



Independent Scientific Review Panel

for the Northwest Power and Conservation Council

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Review of the Idaho Supplementation Studies Project Completion Report 1991-2014

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ISRP Review of the Idaho Supplementation Studies Project Completion Report 1991-2014

Background

In response to the Northwest Power and Conservation Council's April 25, 2016 request, the Independent Scientific Review Panel evaluated the finding from the [Idaho Supplementation Studies Project Completion Report 1991-2014](#). This completion report was drafted under project 1989-098-00, Idaho Supplementation Studies (ISS), by staff from the Idaho Department of Fish and Game (IDFG), Nez Perce Tribe (NPT), and Shoshone-Bannock Tribe (SBT), in collaboration with the US Fish and Wildlife Service.

Over the years, the ISS has also included the following projects:

1. 1989-098-01, Evaluate Supplementation Studies in Idaho Rivers (USFWS, Clearwater Subbasin)
2. 1989-098-02, Evaluate Salmon Supplementation Studies in Idaho Rivers (NPT, Salmon Subbasin)
3. 1989-098-03, Salmon Supplementation Studies in Idaho (SBT, Salmon Subbasin)
4. 1990-055-00, Steelhead Supplementation Studies in Idaho Rivers (IDFG/IOSC, Clearwater Subbasin)
5. 1996-043-00, Johnson Creek Artificial Propagation Enhancement Project (NPT, Salmon Subbasin)

The ISS was designed to measure the population effects of intentional supplementation on the abundance and productivity (per capita production of progeny) on Chinook salmon, *Oncorhynchus tshawytscha*, during and after supplementation.

The ISRP and ISAB have reviewed the study designs and accomplishments of this set of ISS projects ten times over the past two decades with some of the reviews including multiple response steps ([ISRP 1998-1](#), [ISRP 1999-2](#), [ISRP 2001-12a](#), [ISAB 2003-3](#), [ISRP 2003-8](#), [ISRP 2005-18](#), [ISRP 2006-6](#), [ISRP 2010-10](#), [ISRP 2010-44](#), and [ISAB/ISRP 2016-1](#)). This ongoing review process resulted in constructive discussions about developing and maintaining study designs to ensure the studies' effectiveness.

In the ISRP's last review of the ISS proposal as part of the Review of Biological Opinion Fast Track Research, Monitoring and Evaluation Proposals ([ISRP 2010-10](#)), the ISRP recommended a qualification that it should review draft analysis reports as the ISS comes to conclusion. Instead, the ISRP is reviewing a final report. Because the ISS project is complete and the report is final, the ISRP's comments focus on the appropriateness of the analytical methods used, significance of the study's findings, and scientific aspects of management implications. The ISRP also suggests additional opportunities to use ISS data for potential ad hoc analyses and examines implications for the Council's Fish and Wildlife Program and the Council's Research Plan, which is currently in revision.

This is a very important and valuable study. The questions addressed by the study are pivotal for salmonid restoration and recovery. The study showed how supplementation influenced natural populations in two major Snake River subbasins, the Salmon and Clearwater. The study's extensive geographic scope, use of treatment and reference populations, long duration, comprehensive field data, and analytical approaches have provided managers and policy makers with insights and recommendations on how supplementation should occur and be evaluated throughout the Basin. When the project first began, over 23 years ago, a commonly held belief was that the Salmon and Clearwater subbasins would be capable of producing and supporting greater numbers of spring Chinook if more adults could be introduced into these areas. As the study progressed, this perception changed. In many of the streams examined, it was apparent that salmonid populations were already at or near capacity as density dependence was observed. The study showed that in order for supplementation to be effective, an understanding of the factors that limit a population was needed. Once limiting factors become known, it may become possible to increase capacity and abundance. The ISRP compliments the Idaho Department of Fish and Game and its partners, the Nez Perce and Shoshone-Bannock tribes, and the U.S. Fish and Wildlife Service for their dedication, coordination, and hard work that made this study and its results possible.

ISRP Comments

A. How ISS Results Address Fish Propagation Uncertainties in the Council's 2006 Research Plan

The Idaho Supplementation Study (ISS) was designed to address [Critical Uncertainty number 3](#) in the Council's 2006 Research Plan (see [ISAB/ISRP 2016-1](#)). This uncertainty asked: *"What is the magnitude of any demographic benefit to the production of natural origin juveniles and adults from the natural spawning of hatchery-origin supplementation adults?"* The ISS examined this question by looking at how supplementation affected abundance and productivity at juvenile and adult stages in the life cycle. The ISS took place in the Salmon and Clearwater subbasins, involved 27 streams (13 supplemented and 14 reference streams) and spanned 23 years. The geographic scope, differences in the presence of endemic fish in the broodstocks used, the project's duration, use of reference streams, measurements of abundance and productivity at different life stages, and a post-supplementation evaluation phase meant that the project could address long-standing questions related to supplementation.

Results showed that supplementation increased (a) redd numbers, (b) juvenile emigrants, (c) smolts at Lower Granite Dam, and (d) returning adult progeny. The magnitude of these effects, however, decreased throughout the life cycle, with redds receiving the greatest boost in numbers while adult progeny numbers were the least influenced. The study examined how changes in abundance could be explained by a suite of fixed and random factors. Fixed

factors—such as the ratios of supplementation and non-treatment hatchery females to natural-origin females, number and types of hatchery juveniles released, and occurrence of endemic fish in supplementation broodstocks—were important predictors of abundance during the freshwater portion of the life cycle. Effects that were outside of the Program’s ability to adjust—e.g., hydrosystem and ocean conditions—largely controlled adult returns and outweighed any supplementation effects. A trend of increasing abundance in both supplemented and reference streams occurred during the course of the study. Without reference streams, it would have been impossible to determine how much of an increase in supplemented streams was attributable to supplementation.

