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SHOSHONE BANNOCK TRIBES OF THE FORT HALL RESERVATION
IDAHO

IDAHO SUPPLEMENTATION STUDIES
Project Completion Report 1991–2014

December 2015
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Idaho Supplementation Studies
Project Completion Report
1991 – 2014

By

David A. Venditti, Idaho Department of Fish and Game
Ryan N. Kinzer, Nez Perce Tribe
Kimberly A. Apperson, Idaho Department of Fish and Game
Bruce Barnett, Idaho Department of Fish and Game
Matthew Belnap, Idaho Department of Fish and Game
Timothy Copeland, Idaho Department of Fish and Game
Matthew P. Corsi, Idaho Department of Fish and Game
W. Tyler Gross, Idaho Department of Fish and Game
Laurie Janssen, Idaho Department of Fish and Game
Ryan Santo, Nez Perce Tribe
Kurt Tardy, Shoshone-Bannock Tribes
Angelo Teton, Shoshone-Bannock Tribes

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

Shoshone-Bannock Tribe
Fisheries Department
P.O. Box 306
Fort Hall, ID 83203

Nez Perce Tribe
Department of Fisheries Resources Management
125 S. Mission
McCall, ID 83638

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ABBREVIATIONS AND ACRONYMS

Acronym	Definition	Acronym	Definition
AIC_c	modified Akaike Information Criterion	non-treatment hatchery	Fish found in study streams originating from other populations (i.e., general production hatchery or supplementation fish released elsewhere)
BY	Brood Year	NPT	Nez Perce Tribe
BPA	Bonneville Power Administration	PIT	Passive Integrated Transponder
ESA	Endangered Species Act	PNI	Proportionate Natural Influence
GPS	Global Positioning System	PTAGIS	PIT Tag Information System
IDFG	Idaho Department of Fish and Game	R	Reference stream
ISAB	Independent Scientific Advisory Board	REML	Restricted Maximum Likelihood
ISRP	Independent Scientific Review Panel	RRS	Relative Reproductive Success
ISS	Idaho Supplementation Studies	RST	Rotary Screw Traps
km	kilometer	S	Supplemented stream
LGR	Lower Granite Dam	SBT	Shoshone-Bannock Tribes
LMM	Linear Mixed Models	SD	Standard Deviation
LSRCP	Lower Snake River Compensation Plan	SE	Standard Error
m	Meter	US *v.* OR	United States versus Oregon
ML	Maximum Likelihood	USA	United States of America
N	Number	USFWS	United States Fish and Wildlife Service
NPCC	Northwest Power and Conservation Council		

GLOSSARY OF TERMS

Abundance: The number of Chinook Salmon at specific life stages, or their redds.

Adult progeny: Adult Chinook Salmon that are the product of natural spawning by adults of any origin. In the basin-level analyses, these were determined by partitioning redds by **brood year**. In the intensive analyses, these are estimates of natural-origin fish at weirs by brood year.

Basin-level analyses: Analyses that include supplemented and reference streams within either the Clearwater basin or the Salmon basin.

Brood year: Calendar year in which the parents of a cohort of salmon spawned. In Chinook Salmon, this is the year prior to emergence.

Emigrant-at-RST: Juvenile life stages of Chinook Salmon moving downstream past rotary screw traps during the fall and following spring. Note: both groups pass Lower Granite Dam in the same migratory year and become **Smolts at LGR**.

Expected abundance/productivity: Modeled response when all parameters except phase and stream type are held at average values.

Fixed effects: Variables of interest in the analysis and include factors that were manipulated. For basin level analyses, these include: phase, stream type (supplemented or reference), proportion of **non-treatment hatchery** adults. For intensive analyses of supplemented streams with weirs, these include number of juveniles released, life-stage of juveniles released (presmolt or smolt), number of natural-origin females, **supplementation ratio**, ratio of non-treatment adults.

Intensive analyses: Analyses performed at the population level on the most complete ISS data sets, specifically where weirs provided sufficient treatment level control to estimate precisely the number of spawning females by origin.

Non-treatment hatchery adults/females: Chinook Salmon of hatchery origin that were not specifically released into spawning reaches as part of ISS. Such fish were typically **general production hatchery fish** intended for harvest mitigation. These fish could also be supplementation adults that returned to a reference stream.

Non-treatment ratio: The ratio of non-treatment hatchery females to natural-origin females in spawning reaches.

Phase 1: the baseline time period (1992-1995) during which time supplementation broodstocks were developed and pre-supplementation abundances and productivities were estimated.

Phase 2: the treatment time period (1996-2007) during which time **supplementation adults** were allowed to spawn with natural-origin fish in supplemented streams and responses were measured.

Phase 3: the evaluation time period (2008-2014) during which treatment with adult Chinook Salmon ceased and post-supplementation abundance and productivity were estimated.

Productivity: measures of per-capita production of Chinook Salmon through specific life stages (**emigrant at RST** per redd, **smolts at LGR** per redd, and **adult progeny** per redd).

Random effects: Factors included in analyses to account for known sources of variance that cannot be controlled. These include: year, stream, and geographic group (adult or juvenile).

Reference streams: Study streams that received no supplementation treatments of adult Chinook Salmon. In some supplemented streams, **supplementation juvenile** releases were so low or infrequent that no **supplementation adults** returned to these streams, which were reclassified as reference in the final analysis.

Smolt-at-LGR: A juvenile Chinook Salmon that emigrates past Lower Granite Dam.

Supplementation adults/juveniles: Adult/juvenile Chinook Salmon of hatchery origin that were specifically released into spawning reaches as part of the study. These fish were allowed to spawn naturally among natural-origin adults.

Supplemented streams: Study streams that received supplementations of hatchery-origin Chinook Salmon produced specifically for ISS.

Supplementation ratio: the ratio of supplementation to natural-origin adult females in study spawning reaches.

THE AUTHORS

David Venditti

Ryan Kinzer

Kimberly Apperson

Matthew Belnap

Bruce Barnett

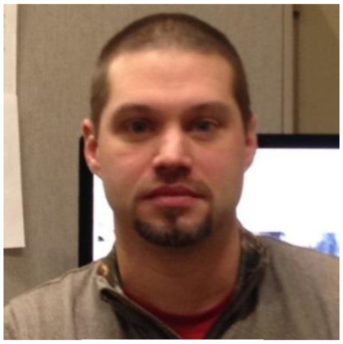
Timothy Copeland

Matthew Corsi

W. Tyler Gross

Laurie Janssen

Ryan Santo



Kurt Tardy

Angelo Teton

EXECUTIVE SUMMARY

Populations of anadromous salmonids in Idaho and most of the Pacific Northwest have declined precipitously since the 1950s. Hatchery programs were developed to mitigate for lost harvest opportunities. As salmon populations continued to decline, dedicated supplementation programs were developed to address conservation needs. Supplementation is defined as the attempt to use artificial propagation to maintain or increase natural production while maintaining the long-term fitness of the target population, and while keeping the ecological and genetic impacts on non-target populations within specified biological limits. However, allowing hatchery fish to spawn in natural-origin populations has been shown to have a variety of consequences; therefore, research was needed to quantify the effects of supplementation and to provide guidance for future supplementation programs.

