural and hatchery-origin adults returning to the tributary (by length break-out for natural fish) by the estimated number of natural-origin fish and the known number of hatchery-origin fish leaving the tributary. *Tributary to LGD* SAR estimates are calculated by dividing the number of PIT tagged adults returning to LGD by the number of PIT tagged juveniles tagged in the tributary. There is no associated variance around this estimate. The adult detection probabilities at LGD are near 100 percent. *LGD to tributary* SAR estimates are calculated by dividing the number of PIT tagged adults returning to the tributary by the estimated number of PIT tagged juveniles at LGD. The estimated number of PIT tagged juveniles at LGD is calculated by multiplying lifestage specific survival estimates (with standard errors) by the number of juveniles PIT tagged in the tributary. The variance for the estimated number of PIT tagged juveniles at LGD is calculated as follows, where X = the number of PIT tagged fish in the tributary and Y = the variance of the lifestage specific survival estimate: $Var(X \cdot Y) = X^2 \cdot Var(Y)$ The variance around the SAR estimate is calculated as follows, where X = the number of adult PIT tagged fish returning to the tributary and Y = the estimated number of juvenile PIT tagged fish at LGD: $Var\left(\frac{X}{Y}\right) = \left(\frac{EX}{EY}\right)^2 \cdot \left(\frac{Var(Y)}{(EY)^2}\right)$
	Progeny-per- Parent Ratio	Adult to adult calculated for naturally spawning fish and hatchery fish separately as the brood year ratio of return adult to parent spawner abundance using data above weir. Two variants calculated: 1) escapement, and 2) spawners.

	Recruit/spawner (Smolt Equivalents per Redd or female)	Juvenile production to some life stage divided by adult spawner abundance. Derive adult escapement above juvenile trap multiplied by the prespawning mortality estimate. Adjusted for redds above juv. Trap. *Recruit per spawner* estimates, or *juvenile abundance (can be various life stages or locations) per redd/female*, is used to index population productivity, since it represents the quantity of juvenile fish resulting from an average redd (total smolts divided by total redds) or female. Several forms of juvenile life stages are applicable. We utilize two measures: 1) juvenile abundance (parr, presmolt, smolt, total abundance) at the tributary mouth, and 2) smolt abundance at LGD.
	Pre-spawn Mortality	Percent of female adults that die after reaching the spawning grounds but before spawning. Calculated as the number of females 25% spawned divided by the total number of female carcasses sampled. [25% spawned = female that contains 75% of the egg compliment].
	Juvenile Survival to Lower Granite Dam	Life stage survival (parr, presmolt, smolt, subyearling) calculated by CJS Estimate (SURPH) produced by PITPRO 4.8+ (recapture file included), CI estimated as 1.96*SE. Apply survival by life stage to LDG to estimate of abundance by life stage at the tributary and the sum of those is total smolt abundance surviving to LGD. So juvenile survival to LGD = Total estimated smolts to surviving to LGD/Total estimated juveniles leaving tributary.
	Juvenile Survival to all Mainstem Dams	*Juvenile survival to Lower Granite and Mainstem Dam(s)*, which is estimated using PIT tag technology. Survival by life stage to and through the hydrosystem is possible if enough PIT tags are available from the stream. Using tags from all life stages combined we will calculate (SURPH) the survival to all mainstem dams.
	Post-release Survival	Post-release survival of natural and hatchery-origin fish are calculated as described above in the performance measure “Survival to Lower Granite Dam and Mainstem Dams”. No additional points of detection (i.e. screwtraps) are used to calculate survival estimates.
Distribution	Adult Spawner Spatial Distribution	Extensive area tributary spawner distribution. Target GPS redd locations or reach specific summaries. Raw database measure only.
	Stray Rate (percentage)	Estimate of the number and percent of hatchery origin fish on the spawning grounds, as the percent within MPG, and percent out of ESU. Calculated from 1) total known origin carcasses, and 2) uses fish released above weir. Data adjusted for unmarked carcasses above and below weir.
	Juvenile Rearing Distribution	Chinook rearing distribution observations are recorded using multiple divers who follow protocol described in Thurow (1994).
	Disease Frequency	Natural fish mortalities are provided to certified fish health lab for routine disease testing protocols. Hatcheries routinely samples fish for disease and will defer to then for sampling numbers and periodicity
Genetic	Genetic Diversity	Indices of genetic diversity - measured within a tributary (heterozygosity - allozymes, microsatellites), or among tributaries across population aggregates (e.g., FST).
	Reproductive Success (Nb/N)	Derived measure: determining hatchery:wild proportions, effective population size is modeled.
	Relative Reproductive Success (Parentage)	Derived measure: the relative production of offspring by a particular genotype. Parentage analyses using multilocus genotypes are used to assess reproductive success, mating patterns, kinship, and fitness in natural populations and are gaining widespread use with the development of highly polymorphic molecular markers

	Effective Population Size (Ne)	Derived measure: the number of breeding individuals in an idealized population that would show the same amount of dispersion of allele frequencies under random genetic drift or the same amount of inbreeding as the population under consideration
Life History	Age Structure	Proportion of escapement composed of adult individuals of different brood years. Calculated for wild and hatchery origin conventional and captive brood. adult returns. Assessed via scale method, dorsal fin ray ageing, or mark recoveries. Juvenile Age is determined by brood year (year when eggs are placed in the gravel) Then Age is determined by life stage of that year . Methods to age Chinook captured in screwtrap are by dates; fry – prior to July 1; parr – July 1-August 31; presmolt – September 1 – December 31; smolt – January 1 – June 30; yearlings – July 1 – with no migration until following spring. The age class structure of juveniles is determined using length frequency breakouts for natural-origin fish. Scales have been collected from natural-origin juveniles, however, analysis of the scales have never been completed. The age of hatchery-origin fish is determined through a VIE marking program which identifies fish by brood year. For steelhead we attempt to use length frequency but typically age of juvenile steelhead is not calculated.
	Age–at–Return	Age distribution of spawners on spawning ground. Calculated for wild and hatchery conventional and captive brood adult returns. Assessed via scale method, dorsal fin ray ageing, or mark recoveries.
	Age–at-Emigration	Juvenile Age is determined by brood year (year when eggs are placed in the gravel). Then Age is determined by life stage of that year . Methods to age Chinook captured in screwtrap are by dates; fry – prior to July 1; parr – July 1-August 31; presmolt – September 1 – December 31; smolt – January 1 – June 30; yearlings – July 1 – with no migration until following spring. The age class structure of juveniles is determined using length frequency breakouts for natural-origin fish. Scales have been collected from natural-origin juveniles, however, analysis of the scales have never been completed. The age of hatchery-origin fish is determined through a VIE marking program which identifies fish by brood year. For steelhead we attempt to use length frequency but typically age of juvenile steelhead is not calculated.
	Size-at-Return	Size distribution of spawners using fork length and mid-eye hypural length. Raw database measure only. Weir and carcass data.
	Size-at-Emigration	Fork length (mm) and weight (g) are representatively collected weekly from natural juveniles captured in emigration traps. Mean fork length and variance for all samples within a lifestage-specific emigration period are generated (mean length by week then averaged by lifestage). For entire juvenile abundance leaving a weighted mean (by lifestage) is calculated. Size-at-emigration for hatchery production is generated from pre release sampling of juveniles at the hatchery.
	Condition of Juveniles at Emigration	Condition factor by life stage of juveniles is generated using the formula: $K = (w/l^3)(10^4)$ where K is the condition factor, w is the weight in grams (g), and l is the length in millimeters (Everhart and Youngs 1992).
	Percent Females (adults)	The percentage of females in the spawning population. Calculated using 1) weir data, 2) total known origin carcass recoveries, and 3) weir data and unmarked carcasses above and below weir. Calculated for wild, hatchery, and total fish.
	Adult Run-timing	Arrival timing of adults at adult monitoring sites (weir, DIDSON, video) calculated as range, 10%, median, 90% percentiles. Calculated for wild and hatchery origin fish separately, and total.
	Spawn-timing	This will be a raw database measure only.

	Juvenile Emigration Timing	Juvenile emigration timing is characterized by individual life stages at the rotary screw trap and Lower Granite Dam. Emigration timing at the rotary screw trap is expressed as the percent of total abundance over time while the median, 0%, 10, 50%, 90% and 100% detection dates are calculated for fish at Lower Granite Dam.
	Mainstem Arrival Timing (Lower Granite)	Unique detections of juvenile PIT-tagged fish at Lower Granite Dam are used to estimate migration timing for natural and hatchery origin tag groups by lifestage. The actual Median, 0, 10%, 50%, 90% and 100% detection dates are reported for each tag group. Weighted detection dates are also calculated by multiplying unique PIT tag detection by a life stage specific correction factor (number fish PIT tagged by lifestage divided by tributary abundance estimate by lifestage). Daily products are added and rounded to the nearest integer to determine weighted median, 0%, 50%, 90% and 100% detection dates.
Habitat	Physical Habitat	
	Stream Network	
	Passage Barriers/Diversions	
	Instream Flow	USGS gauges and also staff gauges
	Water Temperature	Various, mainly Hobo and other temp loggers at screw trap sights and spread out throughout the streams
	Chemical Water Quality	
	Macroinvertebrate Assemblage	
	Fish and Amphibian Assemblage	Observations through rotary screwtrap catch and while conducting snorkel surveys.
In-Hatchery Measures	Hatchery Production Abundance	The number of hatchery juveniles of one cohort released into the receiving stream per year. Derived from census count minus prerelease mortalities or from sample fish- per-pound calculations minus mortalities. Method dependent upon marking program (census obtained when 100% are marked).
	In-hatchery Life Stage Survival	General description would included: In-hatchery survival is calculated during early life history stages of hatchery-origin juvenile Chinook. Enumeration of individual female's live and dead eggs occurs when the eggs are picked. These numbers create the inventory with subsequent mortality subtracted. This inventory can be changed to the physical count of fish obtained during CWT or VIE tagging. These physical fish counts are the most accurate inventory method available. The inventory is checked throughout the year using ‘fish-per-pound’ counts. Estimated survival of various in-hatchery juvenile stages (green egg to eyed egg, eyed egg to ponded fry, fry to parr, parr to smolt and overall green egg to release) Derived from census count minus prerelease mortalities or from sample fish- per-pound calculations minus mortalities. Life stage at release varies (Smolt, Presmolt, Parr, etc.)
	Size-at-Release	Mean fork length measured in millimeters and mean weight measured in grams of a hatchery release group. Measured during prerelease sampling. Sample size determined by individual facility and M&E staff. Life stage at release varies (Smolt, Presmolt, Parr, etc.).
	Juvenile Condition Factor	Condition Factor (K) relating length to weight expressed as a ratio. Condition factor by life stage of juveniles is generated using the formula: $K = (w/l^3)(10^4)$ where K is the condition factor, w is the weight in grams (g), and l is the length in millimeters (Everhart and Youngs 1992).