Productivity was measured by determining the number of emigrants/redd, smolts/redd, and adults/redd. Unlike abundance, productivity decreased during the study period in both supplemented and reference streams. Natural-origin females returning to supplemented populations in the Salmon River were more productive than supplementation females, who in turn were more productive than non-treatment hatchery females. In the Clearwater subbasin, natural-origin females were also more productive than the other two types of females. In this case though, supplementation and non-treatment hatchery females were found to have similar productivities. In the Salmon subbasin, endemic fish were incorporated into supplementation broodstocks. This proved to be impossible in the Clearwater. Spring Chinook from existing hatchery populations were used in the supplementation broodstocks in the Clearwater subbasin. Differences in broodstock composition between the two subbasins showed the value of integrating locally adapted fish into supplementation broodstocks.

By including an evaluation period that examined the effects of stopping a supplementation program, the ISS was also able to address two enduring questions about the benefits and costs of terminating a supplementation program. One of these questions asks how long any boost in abundance might persist once supplementation stops. A slight increase in adult abundance was seen after supplementation ended in Salmon River populations. In the Clearwater, both abundance and productivity generally returned to pre-supplementation levels. These results indicated that increases in abundance will not continue if factors originally limiting a population are not addressed. Habitat restoration, along with restoring access to previously blocked areas, are two approaches being used in both basins to improve carrying capacities and enhance abundance.

The fact that productivity and abundance generally returned to pre-supplementation levels after supplementation ceased, helped answer a portion of Critical Uncertainty #4¹ in the Council’s 2006 Research Plan. That is, does the ability of natural-origin adults to produce adult offspring decrease when returning to streams that have been exposed to supplementation

¹ Critical Uncertainty #4 in the 2006 Research Plan asks “What are the range, magnitude, and rates of change of natural spawning fitness of integrated (supplemented) populations, and how are these related to management rules, including the proportion of hatchery fish permitted on the spawning grounds, the broodstock mining rate, and the proportion of natural origin adults in the hatchery broodstock?” See <http://research.nwcouncil.org/researchQuestions>.

programs? At least in this study, no lasting reductions in abundance or productivity were detected for Chinook salmon. This is an important management finding because it implies that supplementation can occur in a population without incurring lasting reductions in fitness.

In conclusion, the ISS program provided information that has helped address Artificial Propagation Uncertainties numbers 3 and 4 in the Council's 2006 Research Plan. The management recommendations included in the study's final report are thoughtful and should be considered when future supplementation programs are being developed and implemented. Results from the ISS are also certain to stimulate discussions on broader policy questions related to supplementation actions. For instance, when should supplementation be initiated or stopped? How many resources—e.g., money, fish, effort—should be allocated to supplementation, and when does supplementation contribute to recovery and mitigation goals? Although the ISS was not designed to answer such wide-ranging policy questions, results from the study would certainly be germane to policy level discussions about the continued and future use of supplementation as a fisheries management and recovery tool.

B. Analytical Methods

Was the ISS's analytical approach sound, specifically use of the linear-mixed model?

The ISS provided a nice balance between data acquisition and analysis. The analytical approach was thorough, documented clearly, and seems appropriate. Over the duration of the study, several important analytical changes were made that reflected suggestions by the ISRP and ISAB in previous reviews. First, stocking of juvenile hatchery fish was originally considered to be the best way to represent supplementation treatments. That was changed to the number of returning and spawning adults originating from hatchery juveniles. Second, in earlier reports "total adult returns"—natural origin recruits (NORs) plus hatchery adults—was often used as the primary response variable. In that case, adult hatchery returns could replace natural fish, and supplementation could still be regarded as having a positive demographic effect. The primary response variable of interest, however, is the number of natural-origin adults returning in the generation following supplementation. In the completion report, this metric was adopted as the primary response variable when supplementation was appraised.

Some unavoidable issues with implementation caused the number of treatments and reference populations to be unbalanced and resulted in smaller than expected sample sizes. Even so, the experimental design proved robust and powerful enough to allow meaningful inferences about the benefits of supplementation, despite high variability in the responses among individual populations. A concern that is mentioned but not addressed in any detail is if the results might have been biased by the fact that treatment streams were selected from a set of streams that had a previous history of hatchery releases, and that hatchery releases were not randomly located. Rather hatcheries were typically located close to the most productive streams. In other words, might results have been different if the treatment and reference streams had been

selected randomly? This issue is one the ISS team may want to address when results are published in the peer-reviewed literature.

Another issue that warrants further discussion is the project's assessments of productivity. Three measures of productivity—redds/female, smolts/female, and adult progeny/female—are compared among natural-origin, supplementation, and non-treatment hatchery fish. Although these comparisons are informative, we suggest that the authors also attempt to standardize productivity by estimating intrinsic productivity using recruitment relationships (i.e., productivity in the absence of density dependence). This metric has been suggested as an indicator of fitness change (ISRP/ISAB 2005-15). Currently, the report discusses Relative Reproductive Success (RRS) and Proportionate Natural Influence (PNI) as it relates to supplementation, but additional discussion and interpretation of fitness changes in ISS streams due to supplementation would be a valuable addition. Finally, Appendix B in the Completion Report shows the statistical ranking (AICc) scores for models that were developed to examine basin level changes in abundance and productivity. The independent variables in the models were not identified. A simple table could be added when the results are published. Additional comments on the statistical methods used in the study are presented in an appendix at end of our review.

C. ISS Key Findings and Management Recommendations

The nine ISS key findings and management recommendations listed below are from the ISS's Completion Report, pages 73-75. ISRP comments on the management recommendations developed by the ISS are shown directly below each Key Finding.