The Idaho Supplementation Studies (ISS) was designed to measure the population effects of dedicated, intentional supplementation on the abundance and productivity (per capita production of progeny) on Chinook Salmon *Oncorhynchus tshawytscha* during and after supplementation. Prior to ISS in the Clearwater River basin, populations had been extirpated and hatchery-origin Chinook Salmon from non-endemic stocks were introduced. In the Salmon River basin, endemic populations were present and were incorporated into the supplementation broodstock. The study was divided into three phases. In Phase 1 (1992-1995), supplementation broodstocks were developed and baseline measurements were made on abundance and productivity in supplementation and reference streams. Measurements were made at four life stages: redds (as a surrogate for eggs), emigrants at rotary screw traps (RST), smolts at Lower Granite Dam (LGR), and adult progeny returning to study streams. Proportions of non-treatment hatchery females (individuals not intended for supplementation) were estimated as well. Productivity was estimated as emigrants per redd, smolts per redd, and adult progeny per redd. In Phase 2 (1996-2007), returning supplementation adults were passed intentionally above weirs to supplement natural-origin spawners. In Phase 3 (2008-2012), supplementation ceased and the abundance and freshwater productivity of supplemented and reference streams were quantified to determine the legacy of supplementation. The most important and unique aspect of ISS is the evaluation of abundance and productivity *after stopping* supplementation.

This report presents an analysis and interpretation of the ISS experiment. Our objectives were to: 1) Evaluate the effects of supplementation on natural-origin juvenile and adult abundance in the treatment populations in Phase 1 and Phase 2; 2) Evaluate the effects of supplementation on population productivity in Phase 1 and Phase 2; 3) Determine the relationship between numbers of juveniles released by life stage and supplementation adult returns; 4) Determine the relationship between population abundance and the addition of female spawners by origin during Phase 2; and 5) Provide management recommendations to guide supplementation programs in the future.

This report includes two levels of analysis, basin-level analyses, which included reference streams, and intensive analyses of supplemented streams with weirs. In all analyses, we used an analytical modelling approach to infer expected population response in abundance and productivity, assuming all other parameters remained average. The basin-level analyses quantify the effects of supplementation using a life cycle approach and address Objective 1 and Objective 2. For Objective 1, we evaluated supplementation effects on abundance at four life stages. For Objective 2, we evaluated supplementation effects on productivity at three points in the life cycle. For the next two objectives, we completed analyses on supplementation streams with weirs, which afforded precise measurement of the variables most important to implementing a supplementation program: release number and life-stage of supplementation juveniles (Objective 3) and the performance of the adults in the natural environment (Objective 4). These latter two analyses allow us to translate the general results from the basin-level analyses to the management arena and make recommendations based on these findings (Objective 5).

The study incorporated 27 streams and spanned 23 years. There were nine supplemented and four reference streams in the Clearwater River basin, and four supplemented and 10 reference streams in the Salmon River basin. Field activities and data collection for ISS were initiated in 1991, with full implementation by spring of 1992. Data collection concluded with the emigration of smolts in 2014. The sheer length and breadth of the study make it one of the biggest manipulative experiments ever attempted in the fisheries field.

Results from the basin-level analyses demonstrate supplementation effects in Phase 2 and Phase 3. With regard to Objective 1, we observed positive supplementation effects on abundance in Phase 2 that did not persist into Phase 3, with one exception. During Phase 2, abundance increases in supplemented streams attenuated through the life cycle, becoming negative for adult progeny in the Clearwater basin. During Phase 3, there was a negative supplementation effect on abundance of adult progeny in the Clearwater basin but this was not observed at other life stages or in the Salmon basin. Expected abundance for supplemented and reference streams were approximately the same in Phase 3 for redds and emigrants at RST. With regard to Objective 2, productivity estimates predominantly decreased during the study, the inverse of the abundance trend. Expected productivities showed similar responses in reference and supplemented streams, indicating very little effect of supplementation on productivity. There was one exception: supplemented streams in the Salmon basin had a lower adult progeny per redd ratio relative to reference streams. Non-treatment hatchery fish had important population effects. The proportion of non-treatment hatchery fish (both sexes combined) spawning in study streams was associated with an increase in the number of redds, but this effect declined through later life stages (i.e., emigrants at RST, smolts at LGR, and adult progeny). The direction of the estimated effect for non-treatment hatchery fish in both basins was positive on abundance and negative on productivity.

In the Objective 3 analysis, we found evidence that releasing more supplementation juveniles resulted in more returning adults and this effect was greater for the smolt release strategy. Unfortunately, the release strategies for supplementation juveniles implemented during the study were confounded with basin: presmolts were released almost exclusively in the Clearwater basin and Salmon basin releases were mostly smolts.

In the Objective 4 analysis, we found population abundance at all life stages increased with the addition of female spawners, but the rate of increase varied depending on origin and diminished through the life cycle. Passage of natural-origin females above weirs had the greatest effect, followed by supplementation females and then non-treatment hatchery females. During an average return in the Clearwater basin, 0.86 additional redds should be created for every natural-origin female passed. In the Salmon basin under a similar scenario, 1.02 additional redds should be created for every natural-origin female passed. Passing a supplementation female in the Clearwater basin during an average natural-origin return should result in 0.58 additional redds versus 0.72 redds in the Salmon basin. Passage of non-treatment hatchery females during an average return should have very little effect, 0.03 redds per female in the Clearwater basin and 0.24 redds per female in the Salmon basin.

The models used in both the basin-level and intensive analyses performed well. In the basin-level analyses, the amount of variation explained by fixed effects (phase, treatment size, and proportion of non-treatment hatchery adults) was small. The random terms (year, stream, and geographic group) accounted for the largest amount of variance in abundance and productivity analyses and were consistent across the two basins. The year term explained most of the variation in the emigrants at RST, smolts at LGR, and adult progeny per parent responses. In the intensive analyses, the fixed effects (number of juveniles released, life stage of juveniles released [presmolt or smolt], number of natural-origin females, supplementation ratio, and ratio of non-treatment adults) explained most of the variance, particularly for the freshwater life stages, but declined at each successive stage through the life cycle. This progression indicates that fixed effects were important predictors of abundance during the freshwater portion of the life cycle. Random effects (those outside of programmatic control) and out-of-basin effects (e.g., hydrosystem and ocean conditions) were the primary factors determining adult abundance and outweighed any supplementation effect.

We concluded that supplementation resulted in a population boost that did not persist based on the Objective 1 analyses. Abundance, as measured by redd counts, increased across both basins in Phase 2 but supplemented streams increased more than reference streams during that time. The observed abundance increase diminished through the life cycle (emigrants at RST, smolts at LGR, and adult progeny) and this trend was consistent across the Clearwater and Salmon basins. We observed similar overall patterns when addressing effects of non-treatment hatchery fish on redd abundance, but positive effects of these fish were not observed in juvenile life stages or in adult progeny. In Phase 3, abundance at each life stage in treated and reference streams returned to their Phase 1 relationships, suggesting supplementation did not have a lasting influence on abundance. Unless factors limiting abundance are ameliorated, increases resulting from supplementation are unlikely to persist.

Based on the Objective 2 analyses, we found supplementation had few effects on population productivity. We did not observe an effect on emigrants at RST per redd or smolts at LGR per redd in the populations in Phase 2 or Phase 3, but there was a negative effect on adult progeny per redd in Phase 2. The expected number of emigrants at RST per redd and smolts at LGR per redd were nearly identical between supplemented and reference streams. Per capita contribution to juvenile life stages and adult progeny decreased even as total abundance increased in the study streams. Two non-exclusive potential mechanisms could explain this observation. The first is that density may be affecting survival. The second is that fitness loss or altered distribution in hatchery-origin fish may reduce their reproductive success in the natural habitat relative to natural-origin fish, thus reducing productivity.

Based on the Objective 4 analyses, we found natural-origin females had the largest effect on population abundance followed by supplementation and then non-treatment hatchery females in both basins. Assuming average treatment levels, it appears that additional supplementation and non-treatment hatchery females should have little effect on production in the Clearwater basin, where supplementation fish were from non-endemic stocks intended for harvest mitigation. In the Salmon basin, the abundance of both supplementation and non-treatment hatchery females, which were from endemic stocks, corresponded to positive changes in production across life stages but at lower levels than natural-origin females.