	Fecundity by Age	The reproductive potential of an individual female. Estimated as the number of eggs in the ovaries of the individual female. Measured as the number of eggs per female calculated by weight or enumerated by egg counter.
	Spawn Timing	Spawn date of broodstock spawners by age, sex and origin, Also reported as cumulative timing and median dates
	Hatchery Broodstock Fraction	Percent of hatchery broodstock actually used to spawn the next generation of hatchery F1s. Does not include prespawn mortality.
	Hatchery Broodstock Prespawn Mortality	Percent of adults that die while retained in the hatchery, but before spawning.
	Female Spawner ELISA Values	Screening procedure for diagnosis and detection of BKD in adult female ovarian fluids. The enzyme linked immunosorbent assay (ELISA) detects antigen of *R. salmoninarum*
	In-Hatchery Juvenile Disease Monitoring	Screening procedure for bacterial, viral and other diseases common to juvenile salmonids. Gill/skin/ kidney /spleen/skin/blood culture smears conducted monthly on 10 mortalities per stock
	Length of Broodstock Spawner	Mean fork length by age measured in millimeters of male and female broodstock spawners. Measured at spawning and/or at weir collection. (Used in conjunction with scale reading for ageing.)
	Prerelease Mark Retention	Percentage of a hatchery group that have retained a mark up until release from the hatchery. Estimated from a sample of fish visually calculated as either “present” or “absent.” (“Marks” refer to Ad fin clips or VIE batch marks)
	Prerelease Tag Retention	Percentage of a hatchery group that have retained a tag up until release from the hatchery. Estimated from a sample of fish passed through a CWT detector or PIT tag detector. (All types of tags)
	Hatchery Release Timing	Departures according to date and time of day. Normally determined through PIT tag detections at facility exit (Not all programs monitor volitional releases).
	Chemical Water Quality	Hatchery operational measure (DO), Measured continuously at the hatchery with DO meters and 3 times daily at acclimation facilities with hand-held devices. Hatchery operational measures (NH_3 and NO_2), Measured weekly only at reuse facilities (Kooskia Fish Hatchery).
	Water Temperature	Hatchery operational measure (Celsius) , Measured continuously at the hatchery with thermographs and 3 times daily at acclimation facilities with hand-held devices.

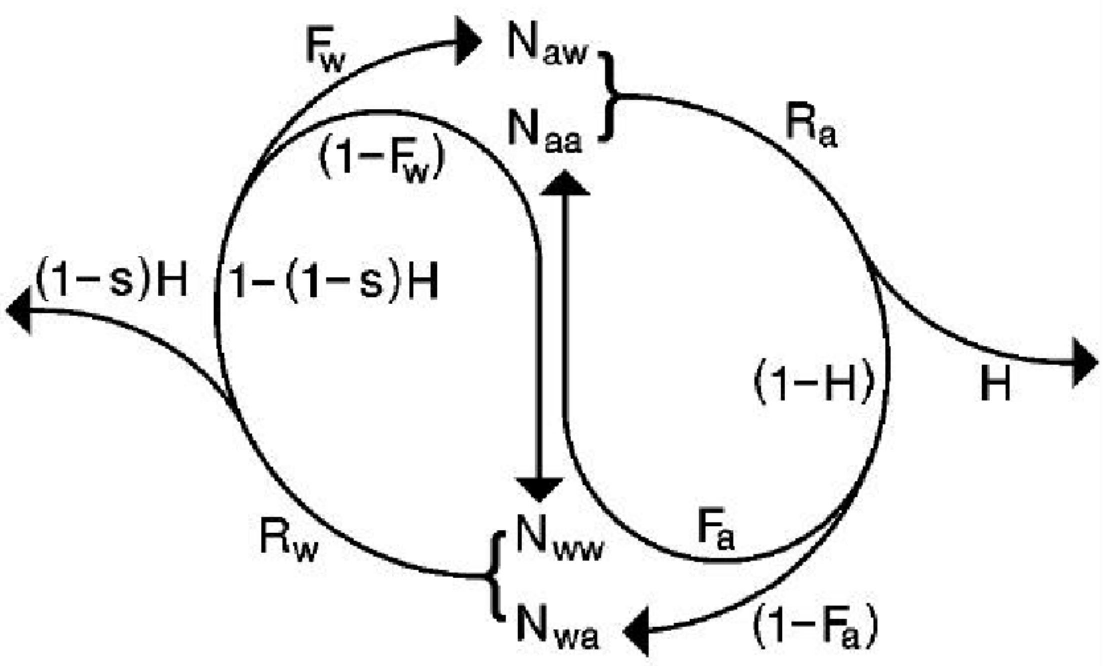


Figure A1. Graphical depiction of the model developed by Goodman (2002), taken from ISAB (2003).

Table A2. Variables used by Goodman (2005), their definition, and relationship to the performance measures (PM) described in Table 1.

Variable	Definition	Relationship to Performance Measures
Nww(t)	Number of naturally spawning adults of natural origin in generation t.	PM5*(1-PM6) with PM35
Nwa(t)	Number of naturally spawning adults of hatchery origin in generation t.	PM5*PM6 with PM35
Naw(t)	Number of broodstock of hatchery origin in generation t.	Known
Naa(t)	Number of broodstock of natural origin in generation t.	Known
Rw	Intrinsic replacement rate of natural spawners.	PM18
Ra	Intrinsic replacement rate of hatchery spawners.	PM18
F	Fraction of the natural origin adult return retained for broodstock after harvest.	Naa(t)/(PM1*(1-PM6))
Fa	Fraction of the hatchery origin adult return retained for broodstock after harvest.	Naw(t)/(PM1*PM6)
H	Fraction of the hatchery origin adult return that is harvested.	PM1*PM7*PM8*PM9*PM10
s	The fraction of the natural origin adult return taken in harvest prior to broodstock collection (ranging from 0 to 1).	PM1/(PM1*PM7*PM8*PM9*PM10)

1) Implementation and Compliance Monitoring

Implementation monitoring of a hatchery program is simply the reporting of the number and characteristics of hatchery fish released, which to a greater or lesser extent already occurs in ongoing programs, albeit in a manner which is not fully standardized. This information should be described relative to the production goals and marking schemes within US v OR agreements. Standardized performance measures associated with implementation monitoring should include: hatchery production abundance, size at emigration (release), and condition of juveniles at emigration (release). A description of identifying marks applied (type of mark, unique code, and marking rate, including estimated marking efficiency/retention) is also included as implementation monitoring. Implementation monitoring performance measures are used to validate categorization of hatchery programs based on spawner composition (broodstock and natural spawners), rearing strategy, and release strategy. Of primary interest is the evaluation and reporting of:

- a) Confirmation of hatchery type (segregated harvest augmentation, integrated supplementation, or conservation),
- b) Status of Hatchery Genetic Management Plan (HGMP) or similar master plan,
- c) target and realized annual hatchery-natural composition of broodstock,
- d) target and realized annual hatchery-natural composition of natural spawners,
- e) target and realized annual Proportionate Natural Influence (PNI)
- c) target and realized annual rearing density,
- d) target and life stage at release,
- e) total release by life stage;
- f) target and realized size at release (length and weight);
- g) target and annual acclimation period,
- h) target and annual and release location, and
- i) duration of program (number of years operated).

This information should be posted to online hatchery release databases at ***www.psmfc.org*** and ***www.fpc.org*** and described in annual reports. Implementation monitoring should be required on <u>all</u> artificial production programs releasing Chinook salmon, coho salmon, sockeye salmon, and steelhead in the Columbia River Basin.

Hatchery program compliance monitoring provides base information on the direct performance of hatchery-origin fish relative to planned performance in adult returns. It should be required on all populations influenced by hatchery programs. Of primary interest is the evaluation and reporting of:

- a) Natural origin population component status relative to viability and management criteria. Criteria based on VSP parameters with emphasis on the abundance and productivity measures. See CSMEP Status and Trends recommendations on performance measures, spatial scale, and temporal frequency (Marmorek et al. 2007a and b).
- b) Hatchery program effects on adult abundance targeting hatchery recruits per spawner (R/S) ratio higher than Natural R/S ratio. Note that in an integrated supplementation/mitigation program with selective harvest occurring, R/S ratio of hatchery fish should be equal or higher than natural fish post harvest.

c) Hatchery production post-release performance relative to planning objectives/assumptions.
d) Abundance to project areas and populations relative to established/stated goals in HGMP/master plans.
e) Harvest contribution by location (i.e. Ocean, mainstem Columbia, mixed stock river segments terminal tributary).

2) Hatchery Effectiveness Monitoring

Hatchery Effectiveness Monitoring described here is broken down into two levels: a) recommended attributes for project specific performance, and b) essential attributes for regional effectiveness assessment.

2a) Project-Specific Hatchery Effectiveness

A standard set of management objectives and assumptions are provided to link independent supplementation programs across the Columbia basin. The following management objectives provide a standardized framework structure for artificial production effectiveness assessment within the construct of the Federal Columbia River Power System Biological Opinion Remand, Northwest Power and Conservation Council Fish and Wildlife Program, and US vs. Oregon processes in the Columbia River Basin. These management objectives are structured to address the RASP definition of supplementation (RASP 1992). To successfully achieve each management objective, performance standards must be met. Performance standards were structured from common management questions expressed through co-management meetings, independent review recommendations, and review of monitoring and evaluation literature. For each Management Objective determining whether the performance standards (expectations) are met (valid) requires expression of the standards in quantifiable terms.

Conducting this level of intensive monitoring is not required on all hatchery programs. It should be focused on a limited number of supplementation projects and different species. The actual methods/study designs to assess each assumption (expectation) can vary across projects, however it is desired that projects utilize standardized performance measures. Hesse et al (2006) provides an example study design and associated performance measures.

<u>Management Objective 1</u>: Maintain and enhance natural production in supplemented populations.
1A. Recruits per spawner (R/S) ratios for hatchery-produced fish significantly exceed those of natural-origin fish.
1B. Natural spawning success of hatchery-origin fish must be similar to that of natural-origin fish.
1C. Temporal and spatial distribution of hatchery-origin spawners in nature is similar to that of natural-origin fish.

1D. Productivity of supplemented populations is similar to productivity of populations if they had not been supplemented (adjusted for density dependence).
1E. Post-release life stage-specific survival is similar between hatchery and natural-origin population components.

Management Objective 2: Maintain life history characteristics and genetic diversity in supplemented and unsupplemented populations.

2A. Adult life history characteristics in supplemented populations remain similar to pre-supplementation population characteristics.
2B. Juvenile life history characteristics in supplemented populations remain similar to pre-supplemented population characteristics.
2C. Genetic characteristics of the supplemented population remain similar (or improved) to the unsupplemented populations

Management Objective 3: Operate the hatchery program so that life history characteristics and genetic diversity of hatchery fish mimic natural fish.

3A. Genetic characteristics of hatchery-origin fish are indistinguishable from natural-origin fish.
3B. Life history characteristics of hatchery-origin adult fish are indistinguishable from natural-origin fish.
3C. Juvenile emigration timing and survival differences between hatchery and natural-origin fish must be minimal.

Management Objective 4: Keep effects of hatchery program on non-target (same species) populations within acceptable limits.

4A. Hatchery strays produced from a hatchery program and aggregated hatcheries do not comprise more than 10% of the naturally spawning fish in non-target populations.
4B. Hatchery strays in non-target populations are predominately from in-subbasin releases.
4C. Hatchery strays do not exceed 10% of the abundance of any out-of-basin natural population.

Management Objective 5: Restore and maintain treaty-reserved tribal and non-treaty fisheries.

5A. Hatchery and natural-origin adult returns can be adequately forecasted to guide harvest opportunities.
5B. Hatchery adult returns are produced at a level of abundance adequate to support fisheries in most years with an acceptable level of impact to natural-spawner escapement.
5C. Harvest monitoring is adequate to ensure that harvest quotas for natural and hatchery origin adults are not exceeded.

Management Objective 6: Operate the hatchery programs to achieve optimal production effectiveness while meeting priority management objectives for natural production enhancement, diversity, harvest, impacts to non-target populations.

6A. We can identify the most effective rearing and release strategies.
6B. Management methods (weirs, juvenile traps, harvest, adult out-plants, juvenile production releases) can be effectively implemented as described in management agreements and monitoring and evaluation plans.
6C. Frequency or presence of disease in hatchery and natural production groups will not increase above unsupplemented levels.

Management Objective 7: Understand the current status and trends natural-origin populations and their habitats.

7A. In-basin habitat is stable or improving and suitable for targeted rates of natural production.
7B. We can describe juvenile fish production in relationship to available habitat in each population and throughout a subbasin.
7C. We can describe annual (and 10-year geometric mean) abundance of natural-origin adults relative to management thresholds (minimum spawner abundance and ESA delisting criteria) within prescribed precision targets.
7D. Adult fish utilize all available spawning habitat in each population and throughout a subbasin.
7E. The relationships between life history diversity, life stage survival, abundance and habitat are understood.

Management Objective 8: Coordinate monitoring and evaluation activities and communicate program findings to resource managers.

8A. Coordination of needed and existing activities within agencies and between all co-managers occurs in an efficient manner (possible with the AHSWG or CSMEP processes).
8B. Accurate data summary is continual and timely.
8C. Results are communicated in a timely fashion locally and regionally.
8D. The M&E program facilitates scientifically sound adaptive management.

2b) Regional Hatchery Effectiveness

Each hatchery program is unique in some way or another, including the particular natural environment in which they are implemented. As such, unquestioned transfer of project-specific results from one hatchery to another is not appropriate. However, hatchery programs can be grouped within a limited number of categories, based on commonality of management objectives and protocols, and performance measures within categories would be expected to be similar. Nonetheless, the management expectations and intensive monitoring objectives described above evaluate performance at the project level, and fail to address a number of important questions associated with the general use of hatcheries across the basin.

Within CSMEP, managers developed a large list of questions related to hatchery management, for which monitoring information is needed. While many of the questions were of a program-specific nature, 16 were identified as addressing the use of hatcheries as a class of action for fisheries management regionally, and evaluated as being of high priority (Marmorek 2007a and b). These effectiveness questions were developed separately for hatchery programs categorized as harvest augmentation or supplementation programs, and are summarized in Tables A3 and A4. Obtaining answers to each of these questions will require a study design and collection of standardized performance measures across representative groups of hatchery programs. However, it is clear that M&E designs to address these questions would be most useful if they viewed harvest augmentation and supplementation as the extremes of a continuum of hatchery management procedures. This approach is anticipated to improve the efficiency of sampling and to provide better management guidance.

Table A3. Harvest augmentation hatchery questions developed by CSMEP, identified as being of high priority and to be addressed at the regional scale (Marmorek 2007a and b)

	Regional Question	**Priority**
1	What are annual harvest contributions and catch distribution of hatchery produced fish?	H
2	To what degree do hatchery programs meet harvest objectives?	H
3	What is the distribution of hatchery strays into natural populations?	H
4	What are the proportions of stray hatchery fish in non-target natural populations?	H
5	What is the relative reproductive success of hatchery origin adults relative to natural origin adults?	H
6	What are the disease agents and pathogens in hatchery fish, to what degree are these agents transmitted to natural fish, and what are the impacts of such transmissions?	H
7	What are the impacts of hatchery strays on non-target populations?	H

Table A4. Supplementation hatchery questions developed by CSMEP, identified as being of high priority and to be addressed at the regional scale (Marmorek 2007a and b).

	Regional Question	Priority
1	What are the status and trends of habitat targeted by supplementation projects and what is/are the life-stage specific factors that limit productivity?	H
2	What is the reproductive success of naturally spawning hatchery fish relative to natural origin fish in target populations?	H
3	What are the disease agents and pathogens in hatchery fish, to what degree are these agents transmitted to natural fish, and what are the impacts of such transmissions?	H
4	What are the relative effective population sizes and genetic diversity of hatchery supplemented vs. un-supplemented populations before, during, and after supplementation?	H
5	What proportion of hatchery origin juveniles return as adults to target versus non-target populations?	H
6	Do hatchery origin juveniles from supplementation programs stray at a greater rate than their natural origin conspecifics?	H
7	What are the proportions of natural spawning stray hatchery fish in non-target natural populations and their impact on the viability of natural populations?	H
8	What is the reproductive success of naturally spawning hatchery fish relative to natural origin fish in non-target populations?	H
9	What are the effects of hatchery supplementation on the productivity, abundance, and viability of non-target natural and hatchery-influenced populations?	H

Note: Question 9, while applicable to target populations, focuses on non-target populations owing to the fact that designs to assess impacts to target populations are well developed. In general, it was agreed that impacts to non-target populations remain largely unknown, thus requiring the development of designs specific to that question.

3) Uncertainty Research

Uncertainty research involves the most rigorous level of Hatchery M&E, consisting of conducting small-scale studies on a limited number of the intensively monitored programs/populations.

Appendix B

Regional analysis of abundance and productivity trends

There exist numerous inherent challenges to understanding how best to design a regional assessment of hatchery supplementation – to determine whether supplementation can provide the benefits of increasing the abundance of a specified population without the risks of negatively impacting long-term productivity of this or other populations. These challenges include:

- the relatively long generation length of Pacific salmon requires monitoring over an extended period
- measurement error introduces uncertainty in empirical measures, which may be magnified when deriving secondary performance metrics
- variation in data collection protocols, which complicates analyses requiring information collected by multiple entities
- somewhat unpredictable large-scale climatic processes which introduce substantial year to year variation in survival
- changes in environmental background within populations from habitat restoration actions, changes in hydrosystem operations, changes in hatchery production, density dependence, and other factors which are expected to influence abundance and productivity metrics within populations over time

Generally, an absolute minimum of three data points are required for statistical calculations. Thus evaluating productivity metrics, such as recruits per spawner (R/S; typically measured as smolts per natural spawner, or returning adults per spawner) for Pacific salmon requires many years of data collection. For example, for stream-type Chinook salmon that may spend up to five years in the ocean, it would take nine years to collect just R/S data points for three successive broodyears.

Aside from the length of time required to collect data, not all data are of known or equal quality. R/S ratios are calculated by dividing the sum of adults returning from a particular brood year by the number of adults that spawned in that brood year. Generally, this requires precise estimates of escapement and reliable and accurate methods to determine the age of returning adults. In practice, both types of primary data (adult abundance and age structure estimates) are accompanied by substantial measurement error that increases uncertainty in estimated R/S ratios. In some cases, primary data are not accompanied by variance estimates and are thus of unknown quality. Finally, depending on the methods used for data collection, estimates may not be strictly compatible. For example, it is unclear how escapement estimates based on redd count expansions compare to adult escapement estimates generated by direct counts of fish at a downstream weir (e.g., Kucera and Orme 2007). Generally speaking, escapement estimates from weirs are accompanied by precision estimates, whereas redd count expansions are not. On the other hand, adult escapement estimates obtained from weirs require an adjustment for prespawning mortality if they are to represent actual spawner abundance.

Lastly, salmonids inhabit an unstable environment. Anthropogenic impacts such as changes in hydrosystem operations coupled with large scale environmental fluctuations introduce significant year to year variation in survival. These sources of variation confound simple evaluations of the influence of management actions. For example, within a given population it is of interest to evaluate whether supplementation, either deliberate or unintentional (straying), has altered productivity. The simplest method of doing so is to compare productivity prior to the initiation of supplementation, to productivity after supplementation is initiated. However, when employing a before versus after (BA) design one must explicitly assume that the only factor that differs between the two time periods is the introduction of the hatchery origin fish. This assumption is unlikely to be realized owing to differences in anthropogenic impacts between time periods, and uncontrollable environmental fluctuations. For example, if the pre-supplementation monitoring period coincides with a large-scale climatic event that influences survival, such as the Pacific decadal oscillation, and that event is not present during the monitoring period following the initiation of supplementation, R/S measures would not be directly comparable between the two periods. There are several ways to deal with potentially confounding factors:

a) increasing the duration of before and after monitoring periods to ensure that sufficient time has elapsed within each to fully represent the range of natural environmental variation;
b) utilizing a spatial reference;
c) including measurements of potential confounding variables and statistically incorporating these into the analysis;
d) utilizing performance metrics that are less strongly influenced by suspected sources of variation; or
e) evaluating several performance metrics.

Several of these are discussed in more detail below.

a) *Increasing the Duration of Monitoring*

Of the alternatives, simply increasing the duration of monitoring is typically the least likely to be effective on its own. While useful for diminishing the confounding influence of environmental fluctuation, this approach is not robust to other sources of variation that asymmetrically impact the evaluation periods. For example, habitat modifications occurring after the implementation of supplementation could alter R/S ratios, and could not be addressed simply by increasing the duration of monitoring. In addition, it is often impossible to increase the period of evaluation prior to the initiation of supplementation. If sufficient data were not collected prior to implementation, they cannot be generated *post facto*.

b) *Incorporating a Reference*

Another commonly used approach is the incorporation of a reference population(s). Ideally, treated and reference populations would exhibit similar R/S or similar trends in

R/S (e.g., significantly correlated) prior to supplementation and be subject to similar environmental and anthropogenic factors. For example, populations located in the same subbasin are more likely to experience similar environmental conditions (e.g., cycles of precipitation) and common anthropogenic impacts (e.g., changes in hydrosystem operation) than populations that are located in different subbasins. Thus, the difference in a given metric between a treated and reference location can be used as the response variable, removing the influence of common sources of variation that influence both populations (Figure B1). By using a reference to remove common sources of variation, such as changes in hydrosystem operation or survival differentials driven by large scale environmental influences, BA comparisons are less likely to be confounded. For the fictitious example illustrated by Figure B1, the mean R/S value in the supplemented population is 2.4 prior to supplementation and 1.2 following supplementation. For a time series of this length, that difference is statistically significant and detectable, and would likely be interpreted to suggest that supplementation has lowered productivity. However, the mean difference in the R/S values between the treated and reference streams are identical for the period before and after supplementation, suggesting that the initial interpretation was erroneous. Comparison with the reference population indicates that instead, the decrease in productivity was likely the result of a common environmental factor, such as a shift in ocean survival rather than a byproduct of supplementation. The same principle applies for experiments that evaluate multiple populations, wherein treatment and reference populations can be paired (as described above) or combined and compared as groups.

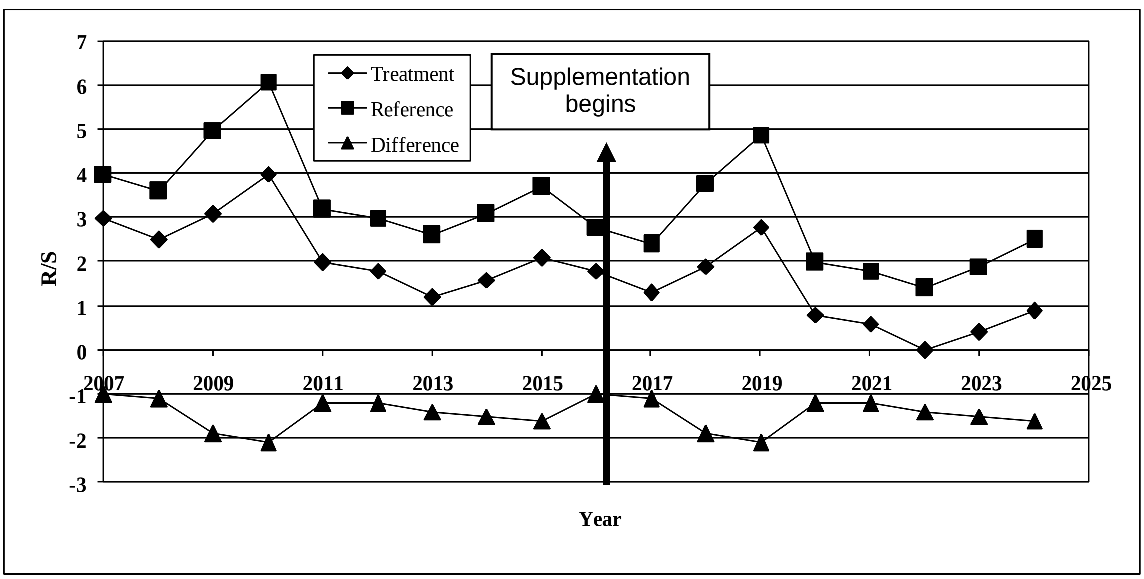


Figure B1. Example of a BA design that incorporates a reference population. The arrow indicates the year supplementation is initiated. (Note: data is fictitious; provided for illustrative purposes only)

c) *Selection of Performance Metrics*

Thus far the focus has been on R/S as a dependent variable. As previously discussed R/S estimates are subject to factors that contribute variance within the freshwater and marine life stages. Therefore, it is useful to consider additional performance metrics that may be influenced by fewer sources of variation. The use of such metrics could decrease the number of independent variables necessary to partition variance, and thereby reduce model complexity, reduce replication requirements, and/or increase the statistical power of analyses. One such metric is relative reproductive success (RRS), which is the ratio of R/S measures, calculated separately for hatchery origin versus natural origin spawners, within broodyears

$$RRS = \frac{R/S_{(hatchery)}}{R/S_{(wild)}}$$

RRS is typically estimated either for adult recruits per spawner (R_A/S), or for juvenile recruits per spawner (R_J/S). Use of R_J/S has the advantage of not including the marine life history stage, which is anticipated to be less variable than R_A/S. Also, R_J/S measures may be obtained relatively quickly - within a year or two following spawning. However, use of R_J/S ratios engenders the disadvantage of the need for an increase in sampling effort - requiring capture emigrating juveniles in addition to returning adults. Additionally, adoption of R_J/S ratios is accompanied by the explicit assumption that the potential impacts of supplementation on productivity will be manifested (primarily) during the freshwater portion of the life history – a product of differential spawning success and/or differential juvenile survival. A deleterious effect associated with hatchery influence could be associated with higher mortality in the marine environment as well.

d) *Utilizing More Than One Performance Metric*

As indicated above, the potential productivity impacts of naturally spawning hatchery origin adults might be expressed as lower relative reproduction, lower freshwater survival and/or lower marine survival. As such, the most thorough understanding of where, and potentially how, hatchery rearing influences natural productivity would be to examine R/S measured at both the juvenile and returning adult stages. Obviously, however, the greater the data requirements within a design, the greater will be the associated costs for implementation.

All of the performance metrics discussed above are subject to sampling error, which contributes variance to the raw data. Variance is also contributed by environmental processes. Generally speaking, metrics accompanied by fewer sources of variation are expected to improve the performance of analyses. As such it is informative to evaluate the sources of error that accompany each performance metric (Table B2). Although it is tempting to simply select the performance metric accompanied by the fewest sources of variation, one must also consider both the magnitude of each source of variation and the ability to estimate it. In general, sources of sampling error are generally easier to identify and estimate than sources of environmental variation.

Table B1. Sources of variation that impact key performance metrics.

Performance Metric	Sources of Variation: Sampling Error: Adult Enumeration	Juvenile Enumeration	Genotyping Error	Environmental Variation: Freshwater	Marine
Juvenile R/S	**X**	**X**		**X**	
Adult R/S	**X**			**X**	**X**
RRS juveniles	**X**	**X**	**X**		
RRS adult	**X**		**X**		

*Note that while individuals are impacted by environmental variation, RRS performance metrics are not impacted *per se* because they rely on ratios that "filter" those impacts.

Example: Preliminary analysis of population trends in supplemented and unsupplemented spring Chinook salmon populations

Here we provide a brief example of the type of analysis the AHSWG expects to occur under recommendation 2a: analyze population trends in supplemented and unsupplemented populations. The workgroup used the spring Chinook salmon abundance and productivity data compiled and synthesized by the Interior Columbia River Basin Technical Recovery Team (ICBTRT). Using these data, we plotted abundance and productivity trends in supplemented (impact) versus unsupplemented (control) populations. These plots are a prelude to more formal statistical analyses, which we recommend be conducted.

Data: The ICBTRT has compiled annual spawning abundance, adult recruits/spawner (R/S), proportion of hatchery fish on the spawning grounds, and related data for 27 ESA listed spring Chinook salmon populations that spawn in the Interior Columbia River Basin (Table B2). The annual spawning abundance estimates were obtained from Tom Cooney, co-chair of the ICBTRT, and were derived from a variety of primary sources, as described in the ICBTRT current status assessments (available at *http://www.nwfsc.noaa.gov/trt/col/trt_current_status_assessments.html*). Three populations, Tucannon (SNTUC), Chamberlain (SRCHA) and Pahsimeroi (SRPAH) were not included in our analysis due to their relatively short time series.

Table B2. Summary information for spring/summer Chinook salmon populations used in analysis

MPG	Population (IC-TRT)	Population (river name)	Start year	End year	Min. wild	Average proportion wild (last 10 years)	Category
Grand Ronde	GRCAT	Catherine Creek	1955	2005	0.00	0.75	impact
Grand Ronde	GRUMA	Grand Ronde Upper Mainstem	1955	2005	0.00	0.77	impact
Grand Ronde	GRLOS	Lostine	1959	2005	0.24	0.70	impact
Grand Ronde	GRMIN	Minam	1954	2005	0.10	0.96	impact
Grand Ronde	GRWEN	Wenaha	1964	2005	0.09	0.95	impact
Grand Ronde	IRMAI	Imnaha	1949	2005	0.20	0.34	impact
Lower Snake	SNTUC	Tucannon	1979	2006	0.01	0.49	impact
Middle Fork Salmon	MFBEA	Bear Creek	1960	2003	1.00	1.00	**control**
Middle Fork Salmon	MFBIG	Big Creek	1957	2004	1.00	1.00	**control**
Middle Fork Salmon	MFCAM	Cameron Creek	1963	2003	1.00	1.00	**control**
Middle Fork Salmon	MFLOO	Loon Creek	1957	2004	1.00	1.00	**control**
Middle Fork Salmon	MFMAR	March Creek	1957	2003	0.99	1.00	**control**
Middle Fork Salmon	MFSUL	Sulfur Creek	1957	2003	1.00	1.00	**control**
South Fork Salmon	SFSEC	Secesh	1957	2005	0.91	0.96	**control**
South Fork Salmon	SFEFS	East Fork South Fork	1957	2003	0.62	0.90	impact
South Fork Salmon	SFMAI	South Fork Mainstem	1958	2003	0.36	0.61	impact
Upper Salmon	SRCHA	Chamberlain Creek	1985	2003	1.00	1.00	**control**
Upper Salmon	SRLEM	Lemhi	1957	2003	1.00	1.00	**control**
Upper Salmon	SRPAH	Pahsimeroi	1986	2005	0.00	0.58	impact
Upper Salmon	SREFC	East Fork Salmon	1960	2005	0.45	0.92	impact
Upper Salmon	SRLMA	Lower Mainstem Salmon	1957	2005	1.00	1.00	**control**
Upper Salmon	SRUMA	Upper Mainstem Salmon	1962	2005	0.50	0.75	impact
Upper Salmon	SRVAL	Valley Creek	1957	2003	1.00	1.00	**control**
Upper Salmon	SRYFS	Yankee Fork	1961	2003	1.00	1.00	**control**
Upper Columbia	UCENT	Entiat	1960	2003	0.37	0.69	impact
Upper Columbia	UCMET	Methow	1960	2003	0.08	0.52	impact
Upper Columbia	UCWEN	Wenatchee	1960	2003	0.35	0.62	impact

Impact populations: A population was put in the impact category if at any point in the time series the fraction of wild fish on the spawning grounds was <90% for at least five consecutive years. Based on the time and type of impact, the impact populations could be subdivided into several groups (Figure B2 and ICBTRT status assessments).

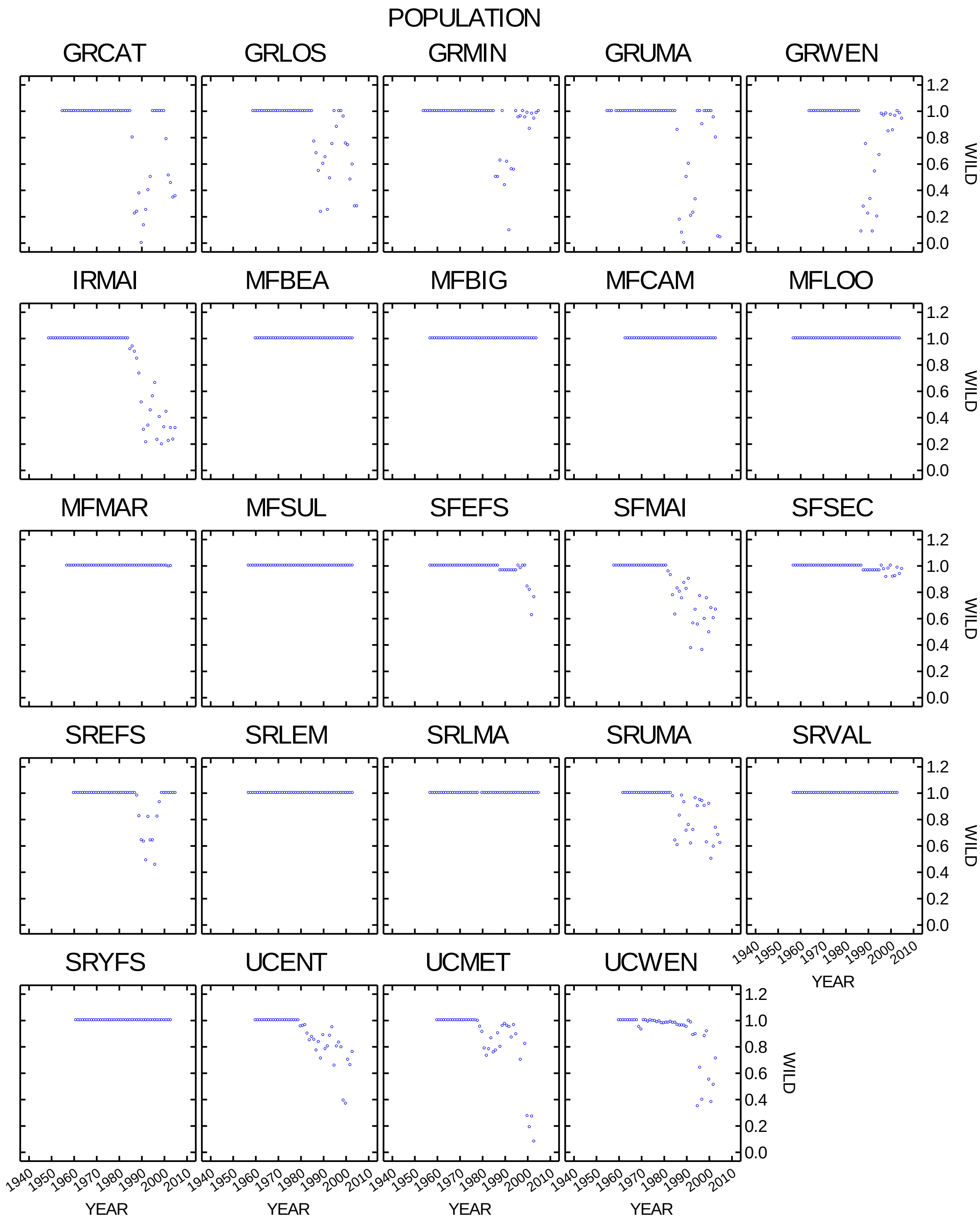


Figure B2. Fraction wild fish on the spawning grounds over time. See Table 2 for population names.

Transiently impacted populations: All of the Grand Ronde populations analyzed experienced relatively high fractions of non-local hatchery fish on the spawning grounds during a period from about 1985 to about 1994, followed by a period of low/zero hatchery fractions from 1995-2000. From 2000 to the present, supplementation recommenced in three populations (GRCAT, GRLOS, and GRUMA) using locally obtained broodstock, while the remaining two populations (GRMIN and GRWEN) continue to be unsupplemented. The SREFS (East Fork Salmon River) population also experienced a transient period of supplementation from 1988-1998.

Ongoing local supplementation populations: The IRMAI (Imnaha), SFMAI (South Fork Salmon Mainstem) and SRUMA (Salmon River Upper Mainstem) have each had long-term supplementation/production programs that were initiated in the mid-to-late 1980's. The UCWEN (Wenatchee) population has been supplemented since the early 1990's, and the SFEFS (Johnson Creek) has been supplemented since ~2000. Broodstock for these programs are (all, or predominantly) natural origin adults collected in-river.

Ongoing non-local 'supplementation' populations: The UCENT (Entiat) and UCMET (Methow) populations have had high fraction of non-local hatchery fish in their spawning populations since ~1980.

Control populations: Populations that did not meet the 'impact' criteria – were subjected to little or no hatchery influence - were defined as 'control' populations. Most of these populations were in the Middle Fork Salmon and Upper Salmon major population groups (MPGs).

Analysis:

Our preliminary analysis involved comparing trends in annual measures for total number of spawners, number of natural origin spawners, and recruits/spawner (R/S), in several different groups of impact versus control populations. For each of the three population statistics, we calculated the annual mean of the statistic in the group of impact populations, the mean in the group of control populations, and the annual ratio between these two means (d), plotted as a moving 5 year average. The annual means and d values were then plotted over time for visual examination of trends. Impact populations were examined as a whole, and as sub-groups of populations with commonalities in the time and type of hatchery impact.

Results:

Comparison 1: All impact populations versus all control populations. In this comparison, we examined average trends in all impact versus all control populations, recognizing that the impacts have occurred at various times and include both transient and ongoing impacts. Based on these plots, total spawner abundance appears to have increased over time in impact populations compared to controls, although some of that relative increase occurred prior to the initiation of any of the hatchery programs (generally in the mid-1980s; Figure B3-A). In contrast, there appears to be little or no trend toward increasing number of natural origin spawners. No trend was apparent for natural recruits/spawner measures in impact populations compared to controls, although the ratios vary considerably over time and control populations have been much more productive than impact populations in recent years (Figure B3-B and C).

A
B
C

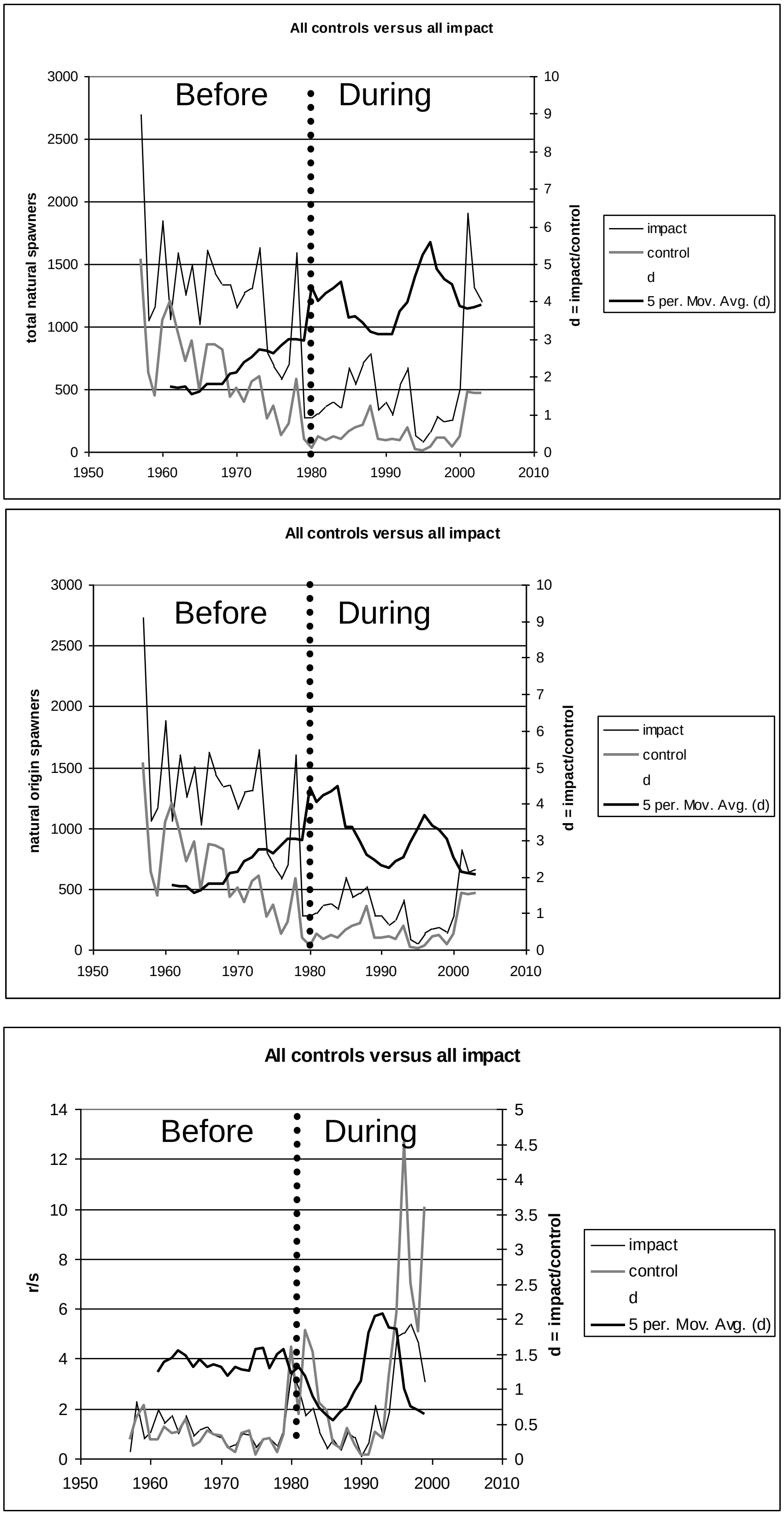


Figure B3. Comparison of all impact versus all control populations. A) total spawners, B) natural origin spawners, C) natural recruits/spawner.

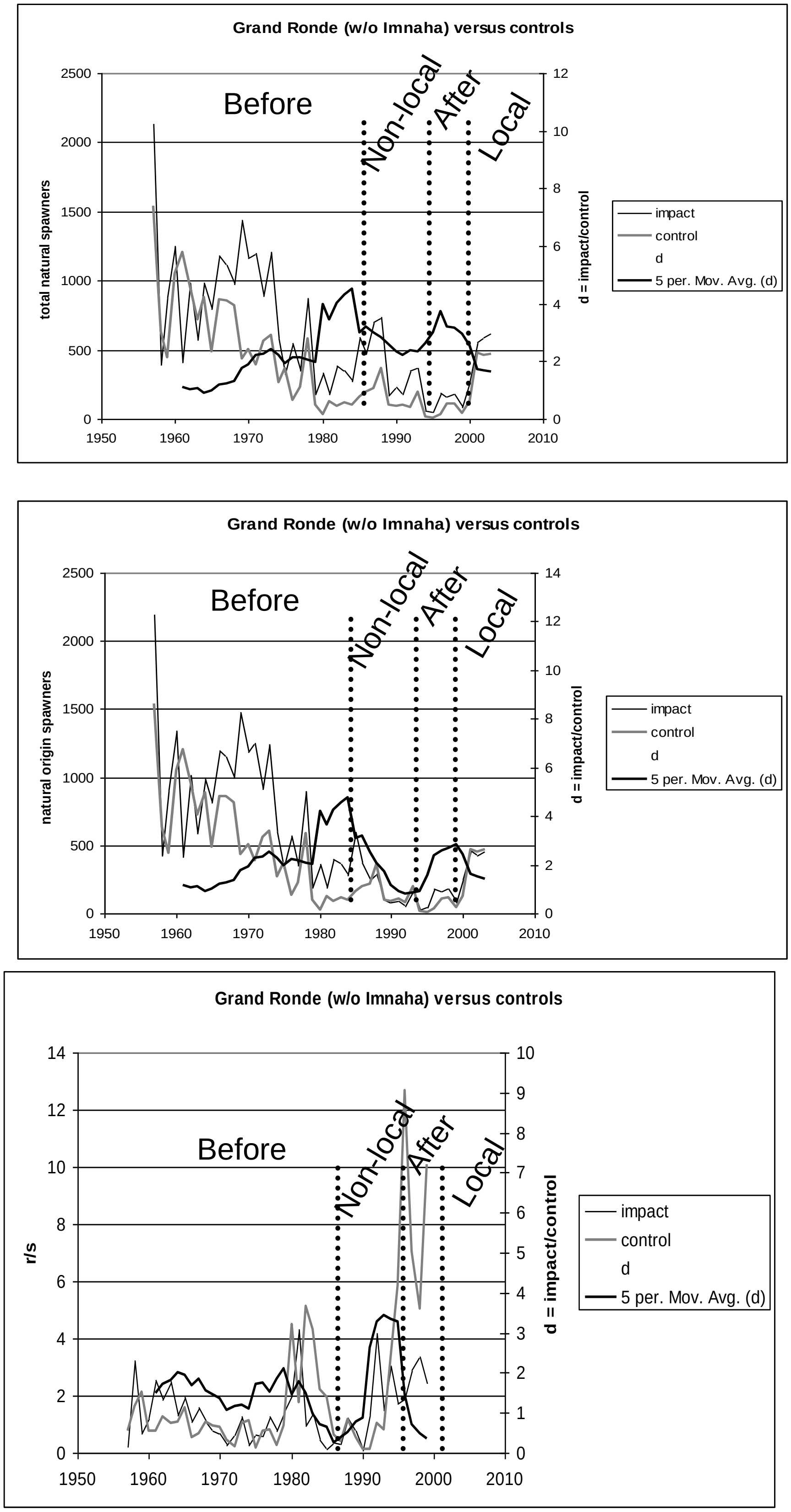
Comparison 2: Transiently impacted populations. We analyzed the Grand Ronde populations alone as a separate group of impact populations, since each of these populations had transiently high levels of non-local hatchery supplementation over roughly the same time period (Figure B4). In this comparison, annual estimates for total spawners, natural origin spawners and natural R/S fluctuated widely in both the impact and control populations, but a consistent overall trend, either positive or negative, was not apparent. In recent years, however, the control populations have had much higher productivity (R/S) than the impact populations (Figure B4-C).

Comparison 3: Ongoing local supplementation programs. In this comparison we examined trends in three Snake basin long-term supplemented populations – IRMAI (Imnaha), SFMAI (South Fork Salmon Mainstem) and SRUMA (Salmon River Upper Mainstem) compared to controls. Like the other comparisons, total spawners in the impact populations was increasing relative to controls during the period prior to the initiation of supplementation, and therefore presumably due to factors other the artificial propagation (Figure B5). Total spawners also increased substantially in the impact populations compared to controls in the 1990’s. During the period of supplementation (mid-1980’s on), differences in natural origin spawners and natural R/S were highly variable between impact and control populations, with no apparent overall trend (Figure B5-B and C).

We also compared controls to a Mid-Columbia long-term supplemented population – the UCWEN (Wenatchee).Total and natural origin spawners varied widely in the UCWEN prior to the initiation of the supplementation program in the early 1990’s, and both total and natural origin spawners have declined relative to controls since initiation of the supplementation program (Figure B6-A and B). Natural R/S measures have also been highly variable, but appear more or less unchanged during the period of supplementation (Figure B6-C).

Comparison 4: Ongoing supplementation with non-local stocks. The UCENT (Entiat) and UCMET (Methow) populations have both had production hatchery programs initiated circa 1980, which used an out-of-basin (Carson Hatchery) stock, although in recent years the Methow program has switched to a local stock. Coincident with the initiation of the hatchery programs, both total and natural spawners increased compared to controls, but then declined to pre-program levels in the mid-1990’s (Figure B7-A and B). Natural R/S in impact populations compared to controls appears to vary cyclically, but also appears to have declined coincident with the hatchery programs, and has been very low compared to controls from the mid-1990’s onward (Figure B7-C).

A



B

C

Figure B4. Comparison of Grand Ronde population (impact) versus controls. A) total spawners, B) natural origin spawners, C) natural recruits/spawner.

A

B

C

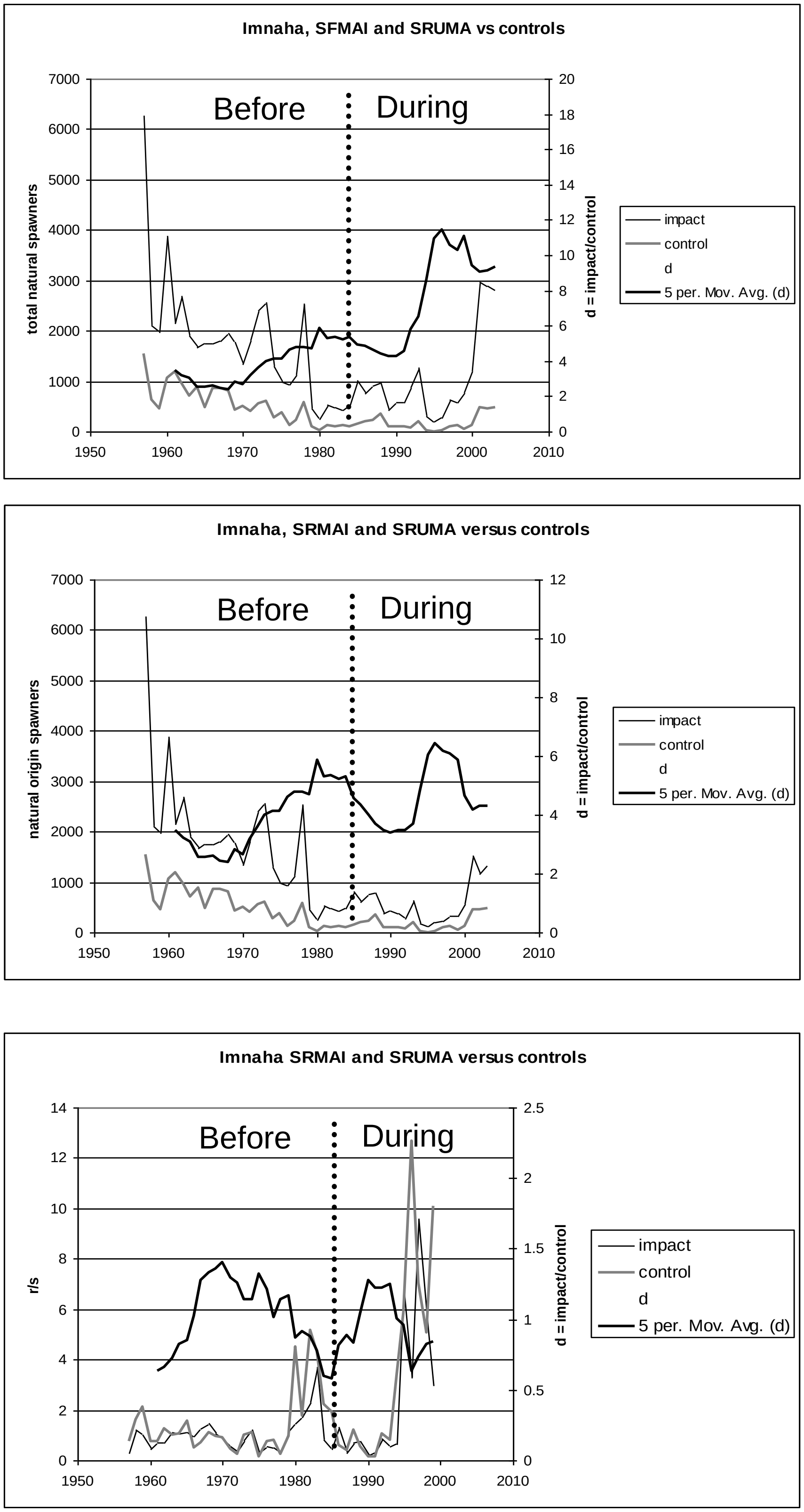
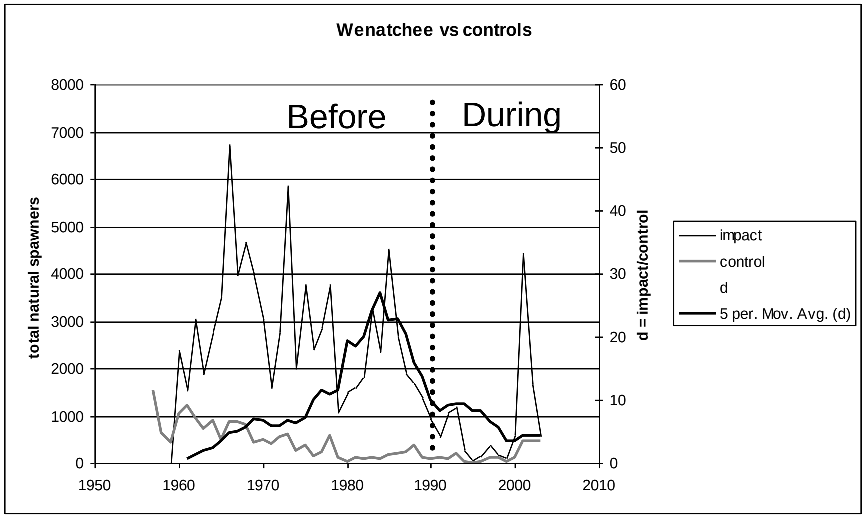
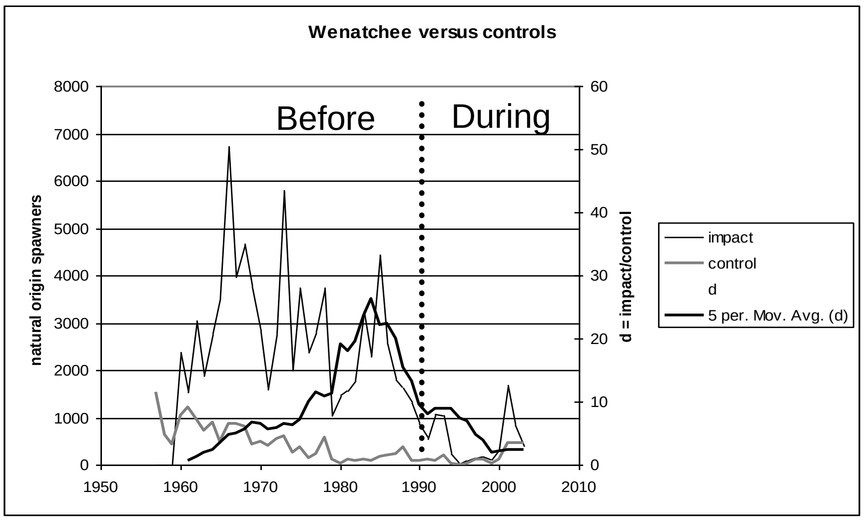


Figure B5. Comparison of Imnaha (IRMAI), South Fork Salmon (SFMAI) and Upper Salmon (SRUMA) populations (impact) versus controls. A) total spawners, B) natural origin spawners, C) natural recruits/spawner.

A



B



C

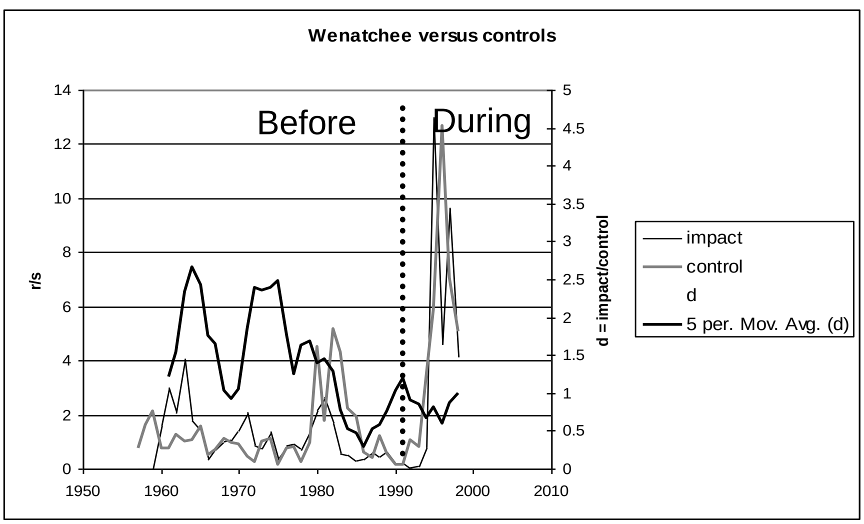
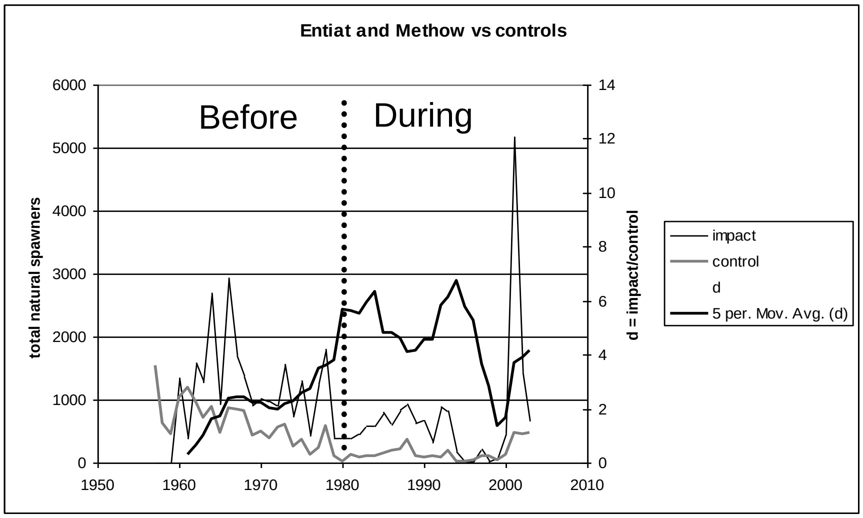
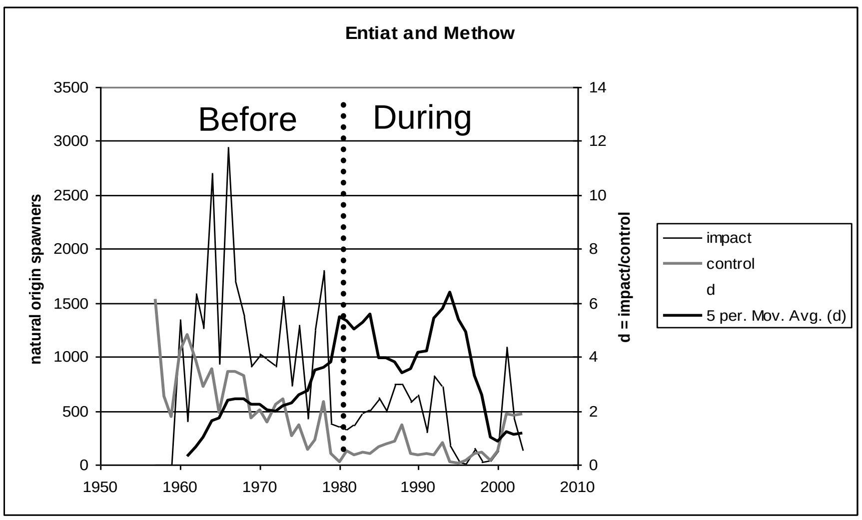


Figure B6. Comparison of Wenatchee (UCWEN) population (impact) versus controls. A) total spawners, B) natural origin spawners, C) natural recruits/spawner.

A



B



C

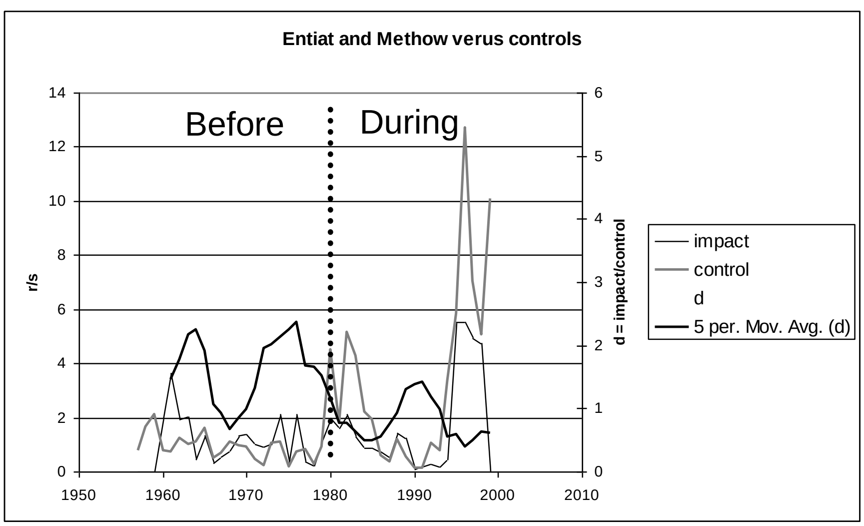


Figure B7. Comparison of Entiat (UCENT) and Methow (UCMET) populations (impact) versus controls. A) total spawners, B) natural origin spawners, C) natural recruits/spawner.

Discussion

The plots presented in this appendix are intended to illustrate the types of trends analyses which can be performed with currently available data for supplemented and unsupplemented populations of ESA listed spring/summer Chinook salmon in the Interior Columbia River Basin. These analyses are preliminary, and are not intended to be used to evaluate the efficacy of supplementation. They do, however, illustrate several important points:

1) The population level abundance and productivity estimates in these plots were compiled by the ICBTRT from data collected by various state and tribal agencies. Generating population level estimates in a temporally and spatially consistent manner required considerable effort on the part of the ICBTRT and its state and tribal collaborators (see status assessment link, above). Such coordination is essential to create the data sets needed for broad scale assessments of population trends, as recommended by the AHSWG.

2) In many comparisons, it is apparent that factors other than supplementation must be influencing population trends in control versus impact populations. In particular, there were trends in impact populations compared to controls prior to initiation of supplementation in several cases (see, e.g., trends in d values prior to 1980). Factors which affected these trends, may include differences in harvest rates, ocean survival, or habitat conditions as well as fish density. Taking into account these other factors in order to better isolate and quantify effects attributable to supplementation will be an important component of any future analysis of these data.

3) Despite the caveats expressed in (2), the trends presented here do allow one to answer such basic questions as: Has total spawning abundance and/or natural origin spawning abundance increased in supplemented populations compared to controls? Examining Figure , for example, one can see that since initiation of supplementation/production programs in the 1980’s and 1990’s, total spawning abundance does appear to have increased in supplemented populations compared to controls, whereas natural origin spawning abundance appears to have decreased. There is also an interesting difference between the trends in productivity (R/S) values for impact populations supplemented with local compared to non-local stocks. In particular, the UCWEN, IRMAI, SFMAI, and SRUMA populations, whose supplementation programs used local broodstock, all had large increases in productivity starting in the late 1990’s, similar to those observed in the control populations (Figures B4, B5 and B6). In contrast, the UCENT and UCMET populations and the 5 Grand Ronde populations were all supplemented with non-local stocks during this period, and had much lower increases in productivity relative to controls (Figure B7). This pattern is intriguing, but due to the many confounding factors that may contribute to these trends it would be premature to infer causality from the plots.

4) Populations trends are highly variable in both treatments and controls. The supplementation programs that were initiated in the 1980’s and 1990’s coincided with a

period of extremely poor survival, in which many populations experienced their lowest returns on record. At these very low levels, populations may not behave in the same way as they do at higher abundances, leading to difficulties in interpreting trends. These difficulties in assessing trends, caused by the natural variability of abundance and productivity within and between populations, are exacerbated by measurement and process error associated with collection of the monitoring data and calculation of the estimates. Observer error, logistical and financial limits which constrain the choice of monitoring methodologies and the reliability of the population measures, inconsistent measurement reliability across populations due to use of non-standardized methodologies, and the compounding effect as multiple measurements are used within calculations can all lead to spurious, and sometimes unrealistic, estimates of productivity. Additionally, error is likely increased when spawning abundances are very low. Due to both high levels of natural variability and of process and measurement error, very long time series may be necessary before strong conclusions about the effects of supplementation on long-term fitness can be drawn from this type of data.