- 1. ISS Key Finding:** *When supplementation females were added to the stream, there was an increase in the number of redds, emigrants at RST [rotary screw traps], and smolts at LGR [Lower Granite Dam] but the slope of that relationship decreased as supplementation ratio increased. Productivity declined as abundance increased, which affected success of supplementation and was evident in populations in the Clearwater and Salmon basins. We conclude that implementing supplementation by simply putting fish over the weir (as done in ISS) may have a diminishing effect as abundances increase and that supplementation and especially non-treatment hatchery fish may exacerbate productivity declines at above-average returns.*

Management Recommendations: **1.1)** *Supplementation rate should be based on risk of population failure. 1.2)* *Scale supplementation rate back as the abundance of natural-origin adult progeny increases, and define the population size where supplementation for conservation is no longer needed. 1.3)* *To address goals of maintaining population smolt at LGR production, use a hierarchical modelling approach to establish population-specific supplementation prescriptions. 1.4)* *At higher abundances, there is an opportunity to seed available habitat optimally. Target releases to under-seeded reaches using the most appropriate life stage (e.g., adult or smolt) from the integrated broodstock.*

1.1:

The ISRP agrees in principle that supplementation rates (percentage of hatchery-origin female spawners allowed to spawn in nature or pHOS) should be based on the likelihood of population failure. Co-managers, however, will need to establish guidance on what pHOS percentages should be. The recent Density Dependence report by the ISAB (ISAB 2015-1), for instance, advises that supplementation should be scaled back or adults harvested when total spawners exceed equilibrium and recruits per spawner are less than one ($R/S < 1$). This helps reduce pHOS and increases PNI and therefore is expected to help integrated populations adapt to natural conditions.

At least two things will need to be in place before this recommendation can be implemented. First, the identity of adult salmon allowed to spawn naturally has to be discernible in a non-lethal fashion via tags or marks. Second, entrance of supplementation and natural origin adults (NORs) into spawning areas will need to be regulated. Mixtures of hatchery and natural origin spawners expected to provide maximum conservation benefits can be created and allowed to spawn naturally when such control is exerted. Other challenges also exist such as the importance of ensuring that hatchery fish will spawn at appropriate times and locations and that they possess suitable genetic backgrounds to supplement targeted natural populations.

1.2:

The ISRP agrees with this recommendation. It is not simply the proportion of hatchery and natural origin adults allowed to spawn that is important. Their total abundance must also be considered. This recommendation indirectly addresses that issue by establishing that spawning abundance targets for populations undergoing supplementation are needed. Controlling the number and timing of adults entering a population helps reduce density dependence effects and thereby provides a mechanism for increasing the productivity of naturally spawning fish under existing habitat conditions. It also makes sense to reduce the proportion of hatchery adults placed into a population once the spawning population approaches the equilibrium point and R/S begins to decline below 1. Adults produced from hatchery juveniles released into supplemented streams have demonstrated an ability to survive from release to adults but have not undergone the natural selection that natural origin adults experienced while in the gravel and during early juvenile rearing. Exposure to these additional mortality factors has likely made natural origin spawners and their offspring better adapted to conditions in natal spawning and rearing areas.

1.3:

This recommendation is unclear. We interpreted it to mean that estimating abundance and productivity at discrete points in the life cycle will help refine how supplementation should proceed in the future. If our interpretation is correct, we agree that such a methodology is a valuable way to ascertain the factors that limit a population's capacity to produce smolts at LGR. It helps to identify where major sources of mortality or decreases in productivity are occurring during spawning and early juvenile life. Once limiting factors are identified, approaches to reduce their impacts can be proposed and evaluated on a population-by-population basis.

1.4:

The ISRP generally agrees that supplementation adults, or juveniles produced from them, could be used to seed newly opened, restored, or under-seeded habitat. Ideally, natural origin adults would also be simultaneously introduced into such areas at established supplementation ratios if adult supplementation fish are being used. That may not always be possible, and in some years it is likely that the proportion of supplementation adults in certain areas may be higher than desired. Adhering to recommendation 1.2 will reduce that concern. Consequently, taking advantage of abundant returns of supplementation adults produced from integrated broodstocks to help with conservation makes sense as long as the underlying factors that previously limited population growth are being addressed.

2. **ISS Key Finding:** *Natural-origin females had the largest effect on population abundance followed by supplementation and then non-treatment hatchery females. We conclude population increases are more effectively generated by increasing the number of natural origin fish followed by integrated supplementation fish.*

Management Recommendations: **2.1)** *When passing fish over weirs, work in order of effectiveness: natural-origin > supplementation > non-treatment hatchery. 2.2)* *Use integrated broodstocks to reduce undesirable hatchery impacts on natural populations while maintaining potential benefits. 2.3)* *Mark integrated broodstock juveniles in a manner that enables use for either harvest or conservation, depending on annual need. 2.4)* *The literature shows hatchery males often have lower reproductive success than hatchery females. If this effect is heritable then passing males incurs risk without benefit; therefore, supplement with females first and rely primarily on natural-origin males for fertilization.*

2.1:

Results produced from the ISS study support the hypothesis that natural origin females are more productive than supplementation and non-treatment hatchery females. When abundances of natural origin females are great enough to fully seed a population and meet hatchery broodstock needs, then we concur, that non-treatment hatchery and supplementation origin females could be removed to increase the percentage of natural origin females on spawning grounds. However, for each stream being supplemented there needs to be an updatable management plan that considers demographic and genetic factors in both the hatchery and natural spawning portions of an integrated population. For example, passing more natural origin adults onto the spawning grounds must be balanced with the potential need to incorporate them into the integrated broodstock.

2.2:

Extensive literature and the results of this report substantiate the importance of using local fish to create integrated broodstocks for supplementation programs.

2.3:

The ISRP agrees that providing a non-lethal way of identifying hatchery origin supplementation adults is critical for the reasons given above.

2.4:

This recommendation is based on the premise that hatchery males may possess heritable traits that make them less capable of reproducing in nature. Therefore, it is concluded their use as naturally spawning fish should be limited as they may pass on domestication effects to their offspring. The risk of passing on domestication effects through hatchery males and females depends upon the number of generations their ancestors have experienced non-natural selection regimes in hatcheries. Greater generational exposure is expected to increase the likelihood of genetic change and adaptation to hatchery conditions. Work by Waters et al. (2015) has also shown that genetic changes in Chinook salmon supplementation populations can be minimal after three generations of hatchery exposure if broodstocks consist entirely of natural origin adults. If this practice is carried out, the potential genetic benefits (larger effective size) from first and second generation hatchery males may be greater than the genetic risks they possess. At present, this is an unresolved question, one that would benefit from future field research and modeling.

3. **ISS Key Finding:** *We found evidence that releasing more juveniles resulted in more returning adults and this effect was greater for smolt releases. We conclude that releasing smolts is the most efficient way to produce adults with which to supplement.*
Management Recommendation: 3.1) *Use smolt releases scaled to produce sufficient adult returns for treatment and to maintain the broodstock. The literature also suggests that juveniles released as smolts should have fewer competitive interactions with natural-origin juveniles during rearing.*

3.1:

Data presented in the summary report indicate that releasing smolts, as opposed to pre-smolts, provides the greatest return of adults back to supplemented populations. It is acknowledged that this finding could have been influenced by the origin of the released juveniles as well as their life stage (endemic smolts vs. non-endemic pre-smolts). Nevertheless, we agree that releases of supplementation smolts are the most productive in terms of producing adult recruits. We also agree that interactions between these fish and naturally produced conspecific juveniles, in supplemented streams, are likely less than what would be expected if the fish were released at a smaller size and earlier stage of development.

However, the recommendation to release smolts to reduce competitive interactions with natural origin fish does not take into account the likelihood of greater genetic changes in hatchery smolts than in hatchery parr due to a longer period of exposure to hatchery conditions. Thus, adverse fitness consequences of subsequent interbreeding between hatchery and natural origin fish might be greater for hatchery fish released at the smolt stage than those released at younger life stages. In the long term, the potential consequence for fitness in the natural environment might offset or outweigh any short term advantage from reducing

ecological interactions between hatchery and natural origin parr. Consequently, we suggest that the life stage at release for hatchery juveniles not be entirely fixed at smolting. Instead, if circumstances (e.g. opening of new habitat) within a supplemented stream can accommodate parr and pre-smolt releases, these could also occur. Releasing juveniles at younger ages may provide opportunities to produce adults with traits that may be better adapted to the natural environment.

4. **ISS Key Finding:** *Natural-origin populations in Clearwater streams are from localized and non-endemic stocks, and these populations continue to see high levels of hatchery fish on the spawning grounds. However, natural-origin females had a greater effect on population abundance measures than supplementation or non-treatment females. Based on the relative effectiveness of the natural origin females, we conclude that there is potential for natural- and hatchery-origin fish to adapt to the Clearwater basin.*
- Management Recommendations:** **4.1)** *Develop local broodstock if possible. 4.2)* *Minimize influence of broodstock from non-endemic stocks or out-of-basin transfers to allow the population to adapt to the basin of release thereby reducing the effects of incidental straying. 4.3)* *Conduct a local adaptation experiment to investigate population recovery from the influx of segregated hatchery fish with a different fitness optimum, and to examine the long-term genetic effects of supplementation.*

4.1:

In salmonids, maturation timing, age at maturation, egg sizes, body shapes, energy reserves, and other traits have all been shaped by previous selection regimes. Consequently, developing local origin broodstocks for supplementation purposes is critically important. By doing so, a conservation program will produce fish that are pre-adapted for the populations they are designed to supplement.

4.2:

We agree that in almost all cases non-endemic fish should not be incorporated into supplementation broodstocks. An exception might be to relieve inbreeding depression. Non-endemic fish will likely possess genetic traits that are not well suited for a new environmental regime. Outcomes reported from the Clearwater River supplementation streams confirm this conclusion and have implications for many of the reintroduction/supplementation projects occurring in the Columbia River basin—coho, Chinook, and sockeye. Many of the coho programs and Chinook programs include provisions to import eggs, fry, or smolts from non-local regions if local production is insufficient to maintain a program at some specified smolt or adult production level. The ISRP has repeatedly cautioned that there is a lack of empirical support for using non-endemic fish in broodstocks. Continuing to import non-local stock may slow down the rate of eventual “re-adaptation” to a watershed, as in the Yankee Fork of the Salmon watershed or the Walla Walla in the Columbia. The observations in the Clearwater suggest that using non-endemic broodstock may be detrimental to program progress in both the short- and long-term.

4.3:

We agree that more experiments on local adaptation would be valuable. In many situations, abundance levels of natural origin adults may be so low that mining a population for broodstock would be problematic, while at the same time adjacent, segregated hatchery populations might be available. An important and, to our knowledge, unanswered question, is how rapidly hatchery-adapted populations can acquire traits suitable for natural populations. Such a study would help determine how quickly cultured salmonids can revert to wild-type fish.

5. **ISS Key Finding:** *Non-treatment hatchery fish had negative effects on population productivity across all phases. We conclude that dedicated, intentional supplementation broodstock should be emphasized for spawning in supplemented streams, and non-treatment hatchery fish used in emergencies.*

Management Recommendations: 5.1) *Establish better control of escapement of hatchery fish into natural spawning areas through harvest, release strategy, and weirs.*

5.2) *Continue carcass collections to assess the influence of non-treatment hatchery fish on the spawning ground.*

5.1:

Results from this study support the idea of controlling the types and abundance of fish allowed to escape and spawn in supplemented populations. In both the Salmon and Clearwater subbasins, natural origin females were more productive than supplementation females who, in turn, were more productive than non-treatment hatchery females. Using management tools such as selective fisheries and weirs along with regulating the numbers, types, and locations of where hatchery juveniles are released to influence the composition of spawning populations is a forward looking strategy. It also provides opportunities to evaluate the effect of different PNI levels and the usefulness of the PNI concept in conservation efforts.

5.2:

Carcass surveys can potentially provide information on the abundance and ratios of natural-origin to supplementation and non-treatment hatchery fish. Opportunities to obtain a suite of trait data (e.g. length, spawn timing, spawning locations, age composition by sex, treatment origins, parent origins, etc.) also become possible. Thus, we agree that carcass surveys should be routinely employed in supplementation and reference populations. Yet at the same time, potential biases in the types of fish being recovered and sampled may occur. The likelihood of carcass retrieval can be affected by fish morphology and behavior. Carcasses of females and larger fish, for instance, may be easier to collect than those of males and smaller fish. Stream features can also affect the types of carcasses that are typically recovered. Such biases will need to be evaluated and considered when estimates of abundance and the types of fish spawning in a sampled stream are made.

6. **ISS Key Finding:** *Multiple reference streams in both basins were critical for detection of supplementation effects across phases. Supplementation effects would be difficult to interpret without a life cycle approach. We conclude that these aspects need to be incorporated into the monitoring and adaptive management of any supplementation program.*

Management Recommendations: 6.1) *Juvenile, hydrosystem, and adult monitoring should be fundamental components of adaptively managing supplementation programs. The following data should be collected in all supplemented streams and a suite of reference streams: spawner abundance, spawner composition (age, sex, and origin), juvenile emigrant abundance, and smolt survival estimates to LGR. 6.2)* *Evaluations of supplementation programs require reference streams across a range of intrinsic productivities to separate treatment effects versus stream and out-of-basin effects. Maintain monitoring in selected natural-origin production areas in the Salmon and Clearwater basins.*

6.1:

Assessing the effects of supplementation efforts at different life stages helps determine where limiting factors associated with supplementation may exist. It may also identify approaches that are successful at increasing abundance and productivity. Consequently, collecting the types of adult and juvenile data suggested above, in both supplemented and reference streams, is important and should occur when supplementation is being used for conservation purposes.

6.2:

Information gathered in reference and supplemented streams make it possible to quantify changes in abundance and productivity caused by supplementation. Data from reference streams are thus pivotal when supplementation is being evaluated. Without such material, it becomes impossible to partition the demographic effects of environmental factors within and outside of the Basin from those originating from supplementation. Indeed, this study nicely demonstrates the difficulty of detecting ecological effects in the face of many uncontrolled factors and high natural variability, and the importance of a strong experimental design with adequate spatial and temporal scale.

In addition to management recommendations 6.1 and 6.2, we suggest two additional recommendations: First, the evaluation of juvenile length at known ages should be conducted so that density effects on growth can be evaluated. Second, the monitoring of adults' origin (natural, integrated hatchery, segregated hatchery) should be continued. The ISS program has developed a valuable dataset that spans over two decades. The ISRP strongly recommends continuation of the monitoring and evaluation effort.

7. **ISS Key Findings:** *Relative reproductive success (RRS) studies rarely link genetic information to demography. Samples are in hand from the upper Salmon and South Fork Salmon rivers. We conclude these legacy samples offer a unique opportunity to conduct RRS evaluations to better understand genetic risks of supplementation fish and link those results to the demographic data collected in this study.*

Management Recommendation: 7.1) Secure funding to perform adult-to-adult RRS analyses on samples from these locations. **7.2)** Use results to provide a baseline to guide integrated brood programs and future investigations.

7.1:

We agree that such a study would be a valuable addition to the RRS literature. Given that samples are at hand and that genetic processing costs are decreasing, we encourage the ISS team to pursue funding to process and analyze these samples. If this study is conducted, efforts should be made to determine the mechanisms behind any detected differences. For instance, were they caused by dissimilarities in spawning locations, spawning dates, age and size at maturation and so on?

7.2:

We agree that results from the study could be used to help guide future integrated supplementation programs.

8. **ISS Key Finding:** *It was difficult to produce broodstocks during Phase 1, a time period that corresponded with low adult returns. We conclude that proactive creation of supplementation broodstocks would lead to quicker responses to conservation crises.*
Management Recommendation: 8.1) *Supplementation broodstocks should be created for appropriate populations before potential crises arise. Identify populations where supplementation is appropriate and initiate an integrated broodstock program before needed for conservation.*

8.1:

A number of questions will need to be answered before this recommendation can be implemented. Among these are, what species are being considered? Would this approach be restricted to summer/spring Chinook, or will fall Chinook, sockeye, steelhead, and possibly coho also be considered as target species? Hatchery infrastructure (water and rearing space) will be needed. Given that resources are limited, what factors will be considered when prioritizing which populations might be regarded as supplementation candidates? There may also be some risks associated with establishing potential supplementation broodstocks. For example, thought will have to be given to possible domestication effects caused by multiple generational exposures to hatchery conditions. Consequently, the ISRP found this to be a problematic management recommendation. In some circumstances, the risk of domestication and the utilization of hatchery infrastructure may outweigh any potential benefits this recommendation could provide. At the same time, we acknowledge that this approach may be appropriate in some situations, such as when a population is facing extirpation. In that case, initiating a broodstock program would help ensure the conservation of important genetic variation and would be an important source of fish once supplementation was initiated.

9. **ISS Key Finding:** *Project, hatchery, and other management activities were often not well coordinated. This led to inconsistent supplementation ratios, lost data collection opportunities, and increased analytical difficulty. We conclude regular coordination is needed for supplementation monitoring and evaluation to be efficient.*

Management Recommendation: 9.1) *Ensure collaboration among research, hatchery, management, and habitat restoration disciplines in all phases of design, implementation, and evaluation to achieve overall program goals.*

9.1:

The types of collaboration and communication recommended here are essential and will help ensure that project goals and objectives are successfully met. The region also needs to continue to establish management processes that integrate findings from multiple studies, establish consensus on the management implications of findings, and then codify those into the Council's Fish and Wildlife Program scientific foundation and strategies.

D. ISRP Suggested Key Findings, Post Hoc Analyses, and Future RME

1. *Does the ISRP identify any other key findings or science-based management recommendations that the ISS results indicate but are not identified in the ISS report?*
 - A) Results produced by the study show that, for systems this far upstream in the Columbia Basin, "out-of-basin" effects (e.g., down river tributary, mainstem, the hydrosystem, estuary, and ocean, including harvest and mortality factors outside the Columbia) make it very difficult to observe responses to supplementation reliably in just one system. The life cycle approach taken by the study is needed, but even then, there remain numerous places where losses and measurement errors can obscure actual effects of supplementation. Given the population responses to supplementation observed in this long-term study, it might be a useful exercise to see how measurement errors propagating through life cycle models and metrics can obscure results. Therefore, research should assess how large of a response is needed to be measurable.
 - B) A key message from this study is that habitat restoration is needed to increase productivity and carrying capacity so that abundance generated through supplementation can be sustained. The report noted the possible confounding effects of density dependence versus hatchery domestication on salmon productivity. We encourage the investigators to collect and analyze juvenile length-at-age data in relation to parent abundances as a means to further evaluate effects of density dependence versus potential fitness related factors.
 - C) What proportion of the natural origin adults are produced from fry, and summer parr emigrants vs. smolts? Can adult otoliths be used to identify the frequency of these juvenile emigration strategies on adult returns? Recent studies in California found that high percentages of adult Chinook returns originated from fry migrants (Miller et al. 2010; Sturrock et al. 2015). If few adults originate from fry and parr emigrants it may indicate that these typical juvenile life histories are being constrained by downstream habitat issues.

D) This study depended heavily on opportunities to mark fish so that natural origin, hatchery origin and non-treatment hatchery origin fish could be distinguished and enumerated separately. It is worth emphasizing this requirement in order to get the most value in terms of adaptive management from other routine monitoring of outcomes from supplementation activities in the Columbia Basin.

2. *Can other useful analyses be conducted with data collected from ISS? Proportionate natural influence (PNI)?*

A) Most of the confidence intervals around point estimates for treatment effects overlapped zero, implying that there was little evidence for treatment effects. Nevertheless, the patterns in point estimates, replicated across basins or treatments, were often consistent and encouraged inferences about the overall direction of effects. We suspect there might be a more rigorous way to examine aggregate patterns in sets of related point estimates whose individual confidence intervals overlap zero. As it stands, the reader is left to draw these comparisons by visual inspection of the report's nicely presented plots.

B) Different ratios of wild and supplementation females were used to create supplementation broodstocks and mixtures on natural spawning grounds. These data could be used to calculate PNI values. The influence of varying PNI values on subsequent productivity at juvenile and adult stages could be examined.

C) The study indicated that natural origin females were more productive than supplementation and non-treatment hatchery females. Why? Previous investigations have shown that spawn timing, spawning locations, and differences in body size have reduced productivity in hatchery-origin females. Data collected on adults and during redd and carcass surveys may make it possible to tease out why productivity differences were influenced by female origin.

D) Previous research has indicated that strays can reduce the productivity of natural populations. Would it be possible to use existing data to determine how the proportion of a spawning population comprised of strays affected the productivity of natural origin females?

E) It is unclear how the numbers and mixtures of fish spawning in supplemented streams were produced. Were weirs, beach seines, purse seines, or other sampling gear used? If so, would it be possible to examine how exposure to sampling gear affected the productivity of natural-origin, supplemented, and non-treatment hatchery females?

F) The report mentions that additional relative reproductive success studies could be conducted using archived samples. If possible, these studies should be carried out. See recommendation 7.2.

- G) Did habitat restoration, including opening of previously blocked areas, occur in supplemented and reference streams? If so, how did these actions affect the metrics used to assess productivity in freshwater (e.g., emigrants/redd and smolts/redd)?
3. *What new research and hypothesis do the ISS findings raise, for example, the RRS identified under ISS Key Finding 7?*
- A) The report recommends the smolt release strategy, but the parr release strategy was typically used in the Clearwater Basin because of logistical reasons. It would be interesting to consider further if the parr release strategy might in fact be more appropriate than the smolt release strategy for non-endemic broodstock when the primary objective is to promote local adaptation. Release at the parr stage is expected to offer more opportunities for natural selection of appropriate rearing and homing behaviors that could improve the fitness of survivors to reproduce naturally in a new environment.
- B) Conduct a long-term experiment to evaluate the potential benefit to salmon and the ecosystem of allowing excess spawners into streams. Compare productivity and abundance values obtained from those basins to those where spawner numbers were near the equilibrium point (i.e. where $R/S = 1$).

Appendix: Review of Statistical Methods in the ISS

The analytical methods employed were fairly standard, applying information theoretic methods such as AICc to rank a candidate set of models, compute model weights, and compute model averaged estimates of effects. Because the models have both fixed and random effects, maximum likelihood was first used to fit the model and determine AIC scores and related quantities. Once the models were ranked they were refit using Restricted Maximum Likelihood (REML) to obtain the parameter estimates prior to model averaging. This two-step procedure was used because of the well-known tendency of maximum likelihood to underestimate variances² which, if uncorrected, would lead to estimates with reported standard errors that are too small, and reported confidence intervals that are too narrow, which could result in false positives (i.e., the reported confidence interval would not cover zero implying a strong effect).

The authors reported that model diagnostics were evaluated for all models (page 24) and found no assumption violations, but no information was presented.

Two issues that need some clarification and further work in the Basin wide analyses are: (a) The candidate set of models (e.g., Tables 3 and 4) represent special cases of the most general model when certain terms are assumed to have the value of 0. It does not appear that the ISS team evaluated a model where there was no effect in Phase 2 but there was an effect in Phase 3. The scenario is similar to the right-most column in Figure 4 where the lines are parallel in Phase 1 and Phase 2, but then diverge in Phase 3. It was not clear why this model was not included, with the two variants for the presence/absence of the “non-treatment effect.”

Similarly, a model was not included where there was a supplementation effect in Phase 2, but then no change in Phase 3 (i.e., a permanent increase after supplementation similar to the bottom curve on the left column of Figure 4 which differs from the top figure in the same row). It is not clear how the model in the lower left corner of Figure 4 can be obtained from the effects shown on Figure 3. The study needs a model where the upper right term in Figure 3 is:

$$m + b_2 + b_3 + b_4$$

This would require additional models to be added to their candidate sets for all the response variables, but the basic analysis flow would be identical as shown in the report. Perhaps the authors thought these models were not biologically reasonable and so did not include them. If so, this should be explicitly stated.

² An example of this tendency is that the maximum likelihood estimate of the variance is computed by dividing by n (the total sample size) rather than $n-1$ is biased downwards. The REML estimator estimates the variance using the $n-1$ divisor and so is unbiased. If the ML estimate of the variance was used in computing a standard error and confidence interval, both would be biased downwards.

(b) In their base model (Equation 1.1), which is diagrammed in their Figure 3 (reproduced in Figure R1 here), the mean response variable has been made equal in Phase 1. Perhaps this was done because the standard BACI model needs to estimate four parameters. The four separate means in the combination of the phase (I and II) and site class (treatment vs reference), but the ISS Figure 3 shows that only 3 means were estimated because they forced the means to be equal in Phase 1. This is, however, unnecessary. In ISRP-2003-8, the effect of supplementation was examined vis the treatment:time interaction term, where “time” is Phase 1 vs Phase 2. This is the classical BACI analysis and does not assume that the means are the same in Phase 1 between treatment and reference streams. Also consider a general Before-After-Control-Impact (BACI) analysis for comparing the mean in Phase 1 and Phase 2 in control and reference streams. Possible patterns for the means are shown in Figure R2. An impact is detected if there is a non-parallel response in the means. It is not necessary that the control and impact sites have the same mean in the before period as assumed in the ISS model.

The standard BACI model with a “fixed impact” with multiple sites (streams) and multiple years in the before and after periods (phases) is (in a standard short hand notation):

$$Y = Phase + Class + Phase : Class + Site(r) + Time(r) + Site : Time(r)$$

where *Phase* represents the change in mean between the before/after phases; *Class* represents the difference in means between control and impact classes of streams in the initial phase (the potential difference seen in Figures R1(b, d, e)); *Phase:Class* is the interaction effect between period and class and represents the differential change (i.e., the non-parallelism seen in Figures R1(c, d, e); the *Site(r)*, *Time(r)*, and *Site:Time(r)* are random effects of streams, time, and unexplained error corresponding to the random effects given the ISS Equation 1.1.³ This interaction term (known as the BACI effect) would represent the effect of the treatment and if the (model averaged) confidence interval for the BACI effect excluded 0, there would be evidence of a treatment effect.

There is an obscure note on Figure 15 and Figure 17: “*The baseline difference between reference and supplemented streams is removed from each phase estimate, resulting in Phase 1 being equal for both stream types.*” However, there is no information on how this was accomplished in the document. Any term to do this does not appear in Equation 1.1—normally, you would add a term in the model to account for this initial difference. Perhaps some initial data normalization was conducted to force the means in Phase 1 to be the same in the reference and treatment streams? If the streams had been assigned at random to treatment and reference, then you could argue that the randomization procedures would ensure that on average the means would be equal in Phase 1. However, on page 15, it is stated that: “*Streams were designated as supplemented or reference based on logistical and biological considerations and status was not randomly assigned.*” Consequently, the equality due to randomization should not be assumed.

³ The ISS model subdivides the stream random effects into a group effect and the streams within the group’s effect, but the overall effect is identical compared to estimating a simple stream effect.

The ISS model equation (1.1) uses the $\log(\text{number of supplemental adult females})$ as the treatment effect rather than a simple indicator for supplemented or not supplemented. This simple indicator variable could form additional models in the model set, but presumably, the model diagnostic plots show that such models would not be suitable. However, this does not change the comments above.

What is the impact of these two concerns? The impact of missing some models will not change the relative ranking of the current models. If the missing models have only small support, then the model averaging will not change much either. If, however, the missing models have strong support, then they could change the model averaged estimates.

The impact of forcing the treatment and reference streams to have the same mean in Phase 1 could go in either direction (i.e., increasing or decreasing the estimated supplementation effects) depending on the magnitude of the initial differences in the mean. Some indication of potential effect may be found by comparing Figures 10, 12, 14, 16 (raw data) to Figure 15 (estimated means from the model).

For example, on the left panel of Figure 10 (Clearwater River), the mean redd counts in Phase 1 may be close, but the right panel (Salmon River) show the means may be quite unequal. Compare the right panel of Figure 10 to the second panel in the top row for Figure 15. The right panel in Figure 10 would appear to show a slight increase in mean redd counts between Phase 1 and Phase 2 for reference streams and a larger increase in mean redd counts for supplemented streams. Yet, the second panel in the top row of Figure 10, shows a decrease in mean $\log(\text{redd counts})$ from Phase 1 to Phase 2. This would be consistent with the model forcing the means in Phase 1 and Phase 2 being equal. (A direct comparison is not possible because of averaging over multiple years and the non-linear averaging of \log vs. raw values, but the faint red lines in the panel in Figure 10 also show most red redd counts increasing between Phase 1 and Phase 2).

There are no concerns about the intensive analyses (Model equation 1.2 and 1.3). Both of these models are regression models with random effects for streams, time, and unexplained variation.

Other Notes:

p.25. Because of the presence of random effect of stream and year, the estimated means in the BACI model must be estimated assuming a value of 0 for the stream or year effect, i.e., at the average stream and average year. This has no impact on the estimate of the effect size as both the stream and year effects simply shift the resulting curves up or down with no change in the non-parallelism. For fixed-effect covariates (such as number of supplemental fish allowed to pass), some value of the covariate must be chosen. Again, the actual value is not that important because different values of the covariates will again simply shift the curves up or down and not affect the non-parallelism. Traditionally fixed-effect covariates are set to their mean value.

p.25. The ISS used an arcsine-square root transform on the proportion of non-treatment hatchery fish (the S_{it}) term to “normalize the predictor.” This is unnecessary (predictors don't need to have a normal distribution—contrast in the predictor is much more important) and the arcsine-transformation won't do this either. Refer to Warton and Hui (2011).

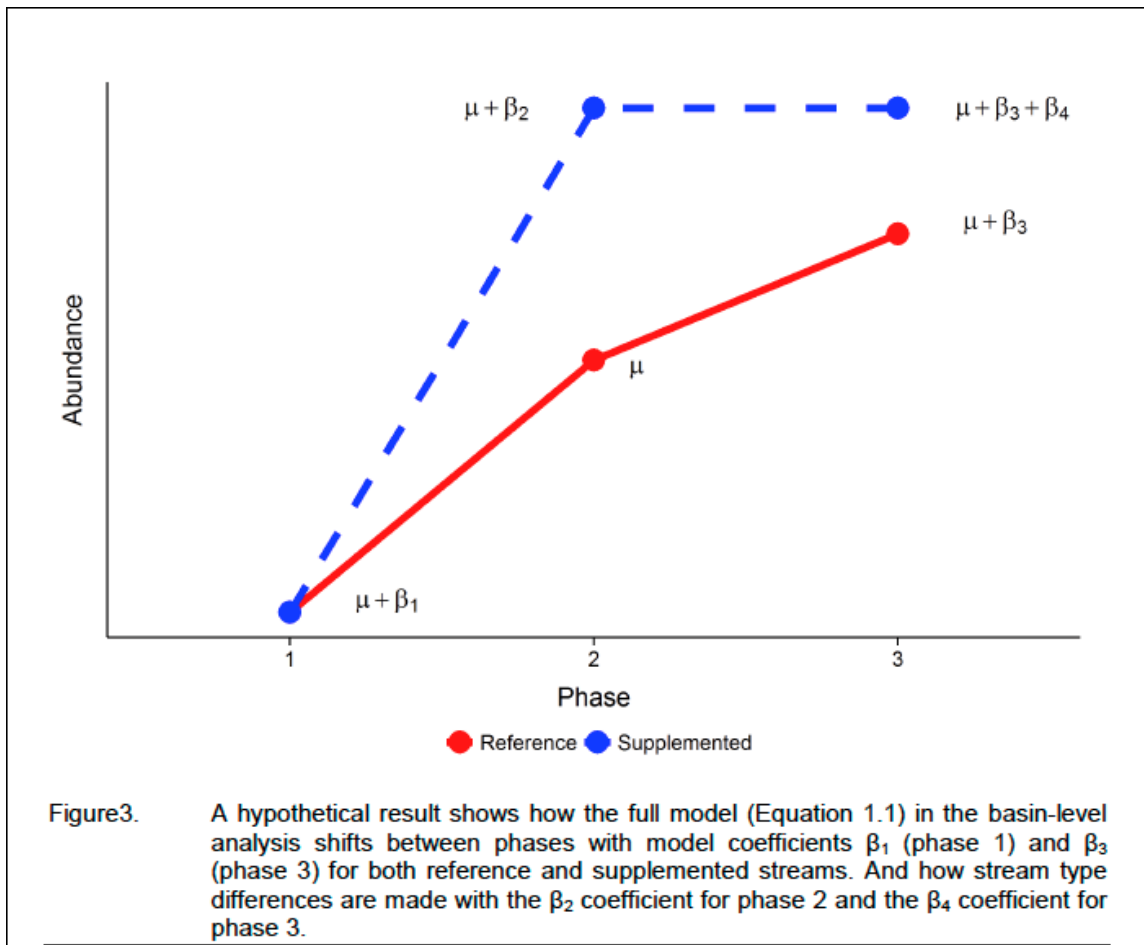


Figure R1. The conceptual model in the ISS.

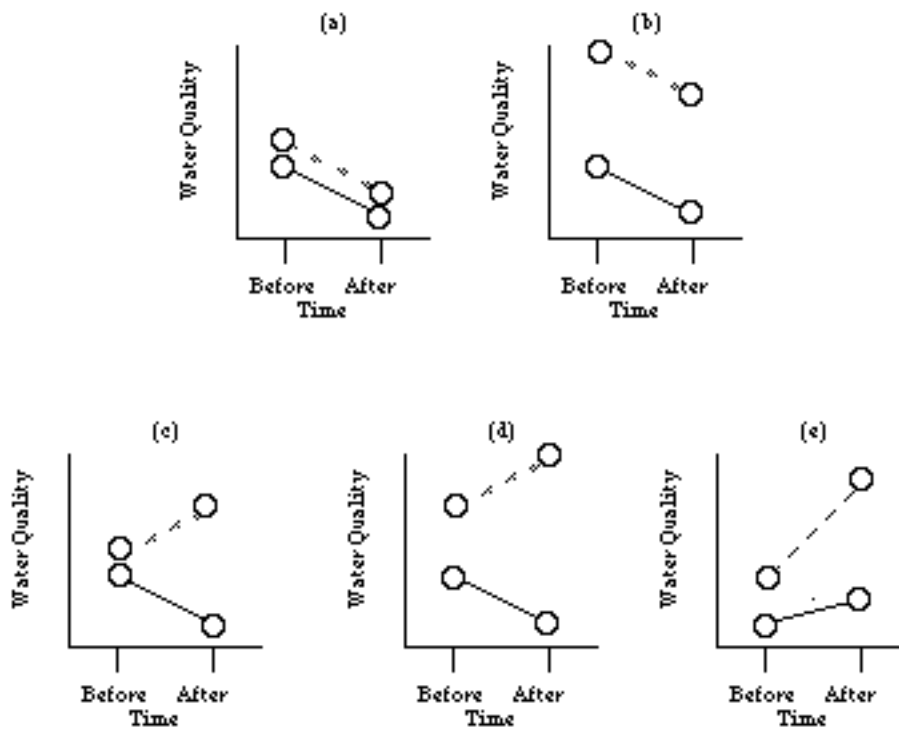


Figure R2. Conceptual BACI results with control (solid) and impact (dashed) sites measured before and after impact occurs (only in the treatment sites). Figures (a) and (b) show no impact, i.e. the control and response sites respond in parallel. Figures (c), (d), and (e) all demonstrate impact—the non-parallelism is what indicates an effect, regardless if both sites start at the same mean in the before period.

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