To fulfill Objective 5, we make four general recommendations: 1) population increases are most effectively generated by increasing the number of natural-origin spawners; therefore, supplementation programs should be integrated with other management approaches; 2) supplementation ratios should be tied to risk of population failure; 3) when risk of demographic collapse is low, investigate alternative ways to use supplementation fish (e.g., harvest, seeding unused habitat, broodstock); and 4) whenever possible, supplementation should be implemented using an endemic or localized broodstock integrated with the natural-origin population. A key uncertainty, particularly in the Clearwater basin, is how quickly the population recovers from the influx of segregated hatchery fish with a different fitness optimum. Until we have a better understanding of this process, questions regarding the long-term genetic effects of supplementation will remain. More specific key findings and management recommendations follow. Implementation of a supplementation program is a policy decision, but in the following recommendations we assume that this decision has already been made.

Management Recommendations

1. **Key Finding:** When supplementation females were added to the stream, there was an increase in the number of redds, emigrants at RST, and smolts at LGR 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.

2. **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.

3. **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.

4. **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.

5. **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.

6. **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.

7. **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.

8. **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.

9. **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.

In summary, lessons learned from ISS will provide guidance for future supplementation programs. The multiple-stream approach to the study design maintained its power to detect supplementation effects, even when management changes occurred in individual watersheds. The variability among study streams demonstrated the idiosyncratic nature of these programs and hence the need for strategic monitoring and adaptive management. Further, because of the powerful design, these results are useful across the Columbia River basin and beyond. Supplementation is useful as part of an integrated management approach to maintain population abundance in the face of poor conditions. Post-supplementation results show that temporary benefits can be achieved while keeping ecological costs low. However, supplementation alone is not a panacea because it does not correct fundamental limiting factors; these limiting factors must be addressed to achieve population levels capable of sustaining ecological function and management opportunities such as harvest.

INTRODUCTION

Naturally produced populations of anadromous salmonids in Idaho and throughout the Pacific Northwest have declined precipitously since the 1950s and hatchery supplementation programs have been developed as one way to address the declines and recover populations. Supplementation is defined as “the attempt to use artificial propagation to maintain or increase natural-origin production while maintaining the long-term fitness of the target population, and while keeping the ecological and genetic impacts on non-target populations within specified biological limits” (RASP 1992). These programs are commonly used either to augment existing populations or to re-establish extirpated ones. However, debate remains on whether or not supplementation can achieve these goals (ISAB 2003).

Much research has been done on the topic of supplementation and its effects. Allowing hatchery fish to spawn with natural-origin populations has been shown to have a variety of consequences (see review by Araki et al. 2008; Buhle et al. 2009). Hatchery fish spawning with wild conspecifics can have genetic effects such as reduced reproductive fitness (Araki et al. 2009; Chilcote et al. 2011) due to domestication selection in hatcheries (Hindar et al. 1991; Kostow 2004) and ecological effects (Flagg et al. 1995; Nickelson 2003). Competition (Berejikian et al. 1999, 2000; Weber and Fausch 2003) and behavioral differences between hatchery and natural-origin salmonids (Berejikian et al. 1997) can also result in deleterious interactions. Alternatively, other studies have documented demographic boosts to natural production (Hess et al. 2012; Fast et al. 2015). The weight of the literature suggests that the negative effects of allowing hatchery-origin salmonids to spawn with their wild counterparts can be real, so the supplementation stock should be as similar to the target population as possible for conservation applications. However, little research has been conducted to quantify the effects of a dedicated supplementation program on the abundance and productivity (a measure of the rate of population change) of the target population. It also remains unclear if the anticipated demographic benefit of supplementation will provide a sufficient boost to overcome the potential reduction in productivity and if (or how long) these changes will persist after supplementation is stopped.

The need for conservation measures including supplementation arose due to widespread declines in anadromous salmonid populations throughout the Pacific Northwest. Runs throughout the region in both interior and coastal systems have experienced significant declines during the past decades. Nehlsen et al. (1991) identified 214 populations of salmon *Oncorhynchus* spp., Steelhead trout *O. mykiss*, and sea-run Cutthroat Trout *O. clarkii* in California, Oregon, Idaho, and Washington that were facing high or moderate risk of extinction, or were of special concern. Many studies have attributed these declines to poor survival through the lower Snake and Columbia river dams and reservoirs (Raymond 1968, 1979; Schaller et al. 1999; Petrosky et al. 2001); although, this line of reasoning does little to explain the concurrent declines in relatively free flowing coastal systems. While dams may be an important limiting factor, logging, irrigation, grazing, pollution, commercial and sport fisheries, and urban and industrial development have affected Pacific salmon throughout their range (Gresh et al. 2000).

Anadromous salmonids in Idaho experienced similar declines during the 1960s and 1970s. Raymond (1988) documented a decrease in the survival of Chinook Salmon *O. tshawytscha* and Steelhead trout in the Snake River during this time. This decline in the number of naturally produced anadromous salmonids in Idaho has resulted in the listing of many populations under the Endangered Species Act (ESA). Idaho populations listed as threatened (year of listing) include Snake River spring/summer Chinook Salmon (1992), Snake River fall Chinook Salmon (1992), and Snake River basin Steelhead (1997). Snake River Sockeye

Salmon *O. nerka* (1991) are listed as endangered, and Coho Salmon *O. kisutch* were declared extirpated in 1986 (Good et al. 2005). Managers reintroduced Chinook Salmon in the Clearwater River after Lewiston Dam functionally extirpated upstream populations. These populations are not currently listed under the ESA (Good et al. 2005).

A particularly troubling aspect of this decline is that Idaho contains some of the least impacted and highest quality spawning and rearing habitat for anadromous salmonids in the Pacific Northwest. The Middle Fork Salmon River flows through a statutory wilderness area and has little history of human development or hatchery influence. Yet, salmonid populations in these streams have fared little better than those that flow primarily through relatively developed areas such as the South Fork Clearwater (and tributaries), Lemhi, and Pahsimeroi rivers. This suggests that out-of-basin effects (e.g., hydrosystem passage and changing ocean conditions) are the primary drivers in determining anadromous salmonid abundance and may outweigh any supplementation effect.

To mitigate for lost anadromous salmonid harvest due to hydroelectric development and other factors in the Snake and Columbia river basins, a number of hatchery programs were initiated from 1960-1990. The Lower Snake River Compensation Plan (LSRCP) was authorized by Congress to mitigate for the four lower Snake River dams. This program includes the Sawtooth, McCall, Hagerman National, Magic Valley, and Clearwater hatcheries. Satellite facilities associated with the Clearwater Hatchery were also constructed on Red River, Crooked River, and at Powell on the upper Lochsa River. Dworshak Hatchery was constructed to mitigate for Dworshak Dam and was later expanded by the LSRCP. Kooskia and Nez Perce Tribal hatcheries were constructed as part of the mitigation for Columbia River dams, and Idaho Power constructed Oxbow, Rapid River, Pahsimeroi, and Niagara Springs hatcheries as mitigation for the Hell’s Canyon Dam Complex. It is important to note that the purpose of all the above programs was not to restore or rebuild wild anadromous runs but to restore lost harvest opportunity.

Upon completion, these hatcheries used various sources to establish their Chinook Salmon programs, and this would ultimately affect the composition of supplementation broodstocks used prior to and during this study. Hatcheries in the Salmon River basin (McCall, Sawtooth, and Pahsimeroi) used endemic populations from the South Fork Salmon River, upper Salmon River, and Pahsimeroi Rivers, respectively. Broodstock sources for Rapid River hatchery and the Clearwater River programs (Dworshak, Kooskia, Clearwater, and its satellites, and Nez Perce Tribal Hatchery) were more complicated. The Rapid River broodstock was originally founded on a composite sample of fish collected at Oxbow Dam (Reingold 1966; Howell et al. 1985), and currently uses a combination of fish collected at Hells Canyon Dam and at the hatchery (Steiner and Johnson 2010). Lewiston Dam effectively extirpated Chinook Salmon from the Clearwater River upon completion in 1927 (and later removed in 1973), so a combination of non-endemic sources were used at these facilities. Clearwater hatchery broodstocks were founded from non-endemic fish, primarily from Rapid River (Bowles and Leitzinger 1991). Clearwater hatcheries currently use returns to the facilities and Rapid River Hatchery as necessary to meet production goals.

As more hatcheries came on line in Idaho, a portion of their production was used in off-site releases to bolster natural-origin populations. Between 1977 and 1990 over 5.5 million Chinook Salmon fry, 8 million smolts, and 8,000 adults were released into Salmon River tributaries, along with over 17 million fry, 3 million smolts, and 2,000 adults released into the Clearwater River and tributaries (Bowles and Leitzinger 1991). There was widespread hatchery influence in both basins including the streams used in this study. Unfortunately, there was little scientific evaluation of the effects of these supplementation activities on natural-origin populations during this period (Bowles and Leitzinger 1991).

In order to address the uncertainty about the long-term effects of supplementation, Bowles and Leitzinger (1991) designed a study to evaluate the potential usefulness of Chinook Salmon supplementation using localized and non-local broodstocks to re-establish self-sustaining populations in the Clearwater River basin and for augmenting populations in the Salmon River basin with endemic broodstocks. This study entitled "*Salmon Supplementation Studies in Idaho Rivers (Idaho Supplementation Studies)*" (ISS) was designed as a three-phase evaluation including supplemented and reference streams, and is described in detail below.

History of Idaho Supplementation Studies

Given the complexity and scope of the ISS program, a brief history is necessary to help understand the challenges associated with a multi-decadal experiment across such a large geographic area and for proper interpretation of the results. Logistical constraints required refinements to the original study design soon after implementation and some streams were added or removed. Changing management objectives of various cooperators also led to changes in the treatment designation of some streams. Some sampling infrastructure originally proposed was not built and other infrastructure was installed when the opportunity presented itself or the need was identified. These changes led to reviews by the Independent Scientific Review Panel (ISRP 2001, 2003), which reviews individual fish and wildlife projects funded by BPA and makes recommendations on their scientific merit and benefits to the Northwest Power and Conservation Council (NPCC). In response to those reviews, changes were made (described below) to the project study design that were subsequently maintained through project completion (Lutch et al. 2003, 2005).

After completion and acceptance (i.e., funding secured) of the original study design (Bowles and Leitzinger 1991), study streams were distributed among cooperators to ensure sufficient ownership in the program and to ensure continued support and adherence to the design. Dividing study sites among multiple agencies also minimized repetitive logistical, personnel, and equipment expenses. Cooperators included the Idaho Department of Fish and Game (IDFG), the Nez Perce Tribe (NPT), the Shoshone-Bannock Tribe (SBT), and the Idaho Fisheries Resource Office of the U.S. Fish and Wildlife Service (USFWS). The IDFG was responsible for coordination of the overall program.

Separate suites of abundance and productivity response variables were included to monitor supplementation effects in ISS study streams and to predict the long-term sustainability of the supplemented population. Abundance measures were selected to provide initial measures of population response to supplementation at crucial life history stages. Productivity measures provide indications of how supplementation affects the direction and rate of change in treated streams at various points throughout the life cycle and for determining the long-term effects on treated streams. Several variables were not maintained throughout the study period and were not used in our analyses.

Important changes to data collected in the study include the discontinuation of snorkel counts, extending screw trap operation into the summer, and expanding redd counts to include all available habitat in study streams. Snorkel estimates of mid-summer parr density and distribution were dropped due to the high variability around these estimates. To offset this, additional screw traps were deployed to provide more locations where the number of natural-origin emigrants at rotary screw traps (emigrants at RST) could be estimated. Redd counts remained a primary metric in the ISS dataset, and substantial effort was made to maintain its integrity. Early in the program, natural-origin Chinook Salmon populations were at very low levels, and most (if not all) spawning took place in the core index reaches identified by Walters et al. (1999). However, as populations expanded, we also expanded our redd count effort to include multiple passes covering all potential spawning habitat.

Over the course of the study, streams were added, dropped, or had their treatment classification changed for several reasons. Important changes to streams included in the study and their treatment classification also occurred. Logistical constraints on stream access and low adult escapement in the first two years of the study necessitated the removal of several streams from the study, addition of streams to replace those removed, and changing the treatment classification of others. Low adult escapement during Phase 1 (1992-1995) prevented the creation of localized broodstocks in the Clearwater basin and resulted in six fewer streams receiving supplementation treatments than prescribed in the original study design (Lutch et al. 2003). The status of Johnson Creek also changed in 1996 from reference to supplemented, when the Nez Perce Tribe secured funding for the Johnson Creek Artificial Propagation Enhancement program (Project Number 199604300).

Following these changes the ISRP raised concerns about the implementation of the program, which resulted in the aforementioned programmatic review. Initial ISRP concerns were that the experimental design was not adhered to and that there did not appear to be commitment to cessation of treatments (ISRP 2001). Through consultation with Dr. Kirk Steinhorst (Professor Emeritus of Statistics, University of Idaho), we completed a statistical review of the ISS study that addressed these concerns. During this process we determined that the study design maintained ample statistical power and sensitivity to detect treatment effects (Lutch et al. 2003). However, the ISRP felt technical questions still remained regarding the ability of ISS to meet some of the original study objectives (ISRP 2003), primarily due to a lack of biological data from carcasses and the status of tissue samples collected for genetic analysis. A second round of consultation with Dr. Steinhorst resulted in an updated study design (Lutch et al. 2005). This document identified the need for carcass collection to evaluate the effect of non-treatment hatchery fish in study streams. It also presented an analytical method to evaluate this, and the inclusion of these data should add to the analytical power of the study. Concurrently, Phase 2 of the study was extended through brood year 2002 to take advantage of improved returns and provide additional supplementation treatments particularly in streams that had received relatively small treatments early in the experiment. The study operated under this final, updated design, approved by the ISRP, through completion.

Overview of Idaho Supplementation Studies

Three aspects of ISS set it apart from other supplementation programs and evaluations. First, the length and breadth of the study make it one of the most extensive manipulative experiments attempted in the fisheries field. The ISS study encompassed a broad geographical region and took place over approximately four Chinook Salmon generations. Most supplementation evaluations focus on one or two streams (e.g., Clune and Dauble 1991; Sharma 2006; Matala et al. 2012), but ISS incorporated 27 streams and 23 years. This scope allows inference beyond the idiosyncrasies of a particular case study. Second, the inclusion of multiple reference streams allowed us to account for random natural variability that can confound interpretation of data from smaller studies. While true experimental controls are impossible in ecological studies of this size, a power analysis conducted by Lutch et al. (2003) showed the design to be robust even if multiple reference streams were lost. Finally, the most important aspect of ISS and the one that sets it apart from other supplementation evaluations is that abundance and productivity of study populations were evaluated *after stopping* supplementation.

The study was divided into three phases. In Phase 1 (1992-1995), few or no hatchery fish were spawning in the study streams. Phase 1 provided baseline data on the abundance and productivity of streams designated for supplementation and those designated as non-supplemented reference streams. In Phase 2 (1996-2007), returning supplementation adults were intentionally passed above weirs to spawn with natural-origin adults. In Phase 3 (2008-2012), few or no hatchery-origin fish were present on the spawning grounds. This provided an opportunity to quantify the abundance and freshwater productivity of supplemented and reference streams to determine the legacy of supplementation on natural-origin populations.

The ISS was designed to test whether adding a prescribed ratio of supplementation adults to natural-origin spawners changed the abundance or productivity in supplemented streams relative to reference streams. Abundance was measured at the adult stage (indexed by the number of redds), at two juvenile stages, and at the adult progeny stage. The first juvenile stage was an index of the number of emigrants at RST, and included subyearlings in the fall and yearlings the following spring. The second was the number of smolts at Lower Granite Dam (smolts at LGR), and included both juvenile groups as they entered the hydrosystem on their way to the Pacific Ocean. Productivity was measured as the number of emigrants at RST per redd, the number of smolts at LGR per redd, and the number of natural-origin adult progeny per parent redd.

Idaho Supplementation Studies Completion Report

This report represents four analyses and interpretations of the ISS experiment examining supplementation effects on population abundance and productivity. We reviewed the original objectives and hypotheses identified in Bowles and Leitzinger (1991) and changes incorporated by Lutch et al. (2003, 2005) along with comments and recommendations provided by the ISRP (ISRP 2005) to identify the key analytical components presented in this report. During this review, we identified the following five objectives along with several sub-objectives or questions to be addressed in this report. Our objectives were to: 1) evaluate the effects of supplementation on natural-origin juvenile and adult abundance, 2) evaluate the effects of supplementation on natural productivity, 3) determine the relationship between juvenile release life stage and adult returns, and 4) evaluate the relative reproductive performance of supplementation and non-treatment hatchery females relative to natural-origin females, and 5) provide management recommendations to guide future use of supplementation and identify areas of future research. The intended audience for this report is managers and policy makers in the Columbia River basin and others involved in salmon conservation. Please note, our analyses are focused on the conservation aspects of supplementation and we do not address any fishery enhancement goals.

The first two analyses are basin-level analyses on the effects of supplementation relative to reference streams using a life cycle approach. For Objective 1, we evaluated supplementation effects on abundance at the four life stages described above. For Objective 2, we evaluated supplementation effects at the three productivity measures described above. In the next two analyses, we provide additional analyses (intensive studies on treatment streams with weirs) where suitable data were available to inform managers on how to operate a supplementation program from release of supplementation juveniles (Objective 3) to the performance of the adults in the natural environment (Objective 4). These analyses allow us to translate the general results from the basin-level analyses to the management arena and make recommendations based on these findings (Objective 5).

Hypotheses and Research Questions

The goal of the ISS was to test the effects of supplementation on the abundance and productivity of Chinook Salmon populations during and after supplementation. We tested the general premise that supplementation would provide an effect in Phase 2 on population abundance and productivity that might continue into Phase 3. We used a model-based approach to make inferences about the effects of supplementation, and drew management recommendations from the modeling results. We developed competing models relative to the effects of supplementation on natural-origin populations that included: a Phase 2 and Phase 3 effect; a Phase 2 effect only; and no treatment effect.

We formulated the following series of questions to assess the effects of supplementation at various points in the life cycle. We assume juvenile releases were sufficient to produce the adults used for supplementation treatments, although this was not always the case. For Objective 1 (abundance) and Objective 2 (productivity) the question is:

> **Does the release of supplementation females into supplemented streams produce an immediate measurable response relative to reference streams (Phase 2), and does the effect persist into future generations (Phase 3)?**

Abundance response variables include total redds, emigrants at RST, smolts at LGR and natural-origin progeny redds. Progeny redds are those produced by natural-origin females in the generation subsequent to supplementation females present on the spawning grounds. Productivity response variables include emigrants at RST per redd, smolts at LGR per redd, and progeny redds per parent redd.

Similar questions were developed for intensive studies (Objectives 3 and 4) to examine the mechanistic effects of supplementation. These questions included the following:

> **At what rate did supplementation juvenile Chinook Salmon return to their natal stream as adults, and was the return rate different due to the life stage released (presmolts and age-1 smolts)?**
>
> **What was the effect of natural-origin, supplementation, and non-treatment hatchery females on the abundance of redds, emigrants at RST, smolts at LGR, and adult progeny?**

This completion report is intended to satisfy the requirements of the ISRP and BPA. Additional analyses directed at important management questions will be presented in subsequent peer-reviewed articles. Cooperators have continued to monitor abundance and productivity measures in selected supplemented and reference streams beyond the data presented here.

IDAHO SUPPLEMENTATION STUDIES STUDY AREA

Overview

The study area encompassed the Salmon River and Clearwater River basins representing all available stream-type Chinook Salmon spawning habitats in Idaho. The basins include portions of the Idaho Batholith, the Middle Rockies, and the Northern Rockies ecoregions (McGrath et al. 2002; Kohler et al. 2013). Study streams in the Clearwater and most of those in the Salmon basin drain areas with sterile granitic parent material associated with the Idaho Batholith, resulting in relatively low-nutrient systems (McGrath et al. 2002; Sanderson et al. 2009). Two exceptions include the Lemhi and Pahsimeroi rivers, which flow through fertile basaltic geologies. Water quality is high and substrates range from sand and small gravels to cobbles and large boulders. Winters are harsh and growing seasons are short (45-100 d). This area is relatively dry with annual precipitation (primarily snowfall during spring, fall, and winter) ranging from 31 cm to 203 cm. During the study period, summer and winter temperatures averaged 15.3^{o}C and -4.0^{o}C, respectively (NOAA National Centers for Environmental Information; http://www.ncdc.noaa.gov/sotc/national/201510). Snowmelt influences most flow regimes with peak spring flows occurring during May and June and base flows occurring for the remainder of the year. Groundwater recharge heavily influences base flows in the Lemhi River and Pahsimeroi River.

Idaho Chinook Salmon migrate long distances during their life cycle. Idaho Chinook Salmon travel 1,451 km from the Pacific Ocean to the highest reaches of their spawning grounds in the Sawtooth National Recreation Area and climb from sea level to elevations over 1,800 m. Eight dams lie between Idaho and the Pacific Ocean including four Snake River dams and four Columbia River dams. The first dam Idaho Chinook Salmon encounter during emigration is Lower Granite Dam (LGR) on the Snake River 695 km from the Pacific Ocean. In the Salmon basin, juveniles migrate between 234 km and 778 km before encountering LGR. In the Clearwater basin, juveniles migrate between 136 km and 313 km before encountering LGR. Lower Granite Dam is the location investigators used to calculate juvenile survival rates from the Clearwater and Salmon basins, and it is the last dam that adult Chinook Salmon encounter during their migration to Idaho.

The Clearwater River originates in the Bitterroot Range at an elevation of 2,685 m and flows 120 km to its confluence with the Snake River near Lewiston, Idaho at an elevation of 226 m. The Clearwater basin drains approximately 24,980 km^2. Approximately 66% of the basin is federally owned and managed, and 47% of the basin is protected as either roadless or wilderness. The Clearwater Basin is mostly forested (approximately 70%). Land use is divided among grazing, road construction, agriculture, grazing, irrigation, impoundments, and timber harvest (ICTRT 2003). Human population densities are low overall but higher than in the Salmon basin.

The Salmon River originates near Galena Summit in central Idaho at an elevation of 2,759 m and flows 663 km to its confluence with the Snake River at an elevation of 270 m. The Salmon River basin drains approximately 36,217 km^2. The U.S. Forest Service and the Bureau of Land Management own 89% of the basin and human population densities are generally low. Approximately 25% of the basin is designated as wilderness (i.e., the Frank Church River of No Return Wilderness). The terrain is steep and mountainous throughout the basin, limiting occupancy and development by humans. Land use is divided primarily between resource extraction (e.g., mining and timber harvest) and agriculture (e.g., crops and grazing) (ICTRT 2003). Some tributaries in the Salmon basin have experienced localized disturbance from these practices; however, overall the basin is relatively pristine compared to other drainages in the Columbia River basin.

Idaho contains both endemic and introduced Chinook Salmon populations. In the Salmon River basin, Chinook Salmon populations are genetically distinct and indigenous although depleted relative to historic abundances. In the Clearwater basin, the construction of Lewiston Dam in 1929 functionally extirpated endemic Chinook Salmon populations. Lewiston Dam was removed in 1972, reopening the Clearwater River to anadromous fishes. In the late 1960s and early 1970s, IDFG implemented a successful program designed to re-establish naturally spawning Chinook Salmon populations by planting eyed eggs in tributaries to the Clearwater River (Doss 1972). Currently the Clearwater River and its tributaries support naturally spawning Chinook Salmon populations because of this effort and continued escapement of hatchery adults from mitigation hatcheries in the basin. The source populations for these plantings were non-endemic (i.e., Little White Salmon, Leavenworth, and Rapid River) to the Clearwater which is why these spring Chinook Salmon populations are not listed as threatened or endangered under the ESA (Good et al. 2005).

Study Reaches

Study streams were selected to provide life cycle monitoring in as many locations as possible and to provide spatial coverage of anadromous waters within the state. However, limited funding precluded the construction or installation of some infrastructure identified in the original study design. In main-stem rivers, logistical constraints (e.g., high flows, wide river channels, and inefficient trapping) limited our ability to operate sampling equipment and accurately monitor these populations from a life cycle standpoint.

The ISS study incorporated supplemented and reference streams in the Clearwater River and the Salmon River basins (Table 1). In the Clearwater River basin, there were nine supplemented and four reference streams (Figures 1). In the Salmon River basin, there were four supplemented and 10 reference streams (Figure 2), resulting in 13 supplemented and 14 reference streams in total. Reaches included in this study were identified as core production areas for Chinook Salmon. The reaches we monitored supported the majority of production for each population except in the Red, South Fork Salmon, and East Fork Salmon rivers. Reach lengths were variable across study locations, because amount of spawning habitat varied among streams. Certain streams were combined because they were tributaries of one another, and investigators were not able to parse them out based on the location of sampling equipment. In the Salmon basin, data from Marsh and Knapp creeks, Alturas Lake Creek and the Upper Salmon River, and Lake Creek and the Secesh River adult and juvenile data were combined in the basinwide analysis. In the Clearwater basin, data from Brushy Fork and Crooked Fork creeks, and Big Flat and Colt Killed Creeks were also combined in the basinwide analysis. Geographic groups were included as random effects variables in the analysis to account for covariance of streams in close geographical proximity and similar intrinsic population productivity (Table 1). Geographic groups differed between adult and juvenile analyses because there were fewer streams with adequate juvenile monitoring.

Logistical constraints on data collection and low adult escapement forced us to alter several of the streams used in the study and change the treatment classification of others. Johns and Bear creeks in the Clearwater basin and Camas Creek in the Salmon basin were dropped as reference streams due to access difficulty. These streams were replaced with Eldorado and White Cap creeks in the Clearwater basin and the Secesh River in the Salmon basin. Low adult escapement prevented the creation of localized broodstocks and resulted in fewer treatments than prescribed in the original study design (Lutch et al. 2003). Crooked Fork Creek was reclassified as a reference stream in 1993. American River was also reclassified as a reference stream in 1996. Both streams only received one juvenile treatment in 1992 and 1995, respectively (Lutch et al. 2003). Additionally, the West Fork Yankee Fork Salmon River received one small presmolt treatment in 1994 and the East Fork Salmon River received three small smolt treatments from 1992-1994, and both are considered reference streams in the final analysis. Slate Creek and the Lemhi River received no juvenile supplementation treatments and were also reclassified as reference streams. Alturas Lake Creek is now included with the upper Salmon River, because it is a tributary to the upper Salmon River without a control structure (Lutch et al. 2003). Several streams were also excluded from the Phase 3 portion of the analysis due to continued supplementation. The excluded streams include Johnson Creek, Lolo Creek, Newsome Creek, and Eldorado Creek.

To protect wild/natural-origin Chinook Salmon populations that had little or no history of hatchery influence, supplementation treatments were restricted to areas where historical hatchery out-plantings occurred. Specifically, the Middle Fork Salmon River received no treatments because as far as investigators were aware, hatchery stockings have not influenced this population since several relatively small releases into Marsh Creek in 1976 (Sekulich 1980). Furthermore, no hatcheries were established as part of this project, which also lessened the program's impact on existing natural-origin populations.

Streams were designated as supplemented or reference based on logistical and biological considerations, and status was not randomly assigned. Streams selected to receive supplementation treatments were typically in close proximity to hatcheries to ensure access to facilities for broodstock collection, juvenile rearing, and ease of juvenile release. However, hatcheries were not located randomly and were established near relatively productive populations. Factors that determined whether a stream would be included in the study were accessibility, history of monitoring, and previous management actions.

Table 1. Study stream characteristics and groupings for final analysis. The redd analysis variable groups streams in close spatial proximity and with similar geology for analysis. The juvenile analysis variable provides a similar grouping for streams with rotary screw traps. Abbreviations are: SF = South Fork; EF = East Fork; MF = Middle Fork; WF = West Fork; R = River; Cr. = Creek; NT = no juvenile trap.

Study Stream	Supplemented (S) or reference (R)	Redd Count Transect Length (km)	Elevation at mouth (m)	Distance from Lower Granite Dam (km)	Adult analysis grouping	Juvenile analysis grouping
Clearwater Basin						
Clear Cr.	S	20.2	379	173	Lower Lochsa	Clearwater
Pete King Cr.	S	5.8	451	210	Lower Lochsa	NT
Newsome Cr.	S	19.1	1,106	253	SF Clearwater	SF Clearwater
Crooked R.	S	18.8	1,162	263	SF Clearwater	SF Clearwater
American R	R	34.6	1,189	269	SF Clearwater	SF Clearwater
Red R.	S	38.5	1,189	269	SF Clearwater	SF Clearwater
Lolo Cr.	S	60.9	318	136	Lower Lochsa	Clearwater
Eldorado Cr.	R	3.5	871	182	Lower Lochsa	NT
Colt Killed Cr.	S	50.9	1,047	267	Upper Lochsa	Clearwater
Crooked Fk. Cr.	R	21.7	1,047	267	Upper Lochsa	Clearwater
Fishing Cr.	S	6	949	300	Upper Lochsa	NT
Legendary Bear Cr.	S	6.8	1,004	309	Upper Lochsa	NT
White Cap Cr.	R	14	950	313	Selway	NT
Salmon Basin						
Johnson Cr.	S	52.6	1,425	423	SF Salmon	SF Salmon
Secesh R.	R	40.1	1,104	399	SF Salmon	SF Salmon
SF Salmon R.	S	25.3	654	341	SF Salmon	SF Salmon
Slate Cr.	R	15.4	468	234	Slate	NT
Bear Valley Cr.	R	35.7	1,877	613	Upper Salmon	NT
Marsh Cr.	R	20.2	1,877	613	Upper Salmon	Upper Salmon
NF Salmon R.	R	36.8	1,101	506	Lower Salmon	NT
Lemhi R.	R	51.7	1,193	540	Lower Salmon	Lower Salmon
Pahsimeroi R.	S	31.5	1,410	615	Lower Salmon	Lower Salmon
EF Salmon R.	R	27	1,630	682	Middle Salmon	Upper Salmon
Herd Cr.	R	16.4	1,746	699	Middle Salmon	NT
Upper Salmon R.	S	42.5	1,963	754	Upper Salmon	Upper Salmon
Valley Cr.	R	33.2	1,894	745	Upper Salmon	NT
W.F. Yankee Fork	R	11.6	1,908	736	Middle Salmon	Upper Salmon

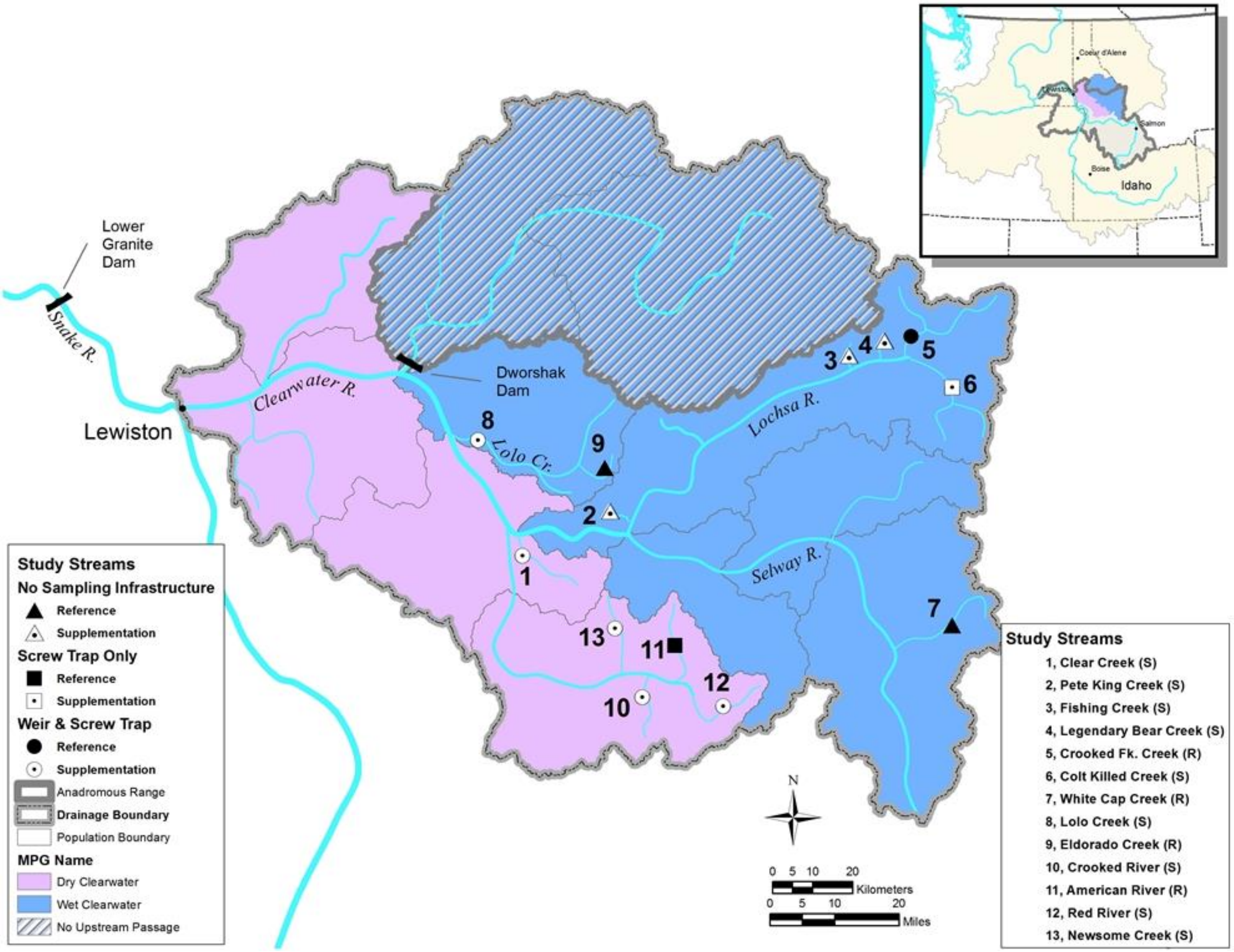


Figure 1. Map displaying study streams by type (reference [R] or supplemented [S]), major rivers, Lower Granite Dam, major population groups (MPG), and populations in the Clearwater River basin, Idaho. Sampling infrastructure is indicated in the legend. Inset shows basin location with respect to the Pacific Northwest.

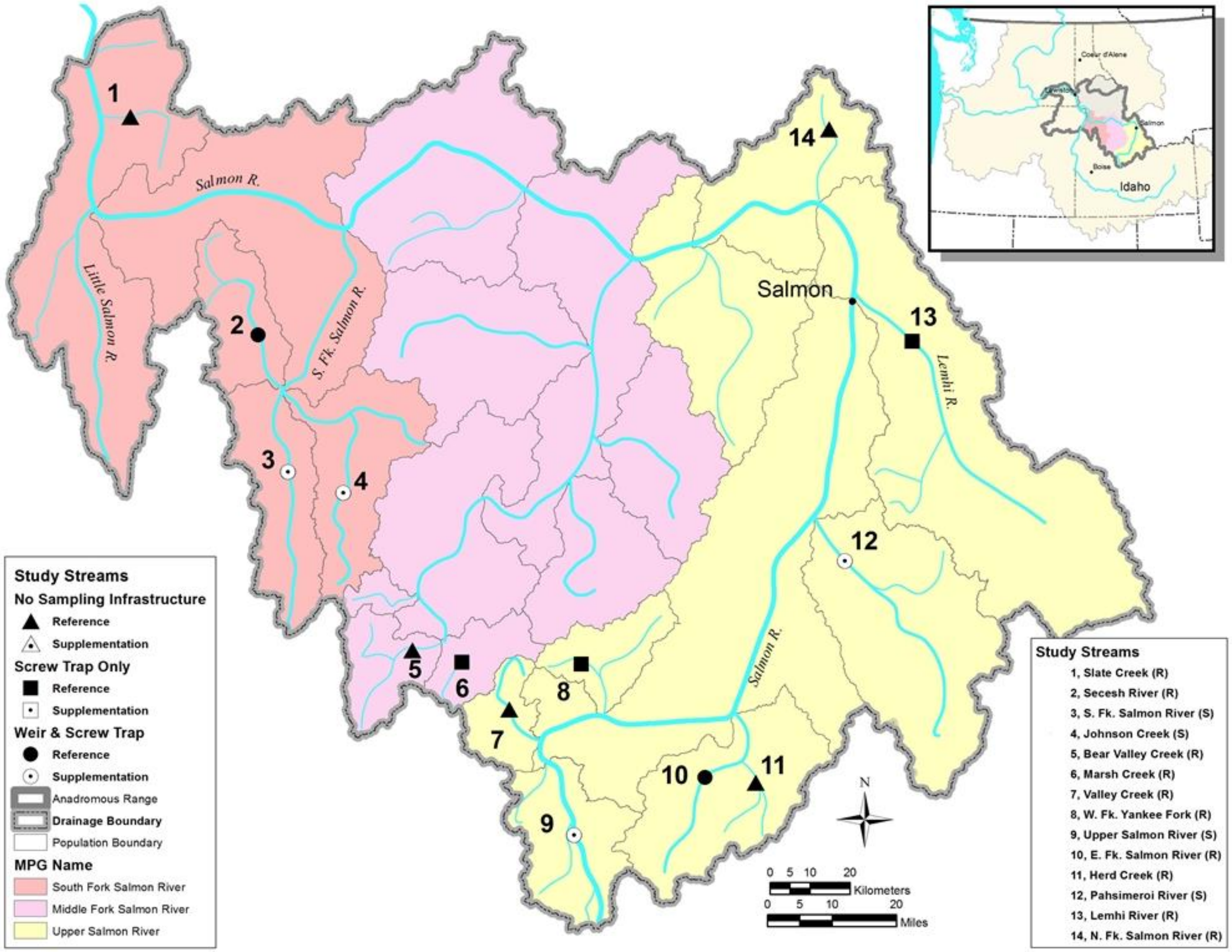


Figure 2. Map displaying study streams by type (reference [R] or supplemented [S]), major rivers, major population groups (MPG), and populations in the Salmon River basin, Idaho. Sampling infrastructure is indicated in the legend. Inset shows basin location with respect to the Pacific Northwest.

FIELD METHODS

Overview

Field activities and data collection for Idaho Supplementation Studies were initiated in 1991, with full implementation by spring of 1992. Data collection concluded June 30, 2014 with completion of monitoring the brood year (BY) 2012 smolt emigration. However, our established protocols for monitoring adult escapement and spawning continued to be followed in most study streams, allowing us to strengthen those datasets by including BY 2013 and 2014 adult data (redds and carcasses) in analyses (Stiefel et al. 2015). This section provides an overview of field activities from 1992 through 2014 that contributed to project data used in analyses, with reference to project progress reports that contain detailed methods.

We developed and followed strict protocols across agencies and administrative regions to obtain consistent data for all study populations. Bowles and Leitzinger (1991) provided the original and overall study design. Throughout the project, as new biological knowledge and technology became available we incorporated new tools and updated protocols as a group to maintain annual consistency in field methods employed. An accounting of activities and data collected by population is provided in Table 2. Below, we give methods for population monitoring of adults, escapement control, implementation of supplementation treatments and juvenile monitoring.

Spawning Grounds Monitoring

Spawning Ground Survey Training

To maintain consistency among cooperators and crews, all personnel responsible for surveying redds and bio-sampling Chinook Salmon carcasses attended an annual training event at the beginning of spawning season. Crews were trained in the identification of redds, use of global positioning systems (GPS), recording thorough data, and techniques for proper collection of biological information from carcasses. Prior to 2006 each agency was responsible for training their staff. In 2006 IDFG ISS staff hosted a statewide spawning ground survey workshop to provide standardized training for all State, Federal, and Tribal agencies conducting redd counts and carcass surveys in Idaho. Beginning in 2008 IDFG and the NPT have alternated hosting this annual training.

Table 2. Summary of data collected for Idaho Supplementation Studies, by basin and population. Cooperating agencies were Idaho Department of Fish and Game (IDFG), Nez Perce Tribe (NPT), Shoshone-Bannock Tribes (SBT), and U.S. Fish and Wildlife Service (USFWS). Data summary contains only observations (years) used in the final analyses. Indented streams are tributaries to the stream above.

Study Population				**Number of years each field activity was used in the analyses, with total possible years in parentheses.**			
Basin	**Stream**	**Lead agency**	**Supplemented (S) or reference (R) for analyses**	**Redd count survey (23)**	**Carcass survey (23)**	**Adult escapement controlled or monitored by weir (23)**	**Juvenile emigration estimated (21)**
Clearwater	American R.	IDFG	R	23	23	0	10
	Crooked Fork Cr. Brushy Fork Cr.	IDFG	R	23	20	15	21
	Eldorado Cr.	NPT	R	16	16	0	0
	White Cap Cr.	IDFG	R	18	0	0	0
	Colt Killed Cr. Big Flat Cr.	IDFG	S	22	16	0	16
	Clear Ck.	USFWS	S	21	21	21	8
	Crooked R.	IDFG	S	21	20	16	14
	Fishing Cr.	NPT	S	21	21	0	0
	Legendary Bear Cr.	NPT	S	21	21	0	0
	Lolo Cr.	NPT	S	16	16	0	12
	Newsome Cr.	NPT	S	16	16	11	9
	Pete King Cr.	USFWS	S	23	23	0	0
	Red R.	IDFG	S	23	23	13	14
Salmon	Bear Valley Cr.	SBT	R	23	21	0	0
	EF Salmon R.	SBT	R	23	20	21	17
	Herd Cr.	SBT	R	23	11	0	0
	Lemhi R.	IDFG	R	23	23	0	19
	Marsh Cr. Knapp Cr.	IDFG	R	23	23	2	20
	NF Salmon R.	IDFG	R	23	23	0	0
	Secesh R. Lake Cr.	NPT	R	23	23	0	17
	Slate Cr.	NPT	R	23	23	0	0
	Valley Cr.	SBT	R	23	23	0	0
	West Fork Yankee Fork Salmon R.	SBT	R	23	23	0	13
	Johnson Cr.	NPT	S	16	16	10	11
	Pahsimeroi R.	IDFG	S	23	23	23	21
	SF Salmon R.	IDFG	S	23	23	23	21
	Upper Salmon R. Alturas Lake Cr.	IDFG	S	23	18	23	20

Redd Counts

Chinook Salmon redds were counted in all study streams from August through September as a measure of spawning escapement. Most reaches were surveyed two, three, or more times with ground counts, as deemed necessary, to obtain an accurate count of total redds. Multiple ground counts allow observation either during redd construction or shortly thereafter and aid in unique redd identification. Multiple counts also increased the number of adult Chinook Salmon carcasses recovered over what would have been collected in a single count design. Specific number of surveys per stream and total stream length surveyed varied annually depending on flow conditions and general magnitude of adult escapement, and are provided in annual project reports (Appendix E). Exceptions to multiple surveys included Big Flat, Colt Killed, and White Cap creeks, which are remote streams where access is difficult. We surveyed these streams once with a single pass ground count that, based on historic spawn timing, coincided with peak spawning activity. The upper Salmon River and its tributary Alturas Lake Creek were physically too expansive to effectively count from the ground and these streams were surveyed with an aerial count timed to peak spawning activity. Access to the Pahsimeroi and Lemhi rivers was limited, so these received a combination of aerial and ground counts. Redds were enumerated as a total stream count, as well as the number above adult weirs and above rotary screw traps. We maintained the core survey reaches as reported in Walters et al. (1999) and expanded surveys to include all probable spawning habitat as abundance increased in our study populations (Appendix D).

Carcass Surveys

We collected data from Chinook Salmon carcasses in conjunction with all ground redd surveys to estimate spawner success, hatchery fraction, age structure, and sex ratio. In some streams and years, we made additional effort to recover carcasses between redd surveys to obtain more complete data sets for estimation of relative spawning success of each origin group. Beginning in 1996 through the completion of this project all year classes of returning adults could be distinguished as non-treatment hatchery-origin, supplementation, or natural-origin fish based on marks and tags.

Management and Monitoring of Adult Escapement

We operated weirs in nine supplemented and four reference streams to enumerate and control adult Chinook Salmon entering study streams (Walters et al. 1999, Table 2). All adult Chinook Salmon trapped at weirs were examined for sex, measured for length, examined for tags and marks to ascertain origin and age of fish. Prescriptions outlined in Bowles and Leitzinger (1991) guided management of escapement upstream from weirs into study reaches for each phase of the study.

Broodstock Development and Adult Treatments

Broodstock Crosses

Supplementation broodstocks were developed for supplemented streams following general prescriptions described by Bowles and Leitzinger (1991). The goal for creating supplementation progeny was to use local broodstock where possible, using at least 50% natural-origin parents. However, low adult escapement during Phase 1 (1992-1995) prevented the creation of localized broodstocks in the Clearwater basin. