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

Final Report of the

***Ad Hoc* Supplementation Monitoring and Evaluation Workgroup (AHSWG)**

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<u>Executive Summary</u>

For over a century, stocking of hatchery-produced salmon has been used in an attempt to augment the number of Columbia basin salmon and steelhead available for harvest in the commercial, sport and tribal fisheries, and more recently as a means to rebuild the abundance of depressed wild populations (supplementation). However, the potential for deleterious effects of hatchery actions on productivity of natural populations is a critical uncertainty relative to the use of hatcheries for achieving these management goals. In a report prepared for Northwest Power and Conservation Council, the Independent Scientific Review Panel (ISRP) and the Independent Scientific Advisory Board (ISAB) reviewed the nature of the demographic, genetic and ecological risks that could be associated with supplementation, and concluded that currently available information was insufficient to provide an adequate assessment of the magnitude of these effects under alternative management scenarios. The ISRP and ISAB recommended that an interagency working group be formed to produce a design(s) for an evaluation of hatchery supplementation applicable at a basin wide scale. Following on this recommendation, the *Ad Hoc* Supplementation Workgroup (AHSWG) was created.

The AHSWG sponsored three workshops in which different approaches for monitoring and evaluating (M&E) the impacts of supplementation on wild populations were reviewed, as were the data types and time frames that would be required to implement potential M&E designs. The members of the AHSWG present in this report their consensus view that a three-pronged approach is required to achieve the basinwide evaluation requested by the ISRP and ISAB. This approach involves, 1) an investigation of the long-term trends in the abundance and productivity of supplemented populations relative to un-supplemented populations, 2) conducting a series of relative reproductive success studies to quantify short-term impacts, and 3) development of a request for proposals to fund several intensive small-scale studies designed to elucidate various biological mechanisms by which introduction of hatchery-produced fish may influence natural population productivity.

To complement to these recommendations, the AHSWG report includes several appendices which provide additional information to: A) clearly define the various management scenarios under which hatchery-reared fish may influence natural populations, B) describe AHSWG activities and those of other regional processes which have addressed similar issues, C) describe a framework within which hatchery monitoring and evaluation (M&E) activities may be standardized and the different types of M&E programs organized for assessment of long-term and short-term effectiveness, and D) a preliminary regional analysis of available abundance and productivity trends among a subset of Columbia basin supplemented and un-supplemented populations.

Finally, the AHSWG recommends creation of a funded interagency workgroup charged with ensuring that relevant project-specific monitoring data is centralized and analyzed within the designs recommended within this report, so as to implement the coordinated basin wide evaluation called for by the ISRP and ISAB (2005).

Introduction and Background

For many years, fisheries managers in the Columbia River basin have used hatcheries to augment the number of salmon and steelhead available for harvest in the commercial, sport and tribal fisheries, and as mitigation for mortality and lost production resulting from construction and operation of hydroelectric projects. Hatcheries are also now increasingly being used with the goal of rebuilding abundance of depressed wild populations. This process, termed supplementation, most commonly involves the stocking of hatchery-reared juveniles into locations within rivers and streams, with the express intention that they return to these locations as mature adults, and contribute to the naturally spawning population (RASP 1992, Cuenco et al. 1993, Appendix A). However, with the greater use of hatcheries for supplementation, biologists are concerned that interactions of the hatchery fish with the natural populations can have substantially deleterious effects on natural population productivity. Insufficient empirical information on the nature and magnitude of these effects is a critical uncertainty relative to the appropriate use of hatcheries for achieving management goals. To obtain better guidance regarding the fitting role of hatcheries within the Fish and Wildlife Program, the Northwest Power and Conservation Council (NPCC) called on the Independent Scientific Review Panel (ISRP) and the Independent Scientific Advisory Board (ISAB) to provide a review of the state of knowledge of the effects of supplementation on natural population fitness, and how the usefulness of hatchery programs funded through the Program might be evaluated.

In their report, Monitoring and Evaluation of Supplementation Projects (2005-15), the ISRP and ISAB examine the nature of the demographic, genetic and ecological risks that could be associated with supplementation. In view of these risks, they re-emphasize that the suitability and efficacy of all hatchery programs needs to be assessed relative to the two standards for use of supplementation identified in the Regional Assessment of Supplementation Projects report (RASP 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 ISRP/ISAB report describes 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 also 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 organization of a workshop/work group to develop an approach "to execute a cooperative management experiment", … involving "selection of designs within the Columbia Basin that utilize data on population demographics and recruitment to assess the effectiveness and impact of supplementation".

Acting on the recommendations of the ISAB and ISRP, the Columbia River Inter-Tribal Fish Commission (CRITFC) and NOAA-Fisheries (Northwest Fisheries Science Center) took the initiative to contact representatives from fisheries organizations and agencies working in the Columbia basin (tribal, state, federal agencies, power companies, universities and private consultants), and organized the *Ad Hoc* Supplementation Workgroup (AHSWG). The AHSWG first convened in 2007, and has been working since that time to review the state of knowledge regarding supplementation and to develop approaches to address the inadequacies identified by the ISRP and ISAB (Appendix B). The approach developed by the AHSWG consists of three elements:

I. Continuation/implementation of a large-scale design to empirically investigate long-term trends in abundance and productivity of supplemented populations relative to un-supplemented populations – a treatment/reference (T/R) study design.

II. Implementation of a genetically-based relative reproductive success (RRS) study design to quantify short-term impacts of supplementation on productivity, targeting a representative range of supplementation projects and strategies.

III. The development of a targeted request for proposals aimed at funding research studies that directly address remaining critical uncertainties that are not amenable to clarification through a large-scale T/R or RRS design.

These approaches are presented in greater detail in following sections. Within each section, we describe the applicability, strengths and weaknesses of the approach with respect to the questions posed by the ISRP and ISAB. As a cautionary note, the members of the AHSWG emphasize that alone, no one of the three approaches identified within this document will be sufficient to address the ISRP and ISAB concerns. Our recommendations should be viewed as a unified design to address the uncertainties accompanying supplementation.

A substantial amount of supporting information is provided in the Appendices to this report. Appendix A contains a detailed description of the range of hatchery management approaches commonly referred to as supplementation. Appendix B details the history of AHSWG activities and describes the complementary contribution of the Collaborative Systemwide Monitoring and Evaluation Project (CSMEP) – a regional project that has addressed similar questions regarding effectiveness of hatchery programs. Appendix C presents a framework within which hatchery monitoring and evaluation (M&E) activities may be standardized and the different types of M&E programs organized, to facilitate assessment of long-term and short-term effectiveness. Finally, Appendix D provides a preliminary regional analysis of available abundance and productivity trends among a subset of Columbia basin supplemented and un-supplemented populations, as described in AHSWG Recommendation I.

Finally, the AHSWG recommends that an interagency workgroup be funded over the coming years, in order to: 1) ensure that data generated are sufficient to meet the design requirements; 2) conduct statistical analyses of data; and 3) generate consensus management recommendations based on those analyses.

Recommendation I: Implementation of a large-scale treatment/reference design to evaluate long-term trends in the abundance and productivity of supplemented populations

Large-scale treatment/reference (T/R) designs require consistent and representative data, and are most successful when implemented within a preexisting experimental framework as opposed to a *post-hoc* analysis of available data. Section A describes data requirements of a T/R analysis, Section B describes two alternative models which may be used for developing analytical design(s) to test for effects of supplementation, and Section C describes how Recommendation I relates to ISRP/ISAB concerns and summarizes the strengths and weaknesses of a T/R approach.

A. Data Requirements

Although some degree of M&E has accompanied the implementation of each to the various supplementation projects enacted within the Columbia basin, the need to evaluate supplementation from a regional perspective has only recently been realized. As such, much of the available information can be viewed as “case-specific” and applicable primarily at the project level. Although it should be possible to aggregate these individual monitoring and evaluation projects to satisfy the information needs of a large-scale treatment reference (T/R) design, this is not a trivial undertaking. Our review suggests that the diversity of data collection strategies, storage, and analysis approaches employed across the region places a substantial limit on our ability to combine data across projects to enable a coordinated large-scale analysis. Additionally, much of the more recently implemented monitoring effort has targeted populations that are actively supplemented, but few un-supplemented populations are monitored in the same way such that they might serve as references for a large-scale T/R design. The ability to aggregate project specific data in a large-scale design requires:

1. Standardized protocols for M&E of salmon/steelhead populations in the basin, and organization of these actions within a regional, multi-tiered Framework (Appendix C) to enable data aggregation and ensure data quality.

2. An expansion of the current monitoring of basic Viable Salmonid Population (VSP) parameters in supplemented and un-supplemented (reference) streams, and coordinated analyses of population trends.

3. The cessation of supplementation in several long-term projects to permit measurement of effects during a post-supplementation period.

1. Standardized protocols for M&E of salmon/steelhead populations in the basin, and organization of these actions within a regional, multi-tiered Framework (Appendix C) to enable data aggregation and ensure data quality.

Monitoring and Evaluation of hatchery programs has generally been conducted on a project-by-project basis across the Columbia River basin. Though the M&E is performed with some commonality in objectives, 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 complicates analyses which would utilize information from across projects, and constrains our ability to make a reliable regional scale assessment of the efficacy and effects of supplementation programs. The AHSWG proposes adoption of standardized methodologies for M&E of salmon and steelhead populations, as described by CSMEP (Marmorek 2007a and b), detailed in Appendix C, and summarized below. 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 collection of hatchery production measures and basic VSP information on supplemented populations. The data obtained from these monitoring activities are used to regulate hatchery operations, and as such, 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 meta-analysis of monitoring data for assessment 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 these data.

- Uncertainties Research involves more controlled designs to test hypotheses about effects of particular hatchery operations, and seeks to elucidate the mechanisms associated with these effects. Because of the need for controlled conditions and more intensive data collection, this sort of M&E is typically conducted at a small project-specific scale.

On an encouraging note, organization of monitoring efforts is becoming less Agency specific within the Columbia basin. Design of current M&E efforts is increasingly being coordinated amongst fisheries management agencies, as well as local salmon recovery boards and subbasin planning groups.

2. *An expansion of the current monitoring of basic Viable Salmonid Population (VSP) parameters in supplemented and un-supplemented (reference) streams, and coordinated analyses of population trends.*

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 C). While theoretical designs to collectively analyze these data within a comprehensive regional evaluation are not difficult to conceive, the logistics of such an analysis are complicated given the complex biological and environmental interrelationships involved; the likewise complex and often conflicting realities of Columbia River fisheries management, and the numerous logistical challenges to enacting a design of sufficient statistical validity.

Assessment of hatchery effects on fitness would be most directly addressed by designs which evaluate trends in the 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 as estimates of the number of adult progeny per parent, or of juvenile recruits per spawner. Logistical constraints to obtaining reliable data for estimating these parameters, however, can be considerable, and use of inconsistent monitoring methodologies over space or time introduces an increased amount of error into trend analyses. Even without measurement error, the trend analyses are complicated by variation resulting from natural environmental fluctuation in stream characteristics (temperature, flow, etc.), as well as from human activities – activities that affect decreases in stream productivity, and restoration activities that are designed to 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 be reasonably expected to alter the magnitude of the effect a particular program, and can compromise the legitimacy of assignment of the population to one particular hatchery program category or another within an analysis. To factor out the effects 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 span multiple salmon generations.

Analyses may take any of several approaches to determine population trends and to 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, as measured by, for example, by proportionate natural influence (PNI, Scott and Gill 2008). 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 Section 2 below, and in Appendix D.

Also included within Appendix D 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, this assessment illustrates how variation in data reliability, and variation in environmental and hatchery management increase the difficulty of interpreting analytical results.

As the first step to developing appropriate designs for trend analyses in Columbia River salmon and steelhead populations, we established a comprehensive list of salmon and steelhead 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 gathered. The table is an expansion of the list of populations identified by the Interior Columbia River Basin Technical Recovery Team (ICTRT) for ESUs listed under the Endangered Species Act, and includes populations in unlisted ESUs. In addition, summary data on abundance, productivity, proportion of wild-origin fish within the spawning escapement and PNI are provided for many populations. Of note, at this point the table is still provisional - some currently available information is likely missing, and the table will require annual updates as new data are acquired with each successive broodyear. Lastly, 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 Bonneville Dam, and downstream from Chief Joseph and Hell's Canyon Dams. Note: blank cells within the table represent instances where data is unavailable, or where data exists but was not collected in time for the current report.

SPECIES/STOCK ESU MPG Stream/Population Name	ICTRT label	Run	Type of hatchery influence	Years of abundance data	Approximate 10-year Average Natural abundance / P:P[1]	Minimum proportion wild	Proportion wild	PNI	Populations recommended for trend analyses
SPRING/SUMMER (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		spring	Supp	1977-present	471 /~4.7	0.2	0.4	?	
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									NO
Snake River Spring-Summer Chinook ESU (SRSS ESU)									
Lower Snake									
Tucannon River	SNTUC	spring	Supp	1979-2006		0.01	0.49	0.6	YES
Asotin Creek	SNASO	spring	(extirpated)						NO

Grande Ronde River									
Wenaha River	GRWEN	spring	Reference	1964-present	376 / 0.74	0.85	0.95	n/a	YES
Lostine River	GRLOS	spring	HA and Supp	1959-present	276 / 0.78	0.28	0.68	0.8	YES
Minam River	GRMIN	spring	Ref	1954-present	337 / 1.02	0.87	0.96	n/a	YES
Catherine Creek	GRCAT	spring	HA and Supp	1955-present	107 / 0.89	0.34	0.71	0.8	YES
Grande Ronde River upper mainstem	GRUMA	spring	HA and Supp	1955-present	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-present	380 / 0.79	0.2	0.35	0.4	YES
Big Sheep Creek	IRBSH	spring	(functionally extirpated) / Supp	1964-presett	4 / 0.29	0	0.62		NO
Dry Clearwater (lower)									
Lapwai/Big Canyon Creeks	CRLAP	spring	(extirpated)						NO
Potlatch River	CRPOT	spring	(extirpated)						NO
Lawyer Creek	SCLAW	spring	(extirpated)						NO
Upper S. Fork Clearwater	SCUMA	spring	HA and Supp (reintroduced)	1992-present					NO
Wet Clearwater (upper)									
Lower N. Fork Clearwater	NCLMA	spring	HA (reintroduced)						NO
Upper N. Fork Clearwater	NCUMA		(extirpated)						NO
Lolo Creek	CRLOL	spring	Supp (reintroduced)	1992-present					NO
Middle Fork Clearwater		spring	HA and Supp (reintroduced)	1992-present					NO
Lochsa R	CRLOC	spring	HA and Supp (reintroduced)	1992-present					NO
Selway - Meadow Creek	SEMEA	spring	Supp (reintroduced)	1992-present					NO
Selway - Moose Creek	SEMOO	spring	HA and Supp (reintroduced)						NO
Upper Selway River	SEUMA	spring	HA and Supp (reintroduced)						NO

South Fork (and lower) Salmon River									
Slate Creek		spring	Reference	1991-present					NO
Little Salmon River	SRLSR	spring	HA					n/a	NO
South Fork Salmon River mainstem	SFMAI	summer	HA and Supp	1958-present		0.36	0.61	0.2	YES
Secesh River	SFSEC	spring/ summer	Reference	1957-present	432	0.91	0.96	n/a	YES
East Fork South Fork Salmon River (Johnson Creek)	SFEFS	summer	HA and Supp	1957-present	302	0.62	0.9	0.8	YES
Middle Fork Salmon River									
Middle Fork Salmon River below Indian Creek	MFLMA	spring/ summer	Reference					n/a	YES
Big Creek	MFBIG	spring/ summer	Reference	1957-present		1	1	n/a	YES
Camas Creek	MFCAM	spring/ summer	Reference	1963-present		1	1	n/a	YES
Loon Creek	MFLOO	spring/ summer	Reference	1957-present		1	1	n/a	YES
Middle Fork Salmon River above Indian Creek	MFUMA	spring/ summer	Reference					n/a	YES
Sulphur Creek	MFSUL	spring/ summer	Reference	1957-present		1	1	n/a	YES
Bear Valley Creek	MFBEA	spring/ summer	Reference	1960-present		1	1	n/a	YES
Marsh Creek	MFMAR	spring/ summer	Reference	1957-present		0.99	1	n/a	YES
Upper Salmon River									
North Fork Salmon River	SRNFS		Reference						YES
Lemhi River	SRLEM		Reference	1957-present		1	1	n/a	YES
Salmon River lower mainstem below Redfish Lake	SRLMA		HA	1957-present		1	1	n/a	YES
Salmon River upper mainstem above Redfish Lake	SRUMA		HA and Supp	1962-present		0.5	0.75	0.4	YES
Pahsimeroi River	SRPAH		Supp	1986-present		0	0.58	0.2	YES
East Fork Salmon River	SREFS		Reference	1960-present		0.45	0.92	n/a	YES

Yankee Fork	SRYFS		HA and Supp	1961-present		1	1	n/a	YES
Valley Creek	SRVAL		Reference	1957-present		1	1	n/a	YES
Panther Creek	SRPAN		(extirpated)					n/a	NO
Chamberlain Creek	SRCHA		Reference	1985-present		1	1	n/a	YES
Mid-Columbia Spring Chinook ESU									
(Yakima)									
Upper Yakima River/Cle Elum River		spring	Supp	1982-present	4658 / 3.1	0.24	0.48	0.67	YES
Naches River/American River		spring	Reference	1982-present	2810 / 2.6	1	1	1	YES
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		(extirpated)						NO
<u>FALL (ocean-type) CHINOOK</u>									
Deschutes River Summer/Fall									
Deschutes River		fall	Reference						YES
Central Columbia Fall Chinook									
Umatilla River			Supp						NO
Yakima River		fall	Supp	1983-present	n/a	n/a	n/a	n/a	NO

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 / 1.79	0.51	0.83	0.8	YES
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 and Supp	1988-present	2,856/ 1.24		.46		YES
Marsing Reach			(extirpated)						NO
Salmon Falls			(extirpated)						NO
<u>STEELHEAD</u>									
Central Columbia									
Wind River									NO
Little White Salmon									NO
White Salmon River	MCWSA-s	winter	HA					n/a	NO
Hood River		summer	Supp						YES
Hood River		winter	Supp						YES
Fifteenmile Cr	MCFIF-s	winter	Reference	1985-2007	703 / 1.82	1	1		YES
Klickitat River	MCKLI-s	summer	HA					n/a	NO
Klickitat River	MCKLI	winter	Reference						NO
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		(extirpated)						NO
Rock Creek	MCROC-s								NO

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								NO
Umatilla River	MCUMA-s	summer	Supp	1967-2007	1472 / 1.50	0.41	0.64		Yes
Touchet River	WWTOU-s	summer	HA					n/a	NO
Walla Walla River	WWMAI-s	summer	HA	1993-2005	650 / 1.34	0.95	0.98	n/a	NO
Yakima aggregate		summer	Reference	1983-present	2496 / na	0.91	0.98	n/a	YES
Satus Creek	YRSAT-s	summer	Reference	1985-2004		0.87	0.94		YES
Toppenish Creek	YRTOP-s	summer	Reference	1985-2004		0.87	0.94		YES
Naches River	YRNAC-s	summer	Reference	1985-2004		0.87	0.94		YES
Upper Yakima	YRUMA-s	summer	Reference	1985-2004		0.87	0.94		YES
Snake River									
Lower Snake									
Tucannon River	SNTUC-s	summer	Supp						YES
Asotin Creek	SNASO-s	summer	Reference						YES
Clearwater									
Lower Clearwater	CRLMA-s	summer	HA					n/a	NO
South Fork	CRSFC-s	summer	HA and Supp						NO
Lolo Creek	CRLOL-s	summer	Supp						NO
Lochsa River	CRLOC-s	summer							NO
Selway River	CRSEL-s	summer							NO
Salmon River									
Little Salmon	SRLSR-s	summer	HA					n/a	NO
South Fork	SFMAI-s	summer	Reference					n/a	YES
Secesh River	SFSEC-s	summer	Reference					n/a	YES
Chamberlain Creek	SRCHA-s	summer	Reference					n/a	YES
Big, Camas, and Loon	MFBIG-s	summer	Reference					n/a	YES

Upper Middle Fork	MFUMA-s	summer	Reference					n/a	YES
North Fork	SRNFS-s	summer	Reference					n/a	YES
Lemhi River	SRLEM-s	summer	HA					n/a	NO
Pahsimeroi River	SRPAH-s	summer	HA					n/a	NO
East Fork	SREFS-s	summer	HA and Supp						NO
Upper Mainstem	SRUMA-s	summer	HA					n/a	NO
Hell's Canyon									
Hell's Canyon	SNHCT-s	summer	HA					n/a	NO
Grande Ronde									
Lower Grande Ronde	GRLMT-s	summer	Reference and HA					n/a	NO
Joseph Creek	GRJOS-s	summer	Reference	1970-2007	2132 / 2.62	1	1		YES
Wallowa River	GRWAL-s	summer	HA					n/a	NO
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	summer	Supp	1986-2006	774 / 0.97	0.11	0.39	0.4	YES
Entiat	UCENT-s	summer	Supp and Reference	1986-2006	108 / 0.52	0.09	0.21	n/a	YES
Methow	UCMET-s	summer	Supp	1986-2006	394 / 0.33	0.02	0.12	0.1	YES
Okanogan	UCOKA-s	summer	Supp	1986-2006	116 / 0.17	0.01	0.07	0.1	YES

[1] P:P = adult progeny per parent

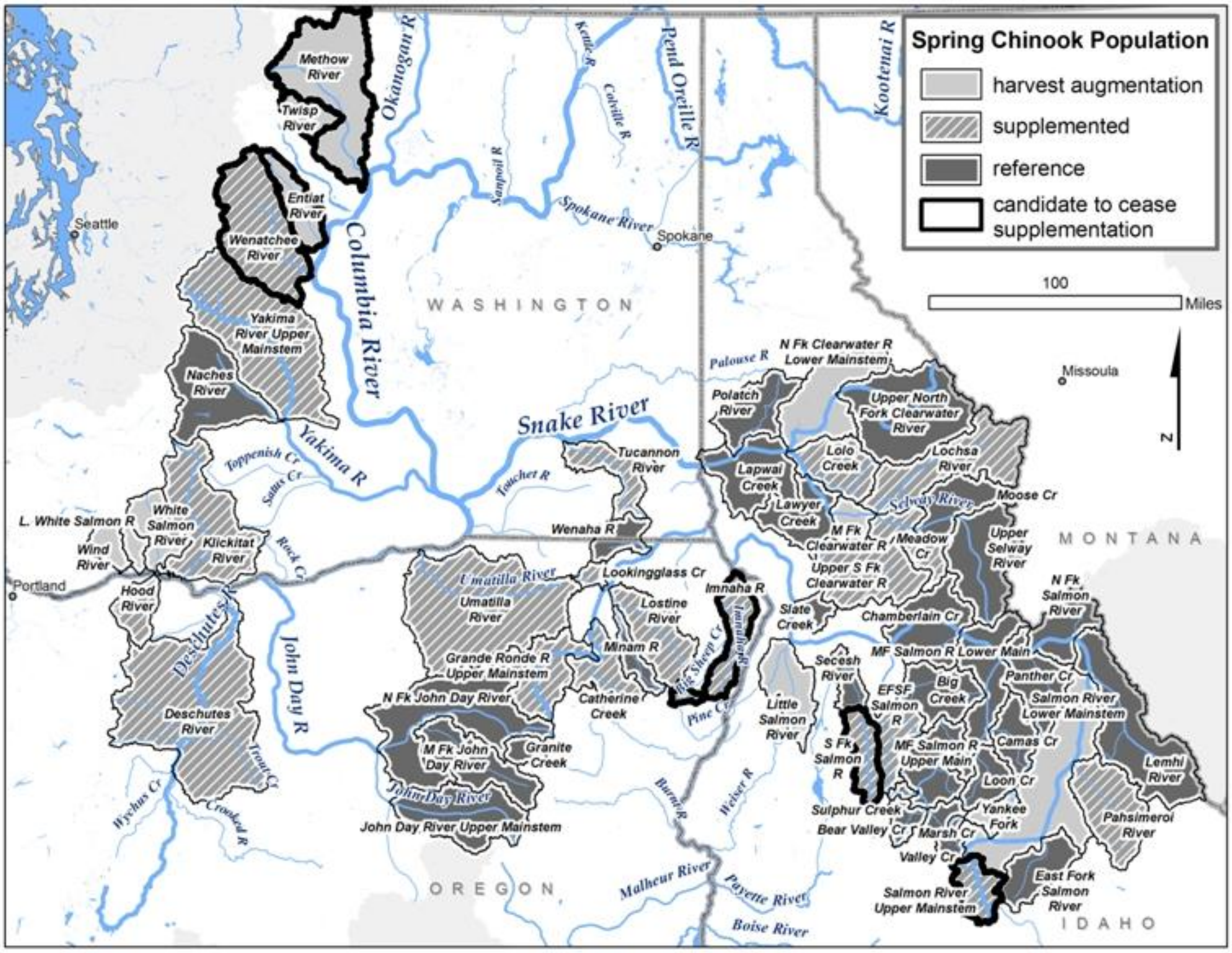

Figure 1. - Potential supplemented and reference Spring Chinook salmon populations for long-term monitoring. Candidates for experimental cessation of supplementation are also illustrated.

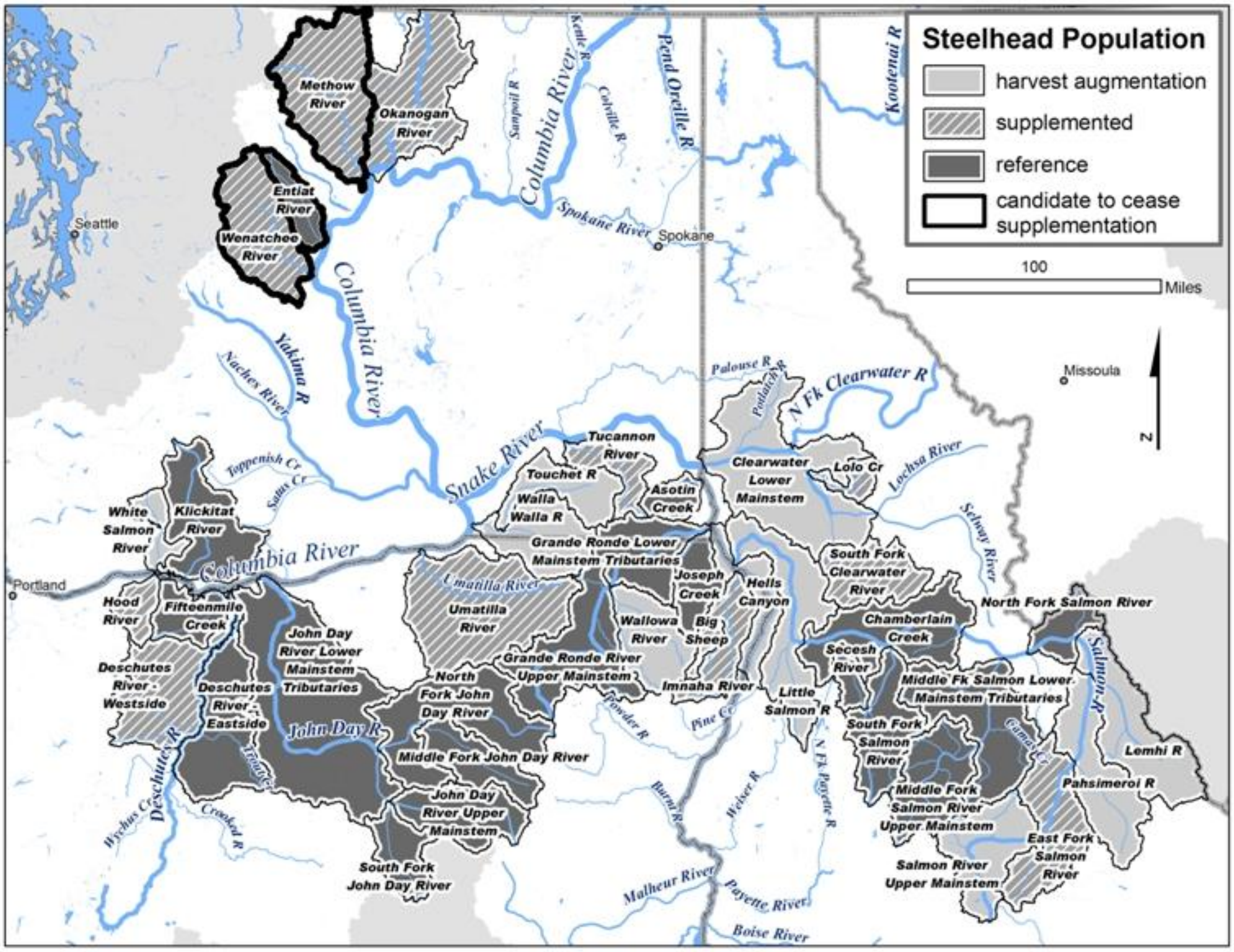

Figure 2. - Potential supplemented and reference steelhead populations for long-term monitoring. Candidates for experimental cessation of supplementation are also illustrated.

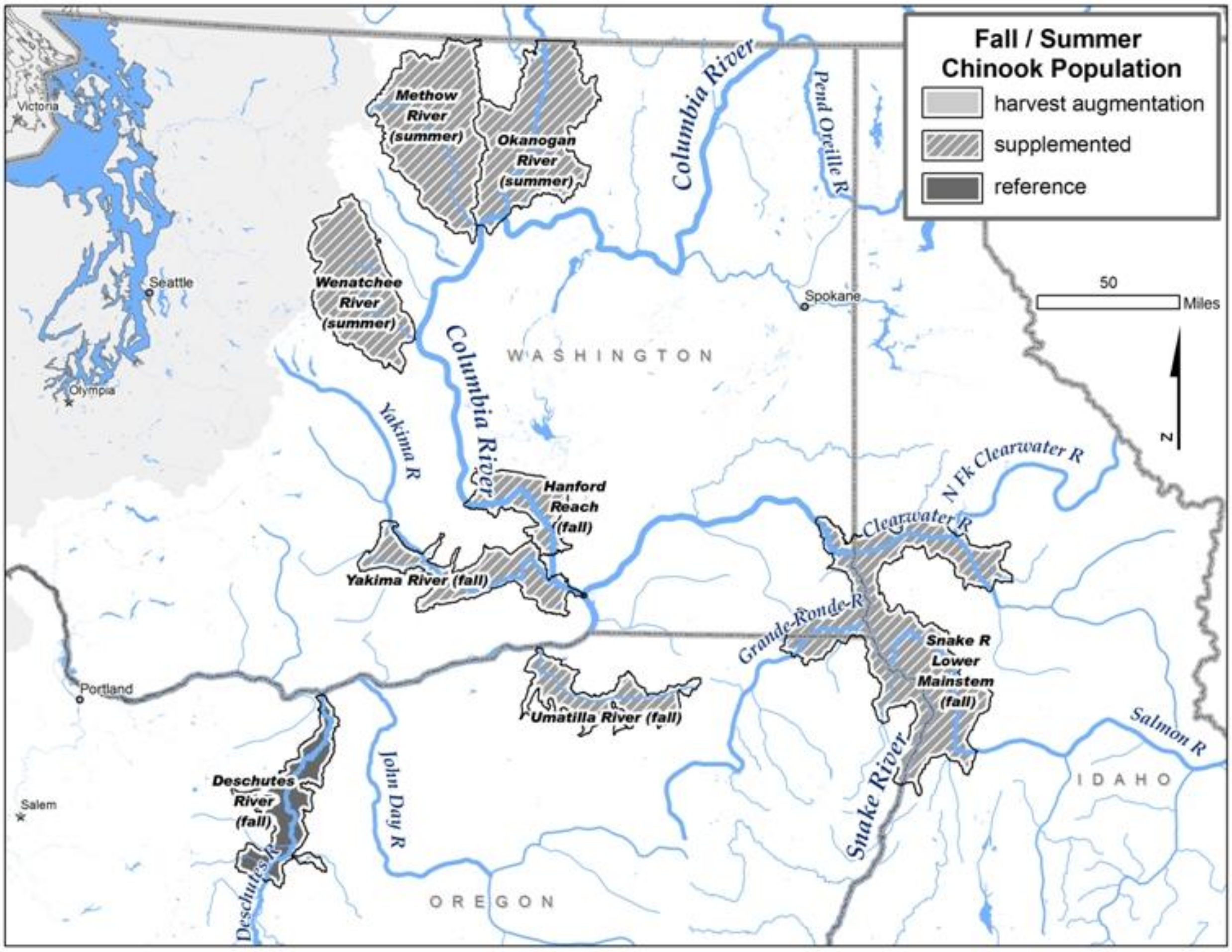

Figure 3. - Potential supplemented and reference fall/summer Chinook salmon populations for long-term monitoring. Note the lack of many existing reference populations.

The AHSWG concurs with recommendations of CSMEP (Marmorek et al. 2007a and b) that informed fisheries management in the region requires the implementation of standardized protocols, in order to obtain comparable estimates of basic VSP parameters, including:

- Abundance – estimates of total spawning population derived from: 1) redd counts (total or expanded index counts) conducted on multiple occasions (e.g., weekly) over the spawning season, 2) direct estimates of the number of fish on the spawning grounds (e.g., AUC or ML), or 3) direct counts made at in-river weirs/traps or counting stations (e.g., direct visual counts from counting towers, or using optical or sonar instruments), corrected for estimated pre-spawn mortality and harvest.

- Productivity - sampling of adults at weirs or as carcasses during spawning ground surveys. Carcasses should be sampled across the entire spawning area in proportion to the distribution of the spawners. Carcass surveys should target at least 20% of the spawning population to obtain information on hatchery of origin, sex ratio, and age structure – which is used in combination with abundance information to estimate productivity. Carcasses 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 – redd and carcass survey data from multiple (e.g., weekly) spawning ground surveys that cover the entire spawning area, will be used to estimate redd number and density across reaches, and to determine the relative distribution of hatchery origin vs. natural origin spawners within the subbasin.

- Diversity – estimation of adult characteristics, e.g., run-timing, spawn-timing, size, sex-ratio, age structure, and morphometric measures.

3. *The cessation of supplementation in several long-term projects to permit measurement of effects during a post-supplementation period.*

The AHSWG also recommends that supplementation programs be experimentally halted 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 also include data during post-supplementation periods, preferably extending over at least three generations (up to 21 years for steelhead populations).

Criteria which would make a supplemented population an attractive choice for 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 reliable time-series data against which post-supplementation information may be compared.

- Freshwater spawning and rearing habitat is adequate to support a natural population.

From among the supplemented populations listed in Table1, an initial list of those which meet the above criteria are identified in Table 2 as potential candidates for permanent or temporary discontinuation of supplementation.

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

Species/ Stock	Population or subpopulation	Years of abundance data	Generations of supp.	Approximate 10-Year Average: Average PNI	Average population size	Natural P:P [1]	Rationale
<u>SPRING(/Summer) (stream-type) CHINOOK</u>							
	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. Limited to habitat upstream of weir ~60% of population.
	South Fork Salmon River mainstem (SFMAI)	1992-2007	2+	0.17			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. Limited to habitat upstream of weir ~50% of 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.
Little Sheep Creek (IRMMT-s)	1982-present	5+				Would be a very dramatic experiment since population is currently >90% hatchery fish. Easily monitored.

[1] P:P = adult progeny per parent

While supplementation was recently halted in most Idaho Supplementation Studies (ISS) spring/summer (stream-type) Chinook populations (four of which meet candidate population critera; 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 salmon population. Identification of which specific program from among the candidates 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 of trends 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 is already ongoing or proposed in the basin, including: in the ISS, Yakama-Klickitat Fisheries Project (YKFP), Northeast Oregon Hatchery (NEOH) project, Johnson Creek, Wenatchee River supplementation projects, and in the Mid-Upper Columbia hatchery programs. Some of the 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.

B. Models for Regional T/R Designs

1. A multivariate time series model for analyzing differences in productivity between hatchery-supplemented and reference populations

Here we outline how one could examine whether differences in mean productivity and abundance, or other metrics, exist between hatchery-supplemented and other, non-supplemented populations. The method uses a set of unaffected populations (i.e. those with no history of intentional hatchery supplementation) as so-called “reference” systems for estimating underlying trends in the time series common to “all” populations of interest. The general idea is to estimate the common signal among the reference populations, which includes the influences of exogenous effects (e.g., habitat, hydropower, climate), and then use that signal to extract the remaining variation from the "impacted" populations - presumably that owing to the effects of hatchery-supplementation.

We propose using a multivariate structural time series model known as dynamic factor analysis (DFA; Zuur et al. 2003). First suppose that we have a univariate response variable y_t (e.g., recruits per spawner) measured in year t, where $t = 1,\ldots,T$. The most basic univariate structural time series model has no explanatory variables (i.e. covariates), and is denoted by:

$$y_t = a_t + \varepsilon_t \tag{1a}$$

$$a_t = a_{t-1} + \eta_t . \tag{1b}$$

This model is commonly referred to as a random walk trend plus noise model. The term a_t represents the unknown trend at time t, and ε_t and η_t are normally distributed error terms.

Now suppose there are N response variables (e.g., recruits per spawner measured from several populations). Each one of them could be modeled as a univariate case, but that would require N trends that have to be interpreted separately plus it would ignore the interactions among all of the time series. The DFA model overcomes most of these caveats by reducing the N univariate trends into M common trends with $1 \leq M < N$. In this case, the model (in matrix notation) becomes:

$$\boldsymbol{y}_t = \boldsymbol{Z}\boldsymbol{a}_t + \boldsymbol{c} + \boldsymbol{\varepsilon}_t \tag{2a}$$

$$\boldsymbol{a}_t = \boldsymbol{a}_{t-1} + \boldsymbol{\eta}_t \tag{2b}$$

The N x M matrix Z contains the unknown factor loadings, a_t is an M x 1 vector containing the M common trends at time t, and c is an M x 1 vector of underlying levels (i.e. intercepts). An important point to stress here is that the trend is not constant across time.

The analysis begins by fitting equation 2 to all of the reference systems. Once we estimate the trend (a), we can subtract it from each of the reference and affected time series to derive the "detrended" time series. We then compare the difference in mean productivity, abundance, etc. between the reference and impacted populations, before and after hatchery supplementation began. A simple way to do so would be to use a two-way ANOVA with reference/impact (treatment) and before/after (time) as the two factors. Of particular interest is whether there is a significant treatment*time interaction, which would indicate a larger change in impacted populations after supplementation began.

2. A process-based modeling approach to analyzing time series from supplemented and reference populations

A complementary approach to estimating the effects of supplementation using time series data involves fitting population-dynamic models that explicitly represent the process of interest, i.e. interactions between wild and hatchery-origin fish. This approach takes advantage of the observed changes in abundance and productivity in response to variation in hatchery inputs, both over time within supplemented populations and between supplemented and reference streams. The general idea is to develop population-dynamic models with distinct parameters for intrinsic (density-independent) fitness and compensatory (density-dependent) processes for wild and hatchery-origin fish, in an effort to distinguish the effects of supplementation on each of these components. The power of the data to resolve these parameters will depend in part on the experimental or sampling design, including the total number of streams and years sampled as well as the degree of contrast in abundance and productivity within and between the reference and supplemented treatments.

A generic model structure begins by considering the total number of natural-origin recruits from brood year *t* in population *j* as the sum of recruits produced by wild parents and hatchery-origin parents spawning in the wild:

$$R_{jt} = S_{w,jt} f_w\left(S_{w,jt}, S_{h,jt}, X_{jt}\right) + S_{h,jt} f_h\left(S_{w,jt}, S_{h,jt}, X_{jt}\right). \qquad (3)$$

The per capita recruitment rates $f_w(.)$ and $f_h(.)$ might be functions of both wild (S_w) and hatchery (S_h) spawner density, and perhaps other covariates X (e.g., ocean conditions). Specific functional forms might include Beverton-Holt or Ricker. Distinct parameters for wild- and hatchery-origin spawners could be used to test specific hypotheses about the relative performance of hatchery fish in the wild. For example, in a Beverton-Holt model where an all-wild population has intrinsic productivity a and carrying capacity K, the corresponding parameters for hatchery spawners could be defined as αa and δK. Here the discount α represents the relative fitness of hatchery-origin spawners at low density (essentially a measure of density-corrected RRS), and δ similarly measures the relative per-capita strength of density dependence due to hatchery-origin spawners. Thus, $\alpha <$ 1 indicates lower fitness for hatchery-origin spawners compared to natural-origin spawners, and $\delta < 1$ indicates stronger density-dependent effects of hatchery-origin fish or their progeny.

Once a specific form of equation 3 has been selected, it can be fit to time series of wild and hatchery spawner density from one or more populations. A nonlinear mixed-effects framework (Pinheiro and Bates 2000) can be used to allow parameters to vary among populations, while using the entire dataset to inform estimates of the common underlying trends (i.e., hyper-means and hyper-variances). Alternative model formulations (e.g., parameters for wild and hatchery fish constrained to be identical or allowed to differ) can be compared using information-theoretic model selection methods (Burnham and Anderson 2002), and the parameter estimates can be compared to directly measured values (e.g., estimates of relative fitness from RRS studies). The process-based approach thus offers a bridge between the descriptive time series models described above, and experimental field studies.

C. Relationship to ISRP/ISAB Comments

The T/R approach addresses the ISRP/AB recommendation for development of a design to evaluate whether supplementation can decrease freshwater productivity. Problematically, however, observed changes in freshwater productivity assessed within a T/R framework cannot always be attributed directly to supplementation. For example, a handful of studies have demonstrated an increase in adult abundance coinciding with supplementation (e.g., Lutch et al. 2003). Some of these studies have also demonstrated a change in productivity within supplemented populations relative to reference populations over the course of supplementation. However, we are unaware of any study that has quantified the density-independent population growth parameters that would enable one to determine whether changes in productivity were attributable to a negative or positive impact of supplementation (i.e., relaxation of natural selection and accompanying accumulation of deleterious genetic of behavioral traits) as opposed to density dependence. In short, one might reasonably expect a decrease in productivity to accompany the observed increase in adult abundance accompanying many supplementation programs, even if the supplementation program had no direct deleterious impact via genetic or behavioral mechanisms. This is particularly true of populations whose habitat has been modified, potentially lowering habitat capacity and quality, and the impact is magnified if reference populations that either linger at low abundance or suffer a decline in abundance over the course of the study. Within the Columbia River Basin, declines in salmonid abundance coincided with both hydroelectric development and increased human population growth; each of which impacted freshwater habitat. Thus, it is unclear how many salmon can be supported by existing habitat, and whether observed decreases in productivity documented for some supplemented populations result from hatchery impacts as opposed to simple density-dependence.

The shortcomings of a T/R design described above could be addressed by artificially limiting escapement in a subset of supplemented populations, and directly estimating the density-independent growth parameters when escapement is similar to that of the pre-supplementation period and/or when escapement is similar to that observed in reference populations. If the density-independent growth parameters are similar to either the pre-supplementation period, or similar to those observed in reference populations, it would suggest that supplementation has not impacted productivity. Alternatively, a decrease in the density-independent growth parameters would suggest that supplementation has decreased productivity. A similar conclusion would be reached if abundance declines following cessation of supplementation.

As an alternative to artificially limiting escapement, one could evaluate whether a fitness differential exists between hatchery and natural-origin adults within supplemented populations; as described in the next section. Similar to the T/R study described above, the results of such an approach, by itself, are not definitive. However, if the populations selected for a fitness study are a subset of the populations selected for the T/R design, the combination of the two types of information can provide a compelling answer.

Recommendation II: Implementation of a genetically-based relative reproductive success (RRS) study to quantify short-term impacts of supplementation on productivity, targeting a representative range of supplementation project strategies.

The T/R design described in the previous section will require accumulation of monitoring data over several salmon generations in order to experimentally test the efficacy of supplementation, although some insight can already be gained through analysis of existing data (see Appendix D). To complement the T/R design and to provide information on hatchery effects within a shorter time frame, we propose implementation of a design involving a series of RRS studies of supplemented populations. The proposed RRS design will help to determine the mechanisms by which hatchery rearing may result in reduced fitness among hatchery origin adults relative to natural-origin fish. Section A describes the specific design criteria of a comprehensive RRS study, and the types of information that can be obtained. Section B develops criteria to guide the selection of populations for inclusion in the design. Section C describes how Recommendation II relates to ISRP/ISAB concerns, and summarizes the strengths and weaknesses of the RRS approach, and how they contrast with those of the T/R approach.

A. Regional RRS Design

We recommend support of existing and additional RRS studies in supplemented populations to effectively complement the T/R design. RRS studies are needed to determine whether the effects of supplementation programs on the abundance and productivity of natural populations identified through the T/R design are attributable to reduced reproductive success of hatchery-origin fish or to other mechanisms (e.g., density-dependent effects) that do not reflect differential fitness of hatchery fish. A regional RRS design should include populations located throughout the basin, which ideally should represent a subset of the treatment populations being studied as part of the T/R design. The experimental design of each individual study should provide for an investigation of the genetic and environmental sources of variation in RRS (see Table 3). We agree with the CSMEP recommendation (Marmorek et al. 2007a and b) concerning Columbia River Basin on spring Chinook that a minimum of 6 RRS studies are necessary within the design for this species. And, we expand on this to recommend a minimum of 6 RRS studies in supplemented steelhead populations, at least 2 studies on ocean-type Chinook (e.g., Snake River fall, Upper Columbia Summer, or Lower Columbia tule), and at least 3 studies of reintroduced populations. RRS studies are currently being performed on 9 different anadromous salmonid populations in the Columbia River Basin, most or all of which should fit into the proposed designs which call for studies in 17 or more populations, distributed among stocks/species.

There are four basic approaches to conducting an RRS study of a supplemented population. Each approach yields somewhat different information, though they are not mutually exclusive and may occur concurrently in one river system.

1. Typical RRS studies are initiated by collection of adult hatchery-origin and natural-origin fish whose ancestry is unknown. The adults are sampled for DNA and released to spawn naturally. The offspring of these matings are sampled at the juvenile and/or adult stage, and "assigned" to the parent(s) that gave rise to them. These studies provide a combined measure of 1) the genetic effects of one generation of selection caused by pre-spawning (holding) in collection ponds, artificial spawning and incubation and rearing in the hatchery through the juvenile stages until release, and 2) the environmental effects of hatchery rearing and release location (assuming preferential homing to the release location). The genetic and environmental effects cannot be clearly parsed with this approach. These studies provide a measure of the proportional contribution of hatchery fish to natural production, but it remains unclear to what extent the production is in supplement to the natural population, and how much might be in replacement of natural fish production (i.e., whether or not there is density dependence).

2. The approach used by Araki et al. (2007) was designed to test strictly for genetically-based differences in fitness of hatchery and natural fish, achieved by comparing the fitness of hatchery fish that have different parentage (either HxH, HxN, NxH, or NxN). Environmental effects are eliminated because all fish are reared in the same (hatchery) environment. However, there are nonetheless potential genotype X environment interactions which may benefit one cross-type or the other, and thus potentially confound interpretation of the results.

3. A third approach would compare the fitness of natural-origin fish with different ancestries (HxH, HxN, NxH, or NxN). However, this design would be difficult to apply, as it requires availability of pedigree data which identifies the ancestry (grand-parentage) of the natural-origin fish being compared to one another. If this information were available, however, this design would provide unconfounded measures of genetic fitness, and an estimate of the magnitude of genetic fitness loss that may occur in a single generation.

4. The fourth approach begins with a natural population and develops a segregated hatchery line that does not interbreed with the natural population either in the hatchery or in nature. The hatchery and natural populations can be compared after one or two or more generations since the initiation of the hatchery program. While a high degree of manipulation is required to enact a study of this sort, it does allow testing for cumulative fitness loss in hatchery stocks. This is not determinable from studies where hatchery and natural-origin fish interbreed, as is the case in supplementation programs. Ongoing examples of this type of study include a study at the Cle Elum Supplementation and Research Facility, Cle Elum WA, in which investigators have developed a segregated line of Yakima River spring Chinook salmon, and a University of Washington/NMFS study of coho salmon in Big Beef Creek, WA.

Sampling and analysis in each of the recommended RRS projects described above should be conducted annually for up to three salmon or steelhead generations (12 to 21 years). This will permit accumulation of adult return data for successive broodyears. Of note, however, initial measures of RRS have already been made or published for some populations and new projects could return adult-to-juvenile RRS results in as little as two years.

B. Program Selection Criteria

1. General study design

A number of important study characteristics should be included in a RRS design in order to maximize the breadth and strength of inferences that can be made. First, RRS should be measured in whole populations or large spawning aggregates if a regional scale of inference is desired. However, smaller scale studies should be considered in cases where larger studies are logistically difficult or impossible (e.g., due to inability to install a weir/trap in a position downstream of the spawning area so as to capture the entire escapement). Second, studies of large populations will include more numerous confounding variables, whereas studies of smaller populations can be better controlled though may have a smaller scale of inference. Third, RRS should be based on productivity assessments of progeny at multiple key life-history stages (parr, presmolt, smolt, and adult) to indicate where differences in fitness may be occurring and what mechanisms may be causing those differences. Finally, and perhaps most importantly, RRS studies should be designed or modified to ensure that inferences about genetic versus environmental effects of hatcheries on fitness differences can be made, and that associated information is collected for factors that might reflect the mechanisms responsible for fitness differences.

Table 3 provides a list of supplemented populations (grouped by species) with ongoing RRS studies, and other populations that we propose as candidates for study (also see Figures 4 and 5). Table 4 provides a list of populations which were reintroduced into areas from which they had previously been extirpated, and are being rebuilt through supplementation (grouped by species), that we also propose as candidates for study. Final selection of specific populations to include in the suite of RRS studies should depend on how well each study either currently or potentially meets the following criteria:

a. The population would be included within the proposed T/R experimental design.

b. The supplementation program follows 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.).

c. An adult trap that can capture nearly all of the migrating adults already exists, or one could be cost-effectively installed and operated.

d. Juvenile trapping at the parr and/or smolt stages already occurs, or could feasibly be implemented.

e. The candidate study population has a reasonably good time series of data for abundance and productivity from previous broodyears, and the history of supplementation is well documented and understood - including annual records of the proportion of hatchery-origin spawners (pHOS), natural-origin spawners (pNOS), and natural-origin spawners used in the broodstock (pNOB).

f. Abundance of the potential spawning population is great enough for adequate statistical power but small enough that parentage analysis is feasible. Using current genetic technology, spawning population sizes between 200 and 2,000 are reasonable, though the expectation is that analysis of larger populations will become easier and relatively less expensive as technology improves.

2. Mechanisms

One of the major objectives of conducting basin-wide RRS studies is to determine the proximate mechanisms causing reduced fitness in hatchery-reared fish. For example, age-composition and therefore adult body size of spring Chinook salmon can be strongly influenced by the hatchery rearing environment (Larsen et al. 2004, Knudsen et al. 2006 and 2008) and body size has been correlated with breeding success for several species of Pacific salmon (reviewed by Esteve 2007). Therefore, environmentally induced variation in age and body size may explain variation in reproductive success and can be accounted for if the proper data are collected on the hatchery and natural populations. Measurement of the following variables will provide the information necessary to elucidate many of the known or expected mechanisms that might be responsible for fitness differences between hatchery and natural-origin fish:

- sex
- river entry and spawn timing of individual spawners
- body size and morphology
- freshwater and saltwater age
- egg retention
- testes depletion
- spawning behavior (e.g., male dominance hierarchies)
- spawning location in relationship to smolt release location
- redd characteristics for individual spawners (location, morphology, depth, velocity, temperature)

Uncertainties research focused on these and other (genetic) mechanisms are discussed in Section III below.

Table 3. - On-going and potential relative reproductive success studies in the Columbia River Basin for supplemented populations. Cells indicate whether a study is currently estimating a particular factor (C), has the potential to estimate that factor if the study were to be initiated or modified (P), or is unable to estimate the factor (No).

Population (sub-basin)	Genetic[1]	Environ-mental[2]	Multi-generation effects[3]	Spawner distribution: spatial (s), temporal (t)[4]	Body size	Age-at-maturity[5]	Life history segment[6]	Ongoing RRS study	Gener-ations of supp.	PHOS (range)	PNOB (range)
SPRING(/Summer) (stream-type) CHINOOK											
Upper Yakima River spring Chinook (Yakima)	P	P	P	C	C	C	AF	Yes	2	0.195 - 0.763 (mean 0.523)	1.0
Chiwawa River (Wenatchee)	C	C	C	C	C	C	AP, AS, L	Yes	4	0.02 - 0.83	0.28 – 1.00
White River (Wenatchee)	C	C	C	C	C	C	AP, AS, L	Yes	4	0.00 - 0.46	0.00
Twisp River (Methow)	P	P	P	P	P	P	AS	No	3	0.00 - 0.96	0.00 - 1.00
Chewuch River (Methow)	P	P	P	P	P	P	AS	No	3	0.00 - 0.93	0.00 - 0.90
Upper Methow River (Methow)	P	P	P	P	P	P	AS	No	3	0.00 - 0.98	0.00 - 0.65
Tucannon River (Lower Snake)							AS	No		0.00 – 0.98	0.00 – 0.54
Pahsimeroi River (Salmon)	P	P	P	P	P	P	AP, AS, L	Yes	2+	0.04 – 0.58	0.00 – 0.39
Salmon River upper mainstem above Redfish Lake (Salmon)	P	P	P	P	P	P	AP, AS, L	No[7]	2+	0.07 – 0.54	0.00 - 0.88
East Fork South Fork Salmon River (Johnson Creek)	N	P	N	C	C	C	AS, L	No	2	0.17 - 0.63	0.95 - 1.00

Catherine Creek (Grande Ronde)							AP, AS, L	Yes	2	0.12 - 0.84	0.85 - 1.00
Lostine River (Grand Ronde	N	C	C?	C	C	C	AP, AS, L	Yes	2	0.29 - .082	0.74 - 1.00
Upper Grande Ronde (Grande Ronde)							AP, AS, L	No	1	0.18 - 1.00	0.28 - 1.00
<u>FALL (ocean type) Chinook</u>											
Snake River											
Wenatchee River (upstream of Tumwater Dam)	P	P	P	P	P	P	AP, L	No	4	0.00 – 0.27	0.51 – 1.00
<u>STEELHEAD</u>											
Kalama River							L	Yes	1		
Hood River (winter run)							L	Yes	1		
Hood River (summer run)							L	Yes	1		
Wenatchee	C	P	P	P	C	C	AP, AS, L	Yes	4	0.30 – 0.89	0.33 – 0.60
Little Sheep Creek (Imnaha)							AP, AS, L	No	4		

[1] Is genetic fitness being determined? This refers to the type of analysis conducted by Araki et al. (2007); that is fish with different hatchery/wild ancestry reared in a common environment (either in the hatchery or natural environment) are the subjects of a relative fitness evaluation.
[2] Are environmental effects on fitness being estimated? This refers to comparing fish of a common genetic background that are reared in two different environments. Environmental effects might include homing to a hatchery release location that affects fitness
[3] Are greater than one-hatchery generation effects being estimated? For example, a two-generation segregated hatchery population compared with its founder natural population.
[4] Is spawner distribution being measured either by live detection or carcass sampling?
[5] Is age-at-maturity being measured in both the hatchery and natural populations?
[6] What life stages are being evaluated (L = lifetime, AF = adult-to-fry, AP = adult to parr, AS = adult to smolt)?
[7] DNA from all adults and a subsample of juveniles sampled since 2002 are archived and ready for analysis.

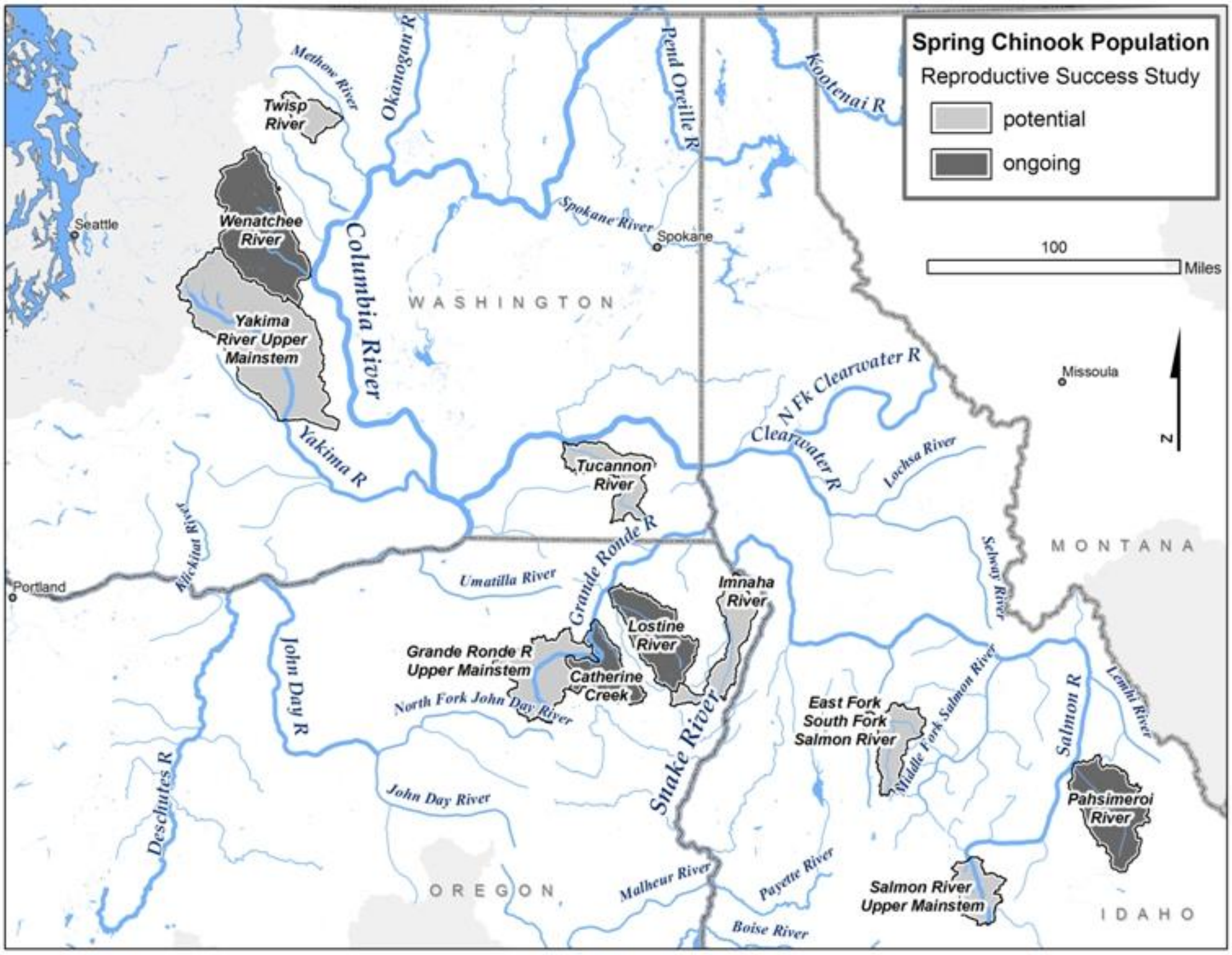

Figure 4. - Ongoing and potential RRS studies of Spring Chinook salmon.

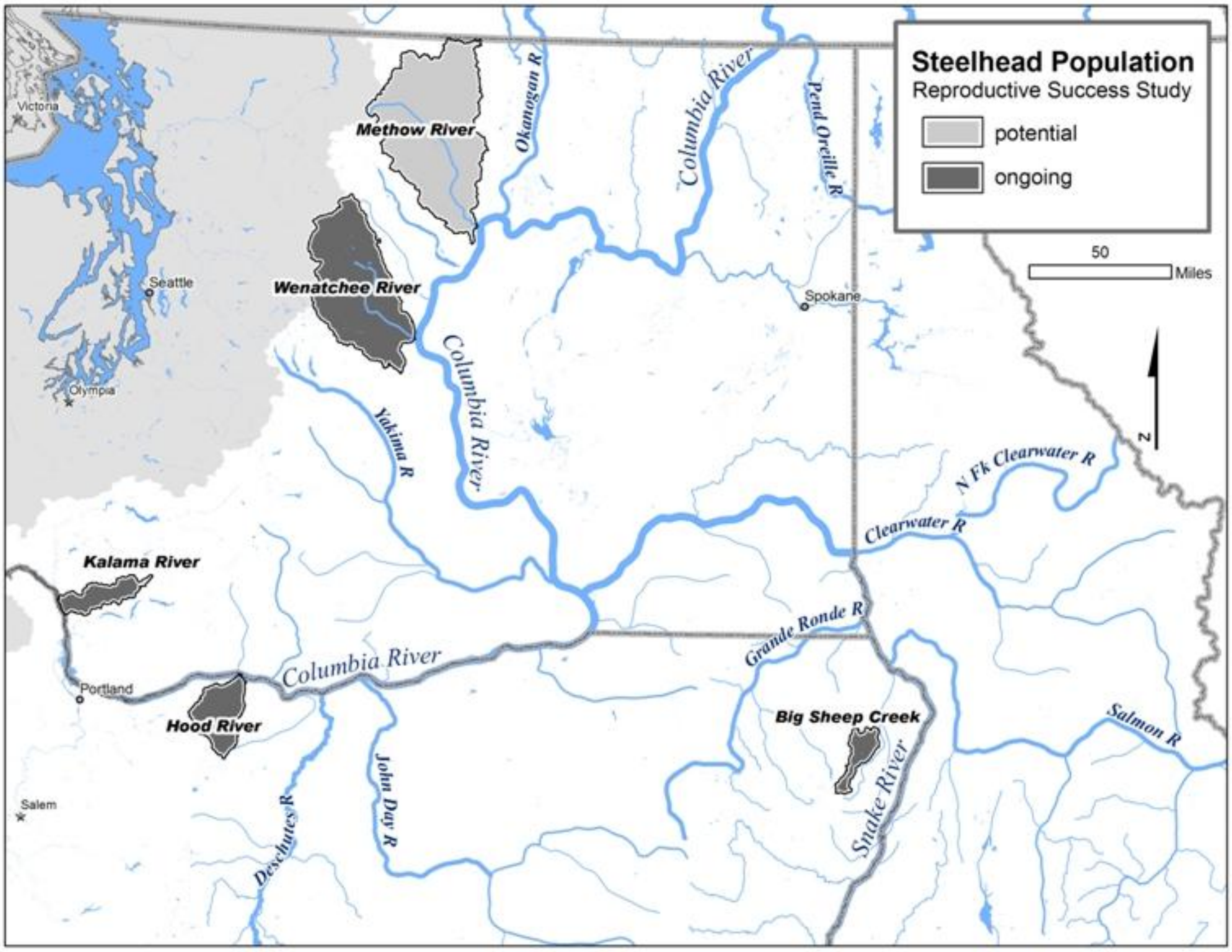

Figure 5. - Ongoing and potential RRS studies of steelhead.

Table 4. - On-going and potential relative reproductive success studies in the Columbia River Basin for reintroduced populations. Cells indicate whether a study is currently estimating a particular factor (c), has the potential to estimate that factor if the study were to be initiated or modified (p), or is unable to estimate the factor (n).

Population (sub-basin)	Genetic[1]	Environ-mental[2]	Multi-generation effects[3]	Spawner distribution: spatial (s), temporal (t)[4]	Body size	Age-at-maturity[5]	Life history segment[6]	Ongoing RRS study	Gener-ations of supp.	pHOS (range)	pNOB (range)
SPRING(/Summer) (stream-type) CHINOOK											
West Fork Hood River								No			
Umatilla River								No			
Newsome Creek (Clearwater)								No			
Red River (Clearwater)								No	2+		
Crooked River (Clearwater)								No	2+		
Clear Creek (Clearwater)								No	2+		
Lookingglass Creek (Grande Ronde)											
COHO											
Upper Wenatchee	P	P	P	P	P	P	P	No	2	0.96 – 1.00	0.00 – 0.04
Upper Yakima	P	P	P	P	P	P	P	No			

C: Relationship to ISRP/ISAB Comments

In their report, (2005-15) the ISRP/ISAB correctly point out that RRS studies, such as those described above, cannot in and of themselves, demonstrate whether supplementation impacts the long-term fitness of targeted populations. Generally, as described by Goodman (2005), the density-corrected fitness of female spawners is the quantity of interest for such evaluations. Neither the T/R or RRS designs described in this document directly estimate this quantity. However, by considering the results of both designs simultaneously we can achieve a less ambiguous result. For example, if RRS is similar to one from inception in supplemented populations, and this relationship holds true over a range of escapement, it would suggest that changes in productivity relative to treatment streams, or the pre-treatment period within a stream, are the result of density dependent mechanisms rather than hatchery impacts. Alternatively, if RRS is less than one, it would suggest that either: 1) hatchery impacts do reduce the productivity of target populations or 2) the combination of fitness reduction and density-dependence have reduced productivity. The degree to which hatchery impacts have reduced productivity versus density-dependent mechanisms could be estimated by calculating the degree of change that could be explained by the observed difference in RRS. The long-term impacts of supplementation on productivity, given alternative two, would likely be best evaluated through experimental cessation of supplementation.

Recommendation III: The development of a targeted request for proposals aimed at funding small-scale studies that directly address remaining critical uncertainties and that are not amenable to large-scale T/R or RRS designs.

Recommendations I and II will allow the region to determine, on a large scale, the overall long and short term effects of supplementation on the abundance and productivity of natural populations. However, it is also important to conduct more focused research aimed at elucidating the underlying biological and ecological mechanisms responsible for the patterns that may be detected through these basinwide evaluations. The AHSWG identified three critical research areas that if successfully addressed would greatly help the region in making both tactical and strategic decisions about how hatcheries are managed and how they might best be used in salmon recovery. These areas are:

1. Determining the genetic, behavioral or physiological mechanisms which may cause low relative fitness in hatchery fish.

2. Determining the mechanisms by which supplementation reduces natural population productivity.

3. Developing decision support tools to help managers make decisions about if and when to initiate and cease supplementation.

The work group recommends that the NPCC Fish and Wildlife Program consider specifically requesting proposals to address these research areas, which are described in greater detail below.

1. *Determining the genetic, behavioral or physiological mechanisms causing low relative fitness in hatchery fish.*

Studies of hatchery salmon relative reproductive success have found that hatchery-origin adults often have lower success when spawning in the wild relative to natural-origin fish (reviewed by Berejikian and Ford 2004 and Araki et al. 2008). However, few studies have attempted to determine the biological causes leading to reduced fitness of the hatchery fish. Understanding why hatchery fish have reduced fitness is important, because different causes of reduced fitness have very different conservation implications. For example, if reduced fitness is primarily caused by relatively plastic traits such as differences in spawning location between hatchery and wild fish this would be of less long-term concern than if reduced fitness was primarily due to genetic factors. Examples of research questions related to this focal area include:

   a. *What proportion of the reduction in fitness observed in hatchery fish is due to genetic causes?*

This question can be addressed through RRS studies that control for environmental effects on fitness. Araki et al. (2007) is the best recent example of this type of study, in which the relative fitness of hatchery fish with one versus two hatchery parents was compared. Because both types of fish were reared in a common environment, the difference in fitness between the two types was inferred to have a genetic basis. This approach, successfully used in Hood River winter run steelhead, clearly needs to be replicated and extended to a broader range of populations and species.

   b. *When genetically based differences in fitness between hatchery and natural fish (or between categories of hatchery fish) are observed, what is the underlying genetic mechanism leading to these differences?*

Past studies of hatchery fish relative reproductive success have indicated that reductions in hatchery fish fitness can occur after only 1-2 generations of hatchery breeding, and that these per-generation reductions are sometimes relatively large (Araki et al. 2007; Araki et al. 2008). Theoretical modeling has demonstrated that strong domestication selection acting on ‘normal’ genetic variation is a possible mechanism for such rapid fitness loss, but only under rather extreme conditions (very strong selection, and high heritability for traits leading to fitness loss). There are essentially no empirical data on the underlying genetic basis for the differences in fitness between hatchery and natural salmon, and until such data are collected the relative rate at which salmon appear to lose fitness in the wild due to effects associated with hatchery rearing will remain something of an enigma. Initiating studies to elucidate the detailed genetic basis of observed fitness differences is therefore a high priority research question. Possible approaches for addressing this question might include: studies of gene expression, epigenetic factors (e.g., methylation), and quantitative trait loci among hatchery and wild fish in populations in which hatchery and wild fish are known to have genetically based differences in fitness (e.g., Hood River steelhead); controlled breeding experiments to obtain estimates of the heritability of fitness traits in hatchery-reared salmon; studies of physiology and behavior of hatchery and natural fish in systems where they are known to differ in fitness.

c. *What are the proximate mechanisms by which fitness in hatchery fish may be reduced?*

Most published studies of salmon reproductive success in natural settings are essentially 'black box' experiments - pre-spawning adults are sampled then returned to the river, and their progeny are sampled at some later date - but what happens in between is unobserved. In contrast, detailed studies of behavioral differences between hatchery and wild fish have been conducted in controlled laboratory environments, and therefore do not provide estimates of fitness in natural settings. Similarly designed studies conducted in spawning channels provide a more natural-like environment, but caution must still be exercised in extrapolating results to natural stream and river settings (Schroder et al. 2008). Because the physical and biological environment in which a salmon spawns can have a large influence on its reproductive success, it is important to determine if hatchery and natural fish experience the natural environment in different ways. For example, Murdoch et al. (2008) found that spawning location within a river played a large role in explaining differences in fitness between hatchery and natural origin spring Chinook salmon. Fish that spawned lower in the river tended to have lower reproductive success than fish that spawned higher in the river, and hatchery fish had a marked tendency to spawn in lower reaches – potentially a response to the proximal location of their acclimation pond. Such an observation may be part of a more general phenomenon: if hatchery fish are released in specific areas within a watershed and tend to return primarily to those areas, they may tend to spawn at locally higher densities than wild fish that originated and return to multiple areas throughout the watershed. Understanding the degree to which highly plastic behaviors such as spawning location explains reduced hatchery fish fitness is therefore a research priority.

2. *Determining the mechanisms by which supplementation reduces natural population productivity.*

The research questions under (1) above and the RRS studies recommended under Recommendation II are largely aimed at explaining differences in fitness at the level of individual fish. In contrast, the broad scale demographic monitoring described in Recommendation I is aimed at quantifying effects of supplementation at the level of a population. Understanding the genetic, behavioral and physiological basis of differences in fitness among individuals is clearly a necessary step in understanding how supplementation may lead to population level declines in productivity. Even together, however, they will be insufficient in providing a clear understanding of how hatchery rearing can affect natural population fitness. Additional research is needed to elucidate the mechanisms by which supplementation may lead to population level declines in productivity. Specific critical research questions needed to address this topic include:

a. *How do rates and patterns of interbreeding between hatchery and natural fish affect mean population fitness?*

Rates of gene flow between hatchery and wild environments are expected to influence the rate and level of fitness change in both environments (Ford 2002), and this expectation is currently driving many of the hatchery reform recommendations throughout the region, e.g., the Pacific Northwest Hatchery Reform Project (http://www.hatcheryreform.us/prod/site/alias__default/home/308/home.aspx) and the US Fish and Wildlife Service Pacific Region Hatchery Review (http://www.fws.gov/pacific/fisheries/hatcheryreview/index.html). However, there have been no empirical studies of how alternative patterns of gene flow between hatchery and natural environments relate to population level declines in fitness. Although part of this question will be addressed in the RRS analyses which will involve some range of pHOS and pNOB values, additional studies in more controlled settings are also needed, perhaps using shorter lived fish species as a models for salmon.

b. *How much does natural productivity decline due to ecological interactions between wild and hatchery salmon?*

Pearsons (2008) recently reviewed what is known and unknown about ecological interactions between hatchery and wild salmon, and concluded that ecological impacts are likely underappreciated, particularly in the ocean, estuary and migration corridors. Experiments to better quantify the individual and cumulative ecological effects of the region's hatchery programs are therefore clearly needed. Specific uncertainties include: when in the life cycle and where in the environment such effects occur; quantifying the density dependent effects of hatchery fish and determining if they differ from wild fish in these effects; and quantifying the effects of releases at varying life-stages on non-target taxa. A particularly important issue is the need to understand the magnitude of the cumulative effects of multiple hatchery releases on a range of natural populations. Possibilities for studying these questions include long-term monitoring of wild fish size and survival rates across a range of hatchery stocking densities, and/or experimentally varying hatchery releases to create a large contrast in the number of hatchery fish in the system in order to increase the power to detect effects. A critical issue is that effects that are clearly large enough to be of management concern (e.g. survival changes in the range of 5-20%) may be difficult or impossible to detect experimentally due to high levels of natural variation in survival (Pearsons 2008). Developing appropriate alternative indicators or increasing the contrast in hatchery fish density through deliberate manipulations may therefore be needed to address this question.

3. *Developing decision support tools to help managers make decisions about if and when to initiate and cease supplementation.*

Even as our knowledge of the effects of supplementation has increased, managers continue to face difficult choices about whether to initiate supplementation programs for specific populations, and how best to manage these programs. Although several tools are available to help managers conduct risk/benefit type analyses of hatchery programs (Ham and Pearsons 2001), no tools have been designed to explicitly provide decision support about when to start and stop supplementation programs. Clear tools of this nature are needed, because making decisions about hatchery supplementation remains one of the more contentious issues associated with salmon management (Ruckelshaus et al. 2002). Decision support tools have been useful in a variety of natural resource management situations (e.g. Reeves et al. 2006), including setting viability goals for ESA listed Pacific salmon (Wainwright et al. 2008).

Conclusions

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. Formed in response to the call from the ISRP and ISAB for an interagency group to define a methodology to evaluate these effects, the AHSWG has been involved in protracted discussion on the merits of different approaches. Making the choice for a particular analytical design(s) was difficult, as measuring the effects that hatchery-produced fish may have on fitness of a natural population involves the complex interplay of a myriad of genetic, physiological, behavioral and environmental factors, overlaid by the range of ways in which a hatchery programs are managed in the basin. In the end, the AHSWG has recommended adoption of two complementary basinwide scale study designs to assess the long-term effects of hatchery supplementation on population abundance and productivity – a T/R design and RRS design. The T/R design exploits time-series data from multiple populations to look for differences in trend between supplemented and non-supplemented populations, though observed differences must be interpreted in light of the possible confounding influence of density-dependent effects on productivity between populations and between broodyears. The RRS design largely avoids problems associated with density-dependence by looking for differences in productivity within broodyears, though this approach precludes assessing the long-term accumulation and persistence of effects over multiple generations. By considering the results of both designs simultaneously, however, we can achieve a less ambiguous evaluation. For example, if since inception of a supplementation project, the RRS ratio is similar to one and this relationship holds true over a range of escapement, it would suggest that observation of changes in productivity in a T/R study is the result of density dependent mechanisms rather than hatchery impacts. Alternatively, if RRS is less than one, it would suggest that either, 1) hatchery impacts do reduce the productivity of target populations, or 2) the combination of fitness reduction and density-dependence have reduced productivity. The degree to which hatchery impacts have reduced productivity versus density-dependent mechanisms could be estimated by calculating the degree of change that could be explained by the observed difference in RRS. The long-term impacts of supplementation on productivity, given alternative two, would likely be best evaluated through experimental cessation of supplementation.

In complement to the T/R and RRS designs, the AHSWG also recommends funding a series of small-scale studies designed to elucidate the underlying biological and ecological mechanisms responsible for effects detected through these basinwide evaluations. Better understanding of these mechanisms could guide hatchery reform efforts, with the objective of moderating deleterious effects that hatchery programs may have on the natural populations.

Implementation of these 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 for a basinwide evaluation of the effects of hatchery supplementation. A coordinated analysis of this information will enable managers to use a cost-benefit approach to help design supplementation projects – one which weighs the advantages associated with 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 obligations for harvest mitigation and conservation. Over the coming years, decisions on hatchery use will likewise need to consider effects that projected climate changes are expected to have on conditions of freshwater habitat, and on survival rates during migration through the hydrosystem and during estuary and ocean rearing. The decision-making process regarding how and when to utilize hatcheries will require considerable policy, management and legal input in addition to the scientific input that may be obtained through implementation of the AHSWG proposals.

As indicated previously, implementation of the proposed designs will result in generation of a considerable amount of data from a large number of different projects. The AHSWG therefore recommends that an interagency workgroup be funded to assemble these data and to coordinate their analysis following appropriate statistical designs. The result should be a defensible evaluation of the effects of hatchery use in the basin and a consensus set of guidelines on how best to manage hatcheries in order to attain defined management goals.

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Appendix A

An Introduction to Supplementation

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, while supplementation programs produce fish that are expected to return to targeted streams and contribute to natural production. Reflecting their contrasting objectives, the two types of programs 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 that return to the hatchery, which are predominantly of hatchery-origin, are collected for spawning (segregated broodstock management), with the remainder of hatchery-origin adults targeted for harvest. In contrast, in a supplementation program, the broodstock (typically of both natural and hatchery-origin) is composed, at least partially, of naturally spawned adults. Progeny of the hatchery-spawned fish in both types of program are reared in the hatchery typically until reaching the parr, presmolt, or 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. Upon return, hatchery-origin adults are targeted in fisheries and collected for broodstock – they are not intended to spawn naturally. 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. Upon return, adults are either collected for broodstock or allowed to escape and spawn naturally in hopes of boosting natural production. In some years, these fish may also be targeted in fisheries when escapement goals and broodstock requirements are exceeded. 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 typically exceeds that of naturally spawning fish. 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 over subsequent generations. Indeed, despite the expectation of short-term demographic benefits, considerable controversy exists regarding the advisability of supplementation, due to concern that hatchery supplementation may have deleterious effects 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 population fitness – 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 was expected to be less fit. Use of local-origin stock, as recommended in a supplementation program, is expected to moderate to a greater or lesser extent these deleterious effects. Unfortunately, there are currently few cases of consistently managed supplementation programs for which reliable data sets for abundance and productivity are available, and a robust assessment of the long-term effects of supplementation has not been possible (see Appendix B).

Additionally, a direct evaluation of the effects of supplementation on a population would include 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 for several supplemented streams 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 salmon (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 would therefore be useful to also 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 within 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):

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

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 decreased level 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 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). Hatchery broodfish collected from local stocks performed substantially better than non-local stocks, but nonetheless, generally demonstrated lower productivity than wild fish (RRS<1). A definitive conclusion regarding the effects of supplementation, however, could not be made as the number of studies using local stocks was limited, and with one exception, the analyses were subject to confounding effects of environmental and genetic factors. In the one study where the design did control for environmental effects, permitting testing only genetic effects, a significant loss in productivity associated with hatchery rearing was observed (Araki et al. 2007).

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.

Appendix B

History of the AHSWG and Contribution of Other Regional Processes

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 progeny-per-parent data for hatchery-origin versus natural-origin adults. Recognizing that life history differences between species (e.g., Chinook versus steelhead) and stocks (e.g., ocean-type versus stream-type Chinook) will likely impact the effects that hatchery rearing in a supplementation program might have on natural productivity, there will be a need to perform multiple studies within each species or stock. 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. While it is likely that alternative analytical designs for making assessments within and between supplemented and reference populations, within approaches it is necessary that monitoring protocols must be standardized to make these analyses meaningful.

- 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:

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

  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.

Following the second workshop, a smaller 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.

The AHSWG produced a final draft version of this report which was submitted in early 2008 to the full list of workshop participants, and to the NPCC (Galbreath et al. 2008) This report provided 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.

A third workshop was held in June 2008, to provide the opportunity for presentation of information from additional studies and reviews. The workshop was followed by further discussions within the AHSWG and workshop participants, to review the draft report and to finalize the group's recommendations within the present document.

Collaborative Systemwide Monitoring an 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 (McElhany 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 final recommendations of the AHSWG within the present report.

Appendix C

Framework for Integrated Hatchery Research, Monitoring and Evaluation

Monitoring of hatchery programs to assess the effects 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) 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 appropriate methods for implementing these measures may differ across species or environmental settings. However it is important that the metrics used in a particular approach be standardized to support comparisons with information from other populations regardless of the general methods used.

Table C1. - Standardized performance measures and definitions for status and trends and hatchery effectiveness monitoring. Modified from Parnell et al. (2004).

Performance Measure		Definition
Abundance	Adult Escapement to Tributary (PM 1)	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 (PM2)	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 Spawners per Redd (PM3)	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 prespawn female 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 mis-sexed fish at weir for 1 above.
	Index of Spawner Abundance - redd counts (PM4)	Counts of redds in spawning areas, in index area(s) (trend), extensive areas, and supplemental areas. Reported as redds and/or redds/km.
	Spawner Abundance (PM5)	In-river: Estimated total number of spawners on the spawning ground. Calculated as the number of fish that return to an adult monitoring site, minus broodstock removals, weir mortalities, harvest, 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. In-hatchery: Total number of fish actually used in hatchery production. Partitioned by gender and origin.
	Hatchery Fraction (PM6)	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 calculated as in 1 above, and 3) Use 2 above and carcasses above and below weir.
	Ocean/Mainstem Harvest (PM7)	Number of fish caught in ocean and mainstem (tribal, sport, or commercial), identified as to-origin - hatchery or natural.
	Harvest Abundance in Tributary (PM8)	Number of fish caught in tributary fisheries (tribal, sport, or commercial), identified as to-origin - hatchery or natural.
	Index of Juvenile Abundance (Density) (PM9)	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 (PM10)	Gauss software (Aptech Systems, Maple Valley, Washington) 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 was developed by the University of Idaho (Steinhorst 2000).

	Smolts (PM11)	Smolt estimates, which result from juvenile emigrant trapping and PIT tagging, are derived by estimating the proportion of the total juvenile abundance at the tributary comprised of each juvenile life stage (parr, presmolt, smolt) that survive to first mainstem dam encountered (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 first mainstem dam (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 (PM12)	This will not be in the raw or summarized performance database.
Survival – Productivity	Smolt-to-Adult Return Rate (SAR) (PM13)	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 first mainstem dam, first mainstem dam to first mainstem dam, and first mainstem dam to tributary. first mainstem dam *to* first mainstem dam SAR estimates are calculated by dividing the number of PIT tagged adults returning to first mainstem dam by the estimated number of PIT tagged juveniles at first mainstem dam. 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 tagged 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 SARs. 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* first mainstem dam SAR estimates are calculated by dividing the number of PIT tagged adults returning to first mainstem dam by the number of PIT tagged juveniles tagged in the tributary. There is no associated variance around this estimate. The adult detection probabilities at first mainstem dam are assumed to be near 100 percent.

Survival – Productivity	Smolt-to-Adult Return Rate (SAR) (PM13)	*F*irst mainstem dam *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 first mainstem dam. The estimated number of PIT tagged juveniles at first mainstem dam is calculated by multiplying life stage 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 first mainstem dam is calculated as follows, where X = the number of PIT tagged fish in the tributary and Y = the variance of the life stage 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 first mainstem dam: $Var\left(\frac{X}{Y}\right) = \left(\frac{EX}{EY}\right)^2 \cdot \left(\frac{Var(Y)}{(EY)^2}\right)$
	Progeny-per-Parent Ratio (P:P) (PM14)	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 (R/S)(Smolt Equivalents per Redd or female) (PM15)	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 juvenile trap. *Recruit per spawner* estimates, or *juvenile abundance (can be various life stages or locations) per redd or 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 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 first mainstem dam.
	Pre-spawn Mortality (PM16)	Percent of female adults that die after reaching the spawning grounds but before spawning. Calculated as the proportion of “25% spawned” females among the total number of female carcasses sampled. (“25% spawned” = a female that contains 75% of her egg compliment).
	Juvenile Survival to first mainstem dam (PM17)	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 first mainstem dam to estimate of abundance by life stage at the tributary and the sum of those is total smolt abundance surviving to first mainstem dam. Juvenile survival to first mainstem dam = total estimated smolts to surviving to first mainstem dam divided by the total estimated juveniles leaving tributary.
	Juvenile Survival to all Mainstem Dams (PM18)	*Juvenile survival to* first mainstem dam *and subsequent Mainstem Dam(s)* - 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 (PM19)	Post-release survival of natural and hatchery-origin fish is calculated as described above in the performance measure “Survival to first mainstem dam and subsequent Mainstem Dams”. No additional points of detection (i.e. screwtraps) are used to calculate survival estimates.
Distribution	Adult Spawner Spatial Distribution (PM20)	Extensive area tributary spawner distribution. Target GPS redd locations or reach specific summaries, with information from carcass recoveries to identify hatchery-origin vs. natural-origin spawners across spawning areas within populations. Raw database measure only.

	Stray Rate (percentage) (PM21)	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 (PM22)	Chinook rearing distribution observations are recorded using multiple divers who follow protocol described in Thurow (1994).
	Disease Frequency (PM23)	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 (PM24)	Indices of genetic diversity - measured within a tributary (heterozygosity - allozymes, microsatellites), or among tributaries across population aggregates (e.g., FST).
	Reproductive Success (Nb/N) (PM25)	Derived measure: determining hatchery:wild proportions, effective population size is modeled.
	Relative Reproductive Success (RRS) (Parentage) (PM26)	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) (PM27)	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 (PM28)	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 a screwtrap use 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 (PM29)	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 (PM30)	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 (PM31)	Size distribution of spawners using fork length and mid-eye hypural length. Raw database measure only. Data obtained at weirs or during carcass surveys.
	Size-at-Emigration (PM32)	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 life stage-specific emigration period are generated (mean length by week then averaged by life stage). For entire juvenile abundance leaving a weighted mean (by life stage) is calculated. Size-at-emigration for hatchery production is generated from pre release sampling of juveniles at the hatchery.
	Condition of Juveniles at Emigration (PM33)	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) (PM34)	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.
	Adult Run-timing(PM35)	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(PM36)	This will be a raw database measure only.
	Juvenile Emigration Timing (PM37)	Juvenile emigration timing is characterized by individual life stages at the rotary screw trap and LGD. 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 LGD.
	Mainstem Arrival Timing (PM38)	Unique detections of juvenile PIT-tagged fish at LGD are used to estimate migration timing for natural and hatchery-origin tag groups by life stage. 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 life stage divided by tributary abundance estimate by life stage). Daily products are added and rounded to the nearest integer to determine weighted median, 0%, 50%, 90% and 100% detection dates.
Habitat	Physical Habitat (PM39)	TBD
	Stream Network (PM40)	TBD
	Passage Barriers/Diversions (PM41)	TBD
	Instream Flow (PM42)	USGS gauges and also staff gauges
	Water Temperature (PM43)	Various, mainly Hobo® and other temp loggers at screw trap sights and spread out throughout the streams
	Chemical Water Quality (PM44)	TBD
	Macroinvertebrate Assemblage (PM45)	TBD
	Fish and Amphibian Assemblage (PM46)	Observations from rotary screwtrap catch and while conducting snorkel surveys.

In-Hatchery Measures	Hatchery Production Abundance (PM47)	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 (PM48)	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 hatch, hatch 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 (PM49)	Mean fork length measured in millimeters (mm) and mean weight measured in grams (g) 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 (PM50)	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 (g) and l is the length (mm) (Everhart and Youngs 1992).
	Fecundity by Age (PM51)	The reproductive potential of an individual female. Estimated as the number of eggs in the ovaries of the individual female - calculated by weight or enumerated by egg counter.
	Spawn Timing (PM52)	Spawn date of broodstock by age, sex and-origin. Also reported as cumulative timing and median dates.
	Hatchery Broodstock Fraction(PM53)	Percent of hatchery broodstock actually used to spawn the next generation of hatchery F1s. Does not include prespawn mortality.
	Hatchery Broodstock Prespawn Mortality (PM54)	Percent of adults that die while retained in the hatchery, but before spawning.
	Female Spawner ELISA Values (PM55)	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 (PM56)	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 (PM57)	Mean fork length (mm) by age of male and female broodstock. Measured at spawning and/or at weir collection. Is used in conjunction with scale reading for ageing.
	Prerelease Mark Retention (PM58)	Percentage of a hatchery group that have retained a mark up until release from the hatchery - estimated from a sample of fish as either "present" or "absent." ("Marks" refer to adipose fin clips or VIE batch marks)
	Prerelease Tag Retention (PM59)	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 (PM60)	Date and time of volitional or forced departure from the hatchery. Normally determined through PIT tag detections at facility exit (not all programs monitor volitional releases).
	Chemical Water Quality (PM61)	Hatchery operational measures include: dissolved oxygen (DO) - measured with DO meters, continuously at the hatchery, and manually 3 times daily at acclimation facilities; ammonia (NH_3) and nitrite (NO_2) - measured weekly only at reuse facilities (e.g., Kooskia Fish Hatchery).
	Water Temperature (PM62)	Hatchery operational measure: temperature (°Celsius) – measured continuously at the hatchery with thermographs and 3 times daily at acclimation facilities with hand-held devices.

This 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 C1) that describes how hatchery operations could be adaptively managed to optimize benefits to natural populations and minimize the risks of artificial propagation. Table C2 lists the variables/parameters of Goodman's model, defines the variables, and shows how they might be derived from these performance measures.

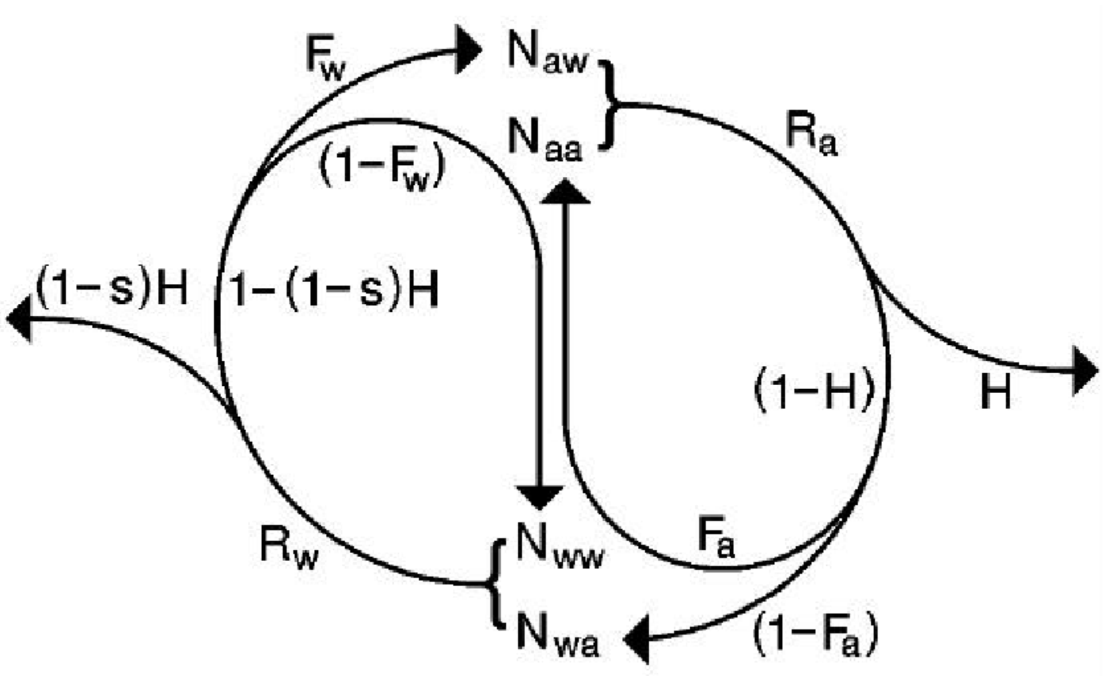


Figure C1. - Graphical depiction of the model developed by Goodman (2002), taken from ISAB (2003).

Table C2. - 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 PM34
Nwa(t)	Number of naturally spawning adults of hatchery-origin in generation t.	PM5*PM6 with PM34
Naw(t)	Number of broodstock of hatchery-origin in generation t.	PM5
Naa(t)	Number of broodstock of natural-origin in generation t.	PM5
Rw	Intrinsic replacement rate of natural spawners.	PM14
Ra	Intrinsic replacement rate of hatchery spawners.	PM14
F	Fraction of the natural-origin adult return retained for broodstock after harvest.	PM5/(PM1*(1-PM6))
Fa	Fraction of the hatchery-origin adult return retained for broodstock after harvest.	PM5/(PM1*PM6)
H	Fraction of the hatchery-origin adult return that is harvested.	PM1*PM6*PM7*PM8*PM1 0
s	The fraction of the natural-origin adult return taken in harvest prior to broodstock collection (ranging from 0 to 1).	PM1/(PM1*PM6*PM7*PM)

1) Implementation and Compliance Monitoring

Implementation monitoring of a hatchery program is simply the reporting of the number and characteristics of hatchery fish released. To a greater or lesser extent, this monitoring is already extensively practiced in ongoing programs, albeit in a manner which is not fully standardized. The information from implementation monitoring 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) 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
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 of all 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 of 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 adult progeny per hatchery parent (Hatchery P:P) ratio higher than Natural P:P ratio. Note that in an integrated supplementation/mitigation program with selective harvest occurring, P:P 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 is subdivided 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.

Management Objective 1: Maintain and enhance natural production in supplemented populations.

- 1a. Adult progeny per parent (P:P) 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 a supplemented population is similar to the natural productivity of the population had it 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 hatchery programs 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: Effects of hatchery programs on non-target (same species) populations remain within acceptable limits.

- 4a. Strays from a hatchery program (alone, or aggregated with strays from other 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 acceptably limited 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 hatchery programs to achieve optimal production effectiveness while meeting priority management objectives for natural production enhancement, diversity, harvest, impacts to non-target populations.

- 6a. 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 of natural-origin populations and their habitats.

- 7a. In-basin habitat is stable or improving, and suitable for targeted rates of natural production.
- 7b. Describe juvenile fish production in relationship to available habitat in each population and throughout a subbasin.

7c. 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 either as harvest augmentation programs or as 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. Nonetheless, it is clear that M&E designs to address these questions would be most useful if they viewed harvest augmentation and supplementation programs not as separate unrelated management strategies, but 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 C3. - 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).

No.	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 C4. - Supplementation hatchery questions developed by CSMEP, identified as being of high priority and to be addressed at the regional scale (Marmorek 2007a and b).

No.	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 stray hatchery fish within the natural spawning escapement in non-target populations, and what is their impact on the viability of these 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. This class of research, monitoring, and evaluation effort consists primarily of intensive small-scale studies on a limited number of programs/populations. The studies typically involve controlled experiments to test particular hypotheses regarding hatchery management practices and on interaction of hatchery-reared fish in the natural environment. A description of this sort of research, and of the need for the kind of information it can provide is developed in the main body of this report under Recommendation III.

Appendix D

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 time of Pacific salmon requires monitoring over an extended period
-
- measurement error introduces uncertainty in empirical measures, which can be further magnified when deriving secondary performance metrics
-
- variation in data collection protocols between programs, which complicates analyses requiring information collected across multiple populations

- 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 over time

Generally, an absolute minimum of three data points are required for statistical calculations. Thus evaluating productivity metrics, such as progeny per parent(P:P; 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 a minimum of nine years to collect P:P data points for three successive broodyears.

Aside from the length of time required for data collection, not all data are of known or equal quality. P:P 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 the derived P:P estimates. 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 assess whether supplementation, either deliberate or unintentional (straying), has altered productivity. The simplest method of doing so is to compare measures of productivity prior to the initiation of supplementation with measures after supplementation is initiated. However, when employing a before versus after (BA) design of this sort, one must explicitly assume that the only factor that differs between the two time periods is 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, P:P measures would not be directly comparable between the two periods. There are several ways to deal with potentially confounding factors such as these:

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

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 P:P ratios, and could not be addressed simply by increasing the duration of monitoring. In addition, it is essentially 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 to incorporate of a reference population(s) against which the treated (supplemented) stream(s) would be compared. Ideally, treated and reference populations would exhibit similar P:P or similar trends in P:P (e.g., significantly correlated) prior to supplementation, and be subject to similar environmental and anthropogenic influences. For example, populations located in the same subbasin are more likely to experience similar environmental conditions (e.g., cycles of precipitation, temperature regime, etc.) 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 D1). 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 D1, the mean P:P 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 P:P 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.

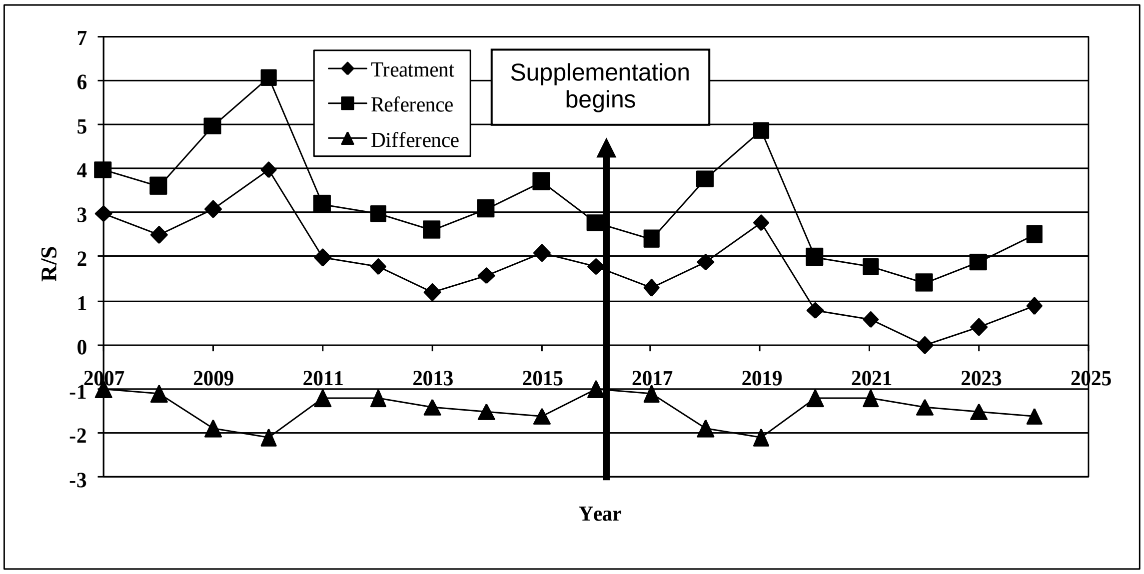


Figure D1. - Example of a BA design that incorporates a reference population. The arrow indicates the year supplementation is initiated. (Note: data is fictitious; provided for illustrative purposes only)

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 progeny per parent (P:P), or for juvenile recruits per spawner (R_J/S). Use of R_J/S has the advantage of not including the protracted marine portion of a salmon's life history. In consequence, R_J/S is anticipated to be less variable than P:P. 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 of 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. If hatchery-rearing is be associated with higher mortality in the marine environment as well, this effect will not be represented in a measure of R_J/S.

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. Therefore, 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 logistical requirements and 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 D2). 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 D1. - Sources of variation that impact key performance metrics.

Performance Metric	Sources of Variation				
	Sampling Error			Environmental Variation	
	Adult Enumeration	Juvenile Enumeration	Genotyping Error	Freshwater	Marine
Juvenile R/S	**X**	**X**		**X**	
Adult P:P	**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 I: Implementation of a large-scale treatment/reference design to evaluate long-term trends in the abundance and productivity of supplemented 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 (treatment) versus unsupplemented (reference) populations. These plots are a prelude to more formal statistical analyses, which we recommend be conducted.

Data

The ICTRT has compiled annual spawning abundance, adult progeny/parent (P:P), 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 and Figure 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 D2. - Summary information used in the preliminary analysis of population trends in supplemented (treatment) and unsupplemented (reference) spring/summer Chinook salmon populations.

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	treatment
Grand Ronde	GRUMA	Grand Ronde Upper Mainstem	1955	2005	0.00	0.77	treatment
Grand Ronde	GRLOS	Lostine	1959	2005	0.24	0.70	treatment
Grand Ronde	GRMIN	Minam	1954	2005	0.10	0.96	treatment
Grand Ronde	GRWEN	Wenaha	1964	2005	0.09	0.95	treatment
Grand Ronde	IRMAI	Imnaha	1949	2005	0.20	0.34	treatment
Lower Snake	SNTUC	Tucannon	1979	2006	0.01	0.49	treatment
Middle Fork Salmon	MFBEA	Bear Creek	1960	2003	1.00	1.00	reference
Middle Fork Salmon	MFBIG	Big Creek	1957	2004	1.00	1.00	reference
Middle Fork Salmon	MFCAM	Cameron Creek	1963	2003	1.00	1.00	reference
Middle Fork Salmon	MFLOO	Loon Creek	1957	2004	1.00	1.00	reference
Middle Fork Salmon	MFMAR	March Creek	1957	2003	0.99	1.00	reference
Middle Fork Salmon	MFSUL	Sulfur Creek	1957	2003	1.00	1.00	reference
South Fork Salmon	SFSEC	Secesh	1957	2005	0.91	0.96	reference
South Fork Salmon	SFEFS	East Fork South Fork	1957	2003	0.62	0.90	treatment
South Fork Salmon	SFMAI	South Fork Mainstem	1958	2003	0.36	0.61	treatment
Upper Salmon	SRCHA	Chamberlain Creek	1985	2003	1.00	1.00	reference
Upper Salmon	SRLEM	Lemhi	1957	2003	1.00	1.00	reference
Upper Salmon	SRPAH	Pahsimeroi	1986	2005	0.00	0.58	treatment

Upper Salmon	SREFC	East Fork Salmon	1960	2005	0.45	0.92	treatment
Upper Salmon	SRLMA	Lower Mainstem Salmon	1957	2005	1.00	1.00	reference
Upper Salmon	SRUMA	Upper Mainstem Salmon	1962	2005	0.50	0.75	treatment
Upper Salmon	SRVAL	Valley Creek	1957	2003	1.00	1.00	reference
Upper Salmon	SRYFS	Yankee Fork	1961	2003	1.00	1.00	reference
Upper Columbia	UCENT	Entiat	1960	2003	0.37	0.69	treatment
Upper Columbia	UCMET	Methow	1960	2003	0.08	0.52	treatment
Upper Columbia	UCWEN	Wenatchee	1960	2003	0.35	0.62	treatment

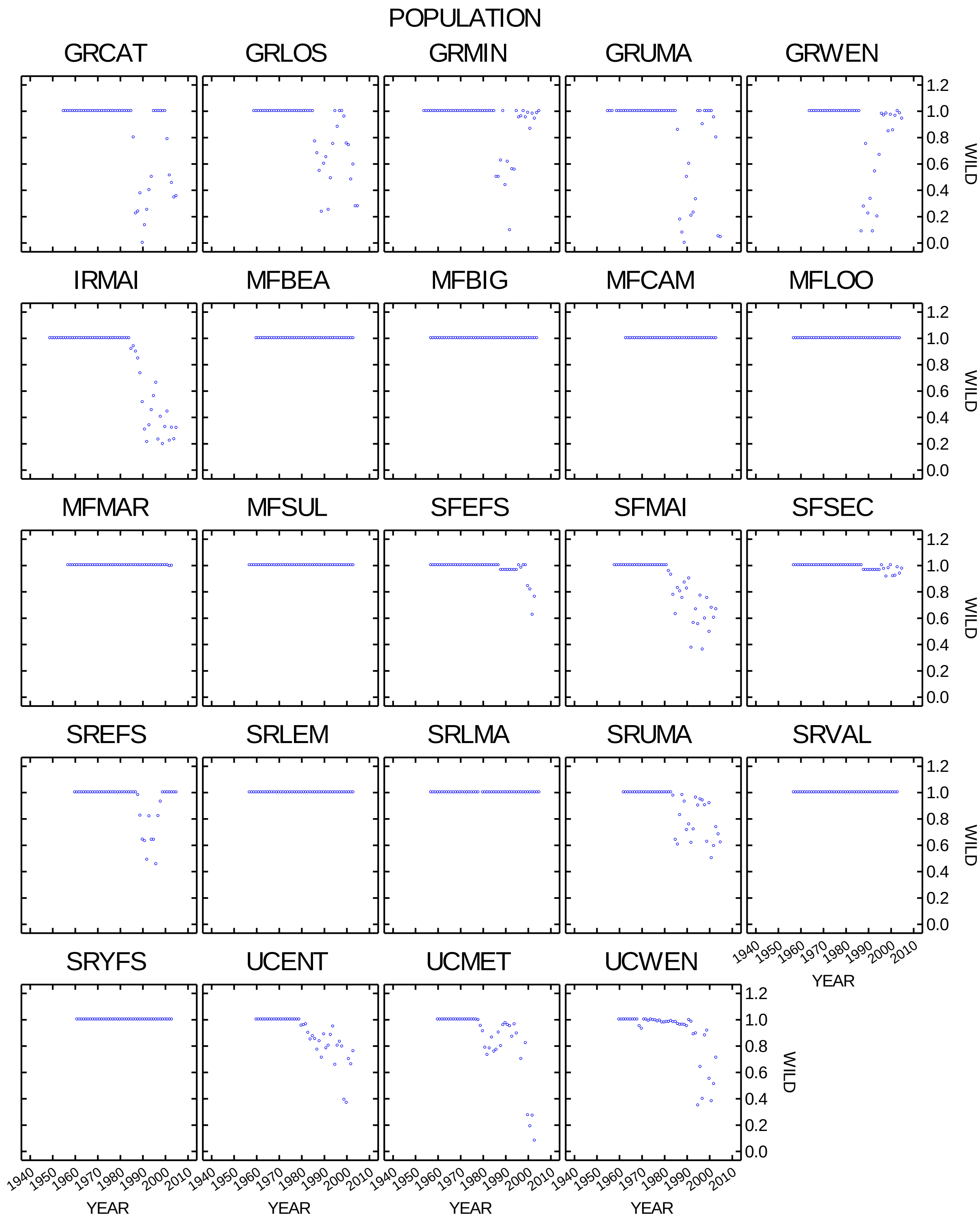


Figure D2. - Fraction wild fish on the spawning grounds over time. See Table 2 for population names.

Treatment populations: A population was put in the treatment 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 treatment, these populations could be subdivided into several groups (Figure B2 and ICBTRT status assessments).

a) Transiently treated 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.

b) 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.

c) 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.

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

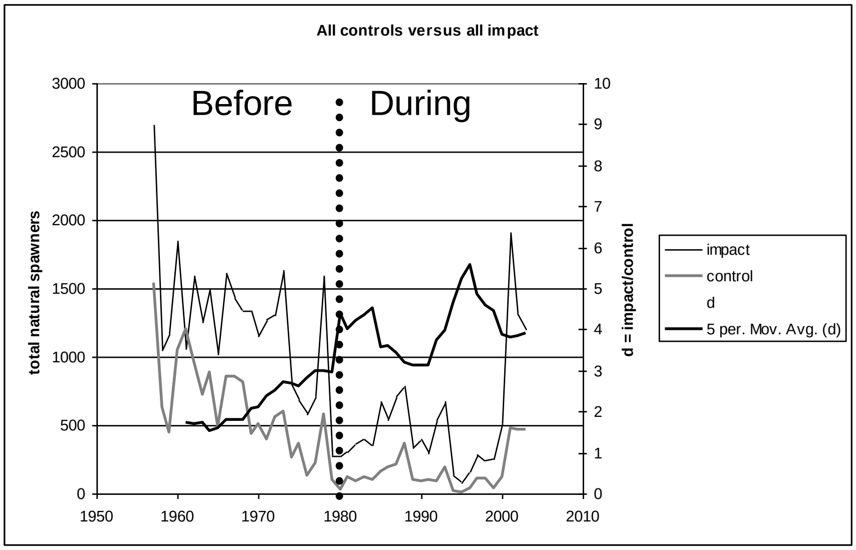
Analysis

Our preliminary analysis involved comparing trends in annual measures for total number of spawners, number of natural-origin spawners, and progeny per parent (P:P), in several different groups of treatment versus reference populations. For each of the three population statistics, we calculated the annual mean of the statistic in the group of treatment populations, the mean in the group of reference 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. Treatment populations were examined as a whole, and as sub-groups of populations with commonalities in the time and type of hatchery treatment.

Results

Comparison 1: All treatment versus reference populations. In this comparison, we compared average trends in all treatment populations with trends in all reference populations, recognizing that the treatments have occurred at various times and include both transient and ongoing treatments. Based on these plots, total spawner abundance appears to have increased over time in treatment populations compared to references, 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 P:P measures in treatment populations compared to references, although the ratios vary considerably over time and reference populations have been much more productive than treatment populations in recent years (Figure B3-B and C).

A



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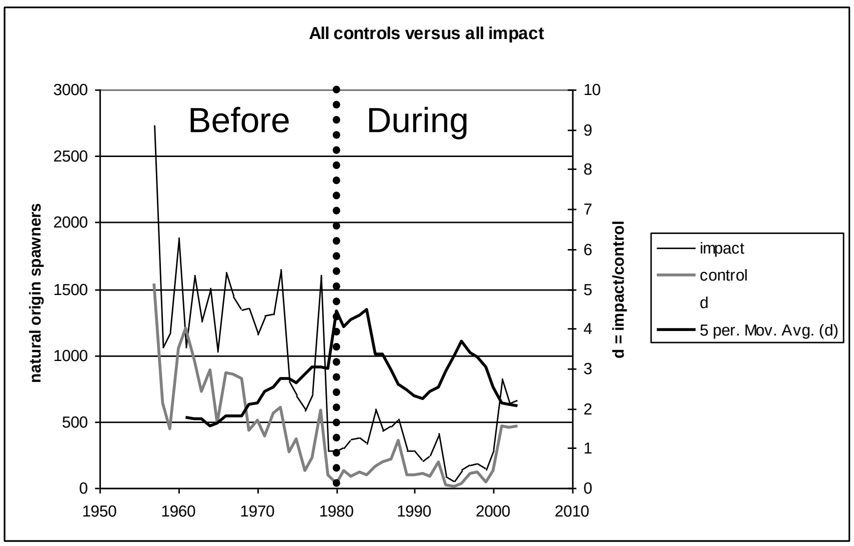

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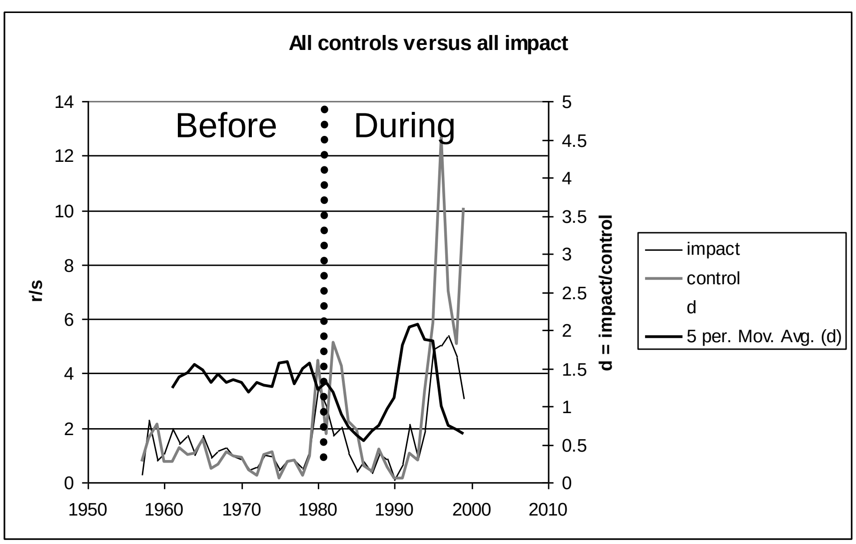


Figure D3. Comparison of all treatment versus all reference populations. A) total spawners, B) natural-origin spawners, C) natural progeny/spawner.

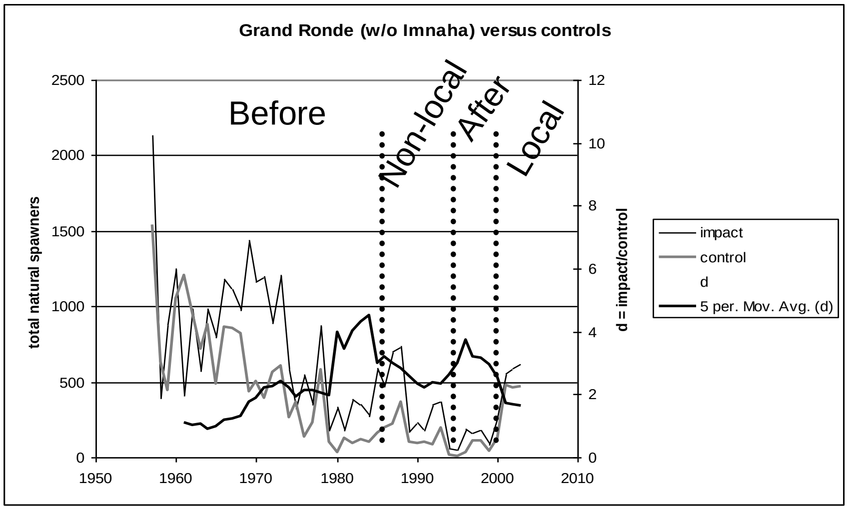
Comparison 2: Transiently treated populations. We analyzed the Grand Ronde populations alone as a separate group of treatment populations, since each of these populations had transiently high levels of non-local hatchery supplementation over roughly the same time period (Figure B4). In this comparison, annual estimates for total spawners, natural-origin spawners and natural P:P fluctuated widely in both the treatment and reference populations, but a consistent overall trend, either positive or negative, was not apparent. In recent years, however, the reference populations have had much higher productivity (P:P) than the treatment 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 references. Like the other comparisons, total spawners in the treatment populations was increasing relative to references 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 treatment populations compared to references in the 1990's. During the period of supplementation (mid-1980's on), differences in natural-origin spawners and natural P:P were highly variable between treatment and reference populations, with no apparent overall trend (Figure B5-B and C).

We also compared references 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 references since initiation of the supplementation program (Figure B6-A and B). Natural P:P 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 ~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 references, but then declined to pre-program levels in the mid-1990's (Figure B7-A and B). Natural P:P in treatment populations compared to references appears to vary cyclically, but also appears to have declined coincident with the hatchery programs, and has been very low compared to references from the mid-1990's onward (Figure B7-C).

A



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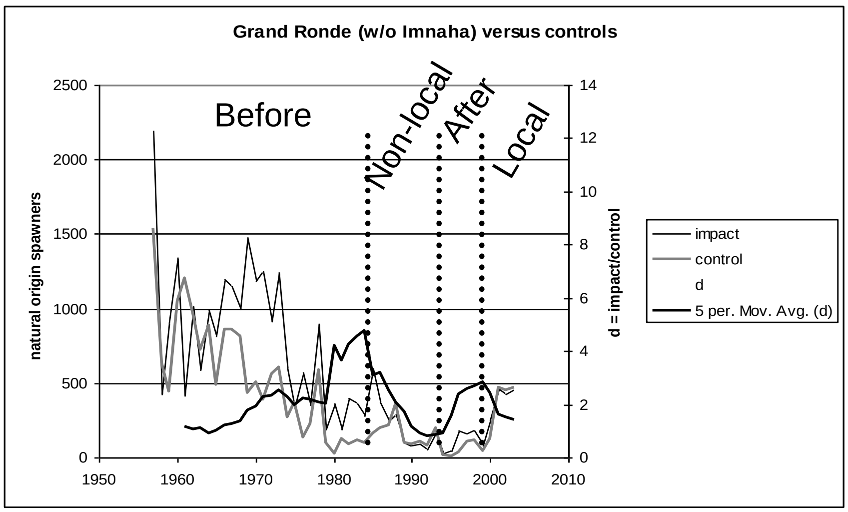

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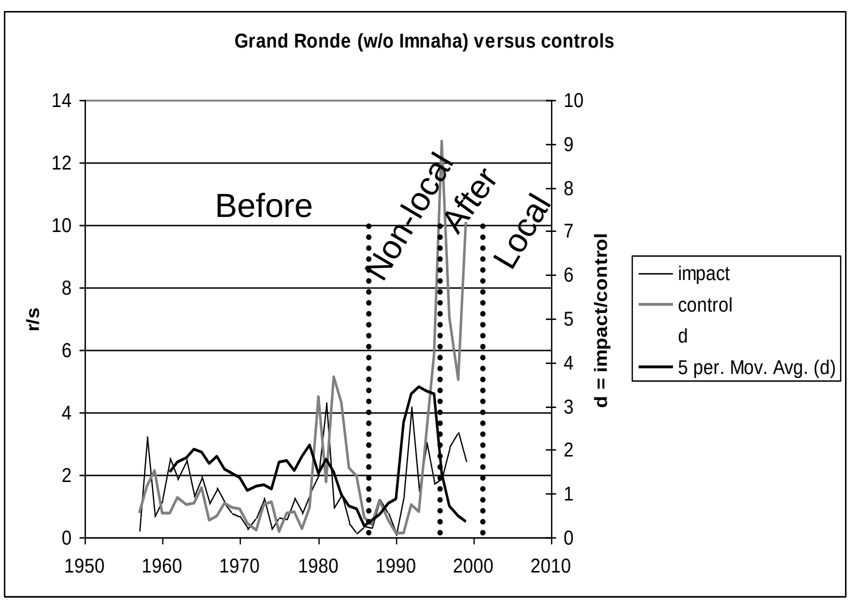
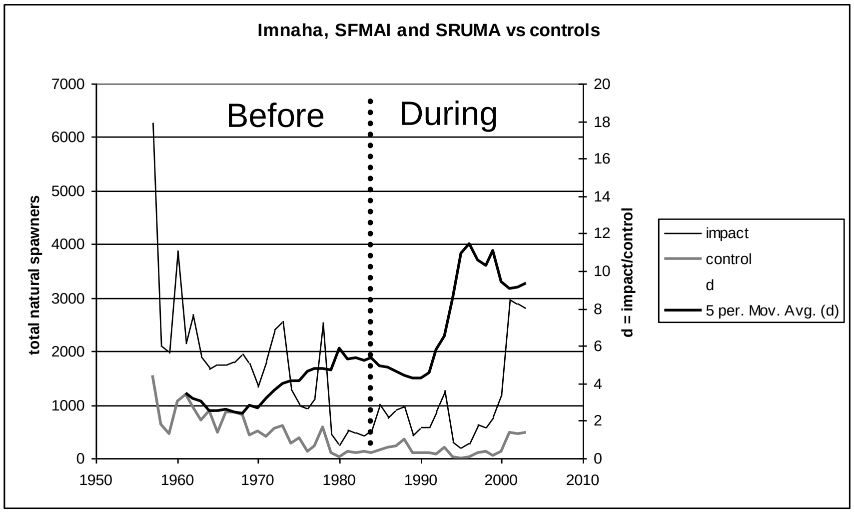


Figure D4. - Comparison of Grand Ronde population (treatment) versus references. A) total spawners, B) natural-origin spawners, C) natural progeny/spawner.

A



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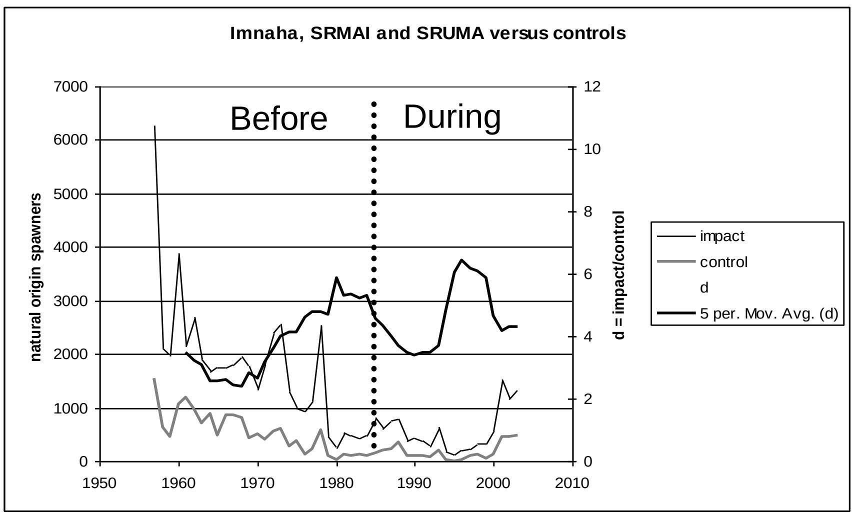

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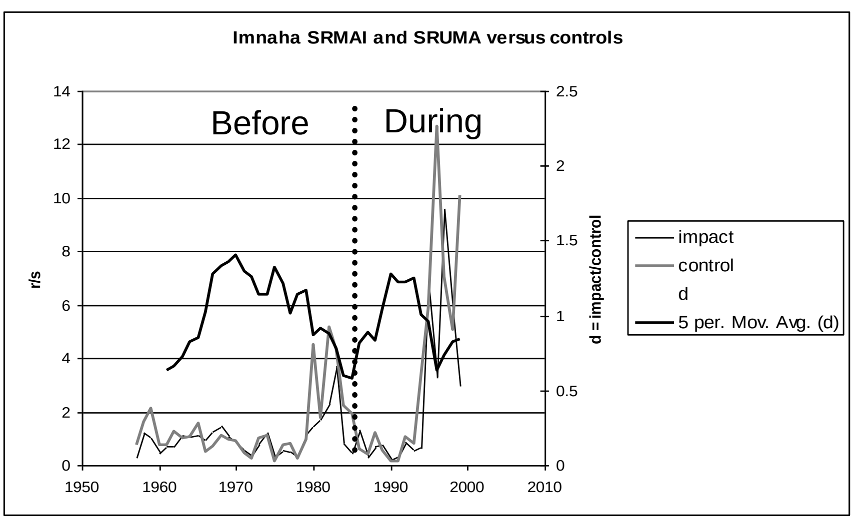


Figure D5. - Comparison of Imnaha (IRMAI), South Fork Salmon (SFMAI) and Upper Salmon (SRUMA) populations (treatment) versus references. A) total spawners, B) natural-origin spawners, C) natural progeny/spawner.

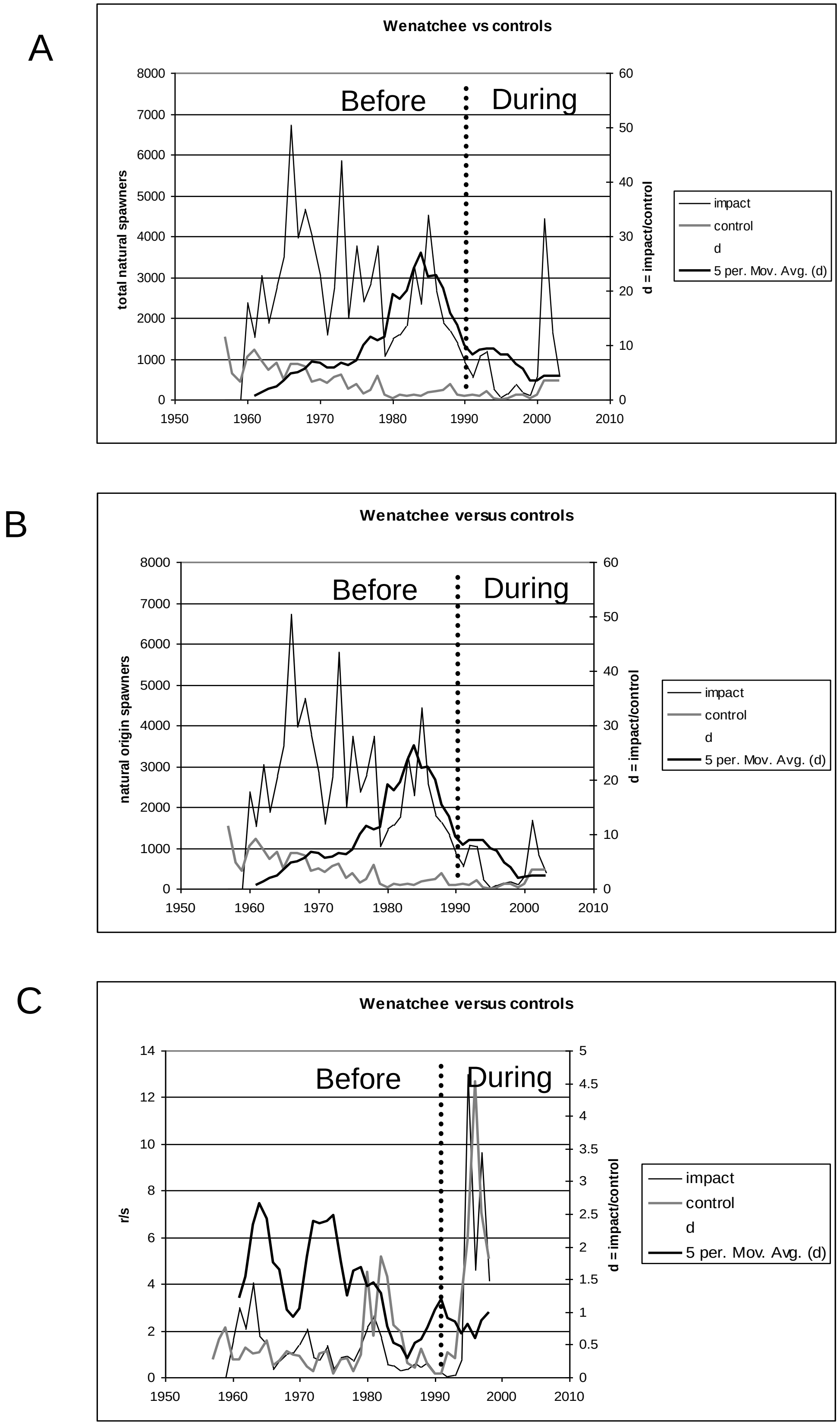
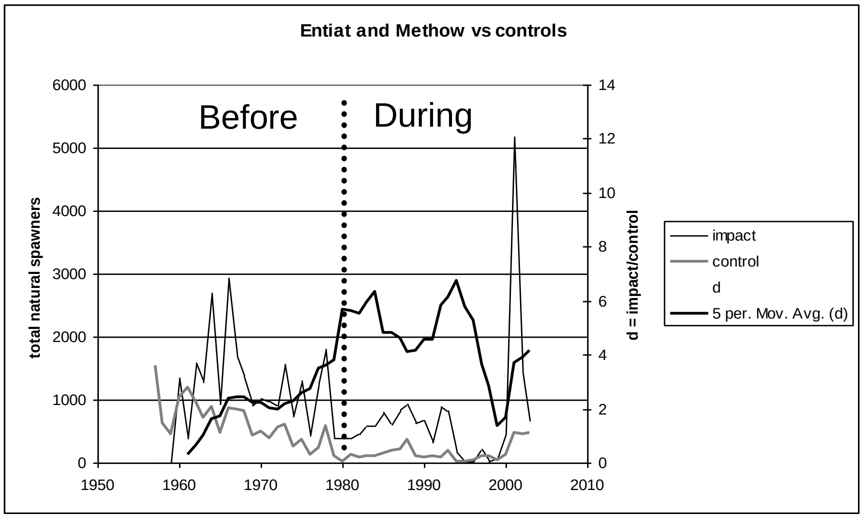


Figure D6. - Comparison of Wenatchee (UCWEN) population (treatment) versus references. A) total spawners, B) natural-origin spawners, C) natural progeny/spawner.

A



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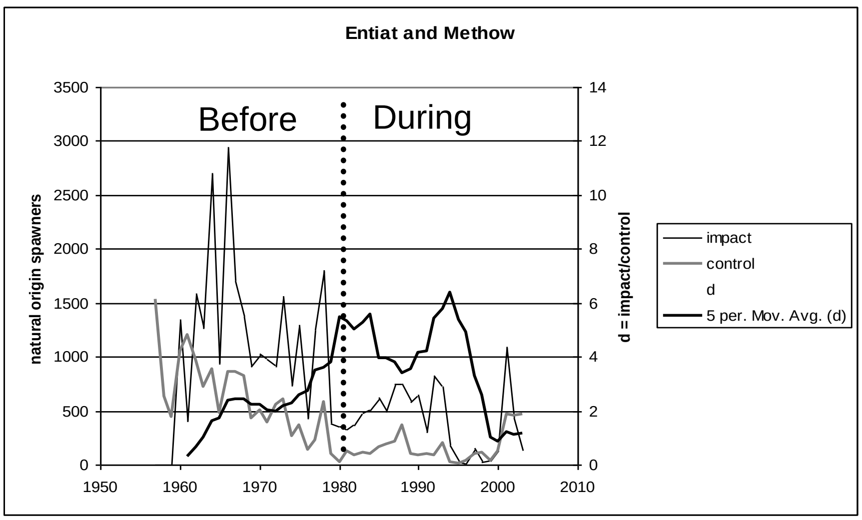

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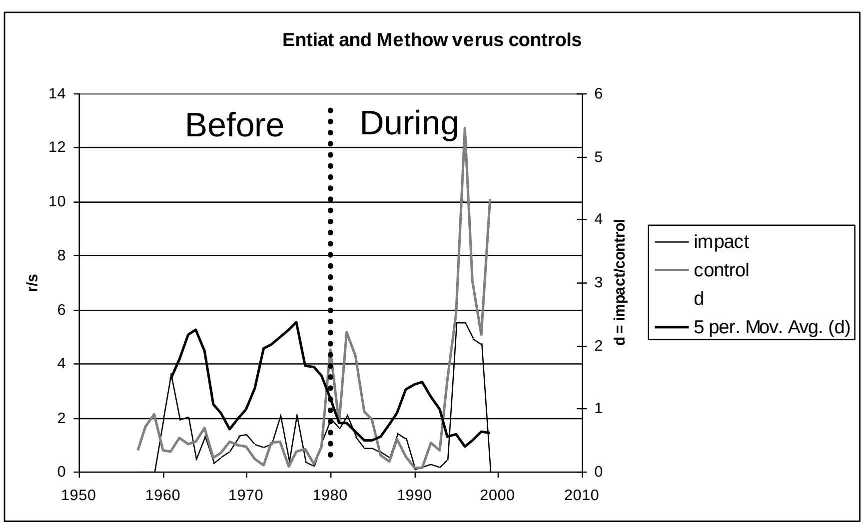

Figure D7. - Comparison of Entiat (UCENT) and Methow (UCMET) populations (treatment) versus references. A) total spawners, B) natural-origin spawners, C) natural progeny/spawner.

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 reference versus treatment populations. In particular, there were trends in treatment populations compared to references 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 references? Examining Figure B3A and B, 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 references, whereas natural-origin spawning abundance appears to have decreased. There is also an interesting difference between the trends in productivity (P:P) values for treatment 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 reference 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 references (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 references. The supplementation programs that were initiated in the 1980's and 1990's coincided with a

general period of extremely poor survival, in which many Columbia basin 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.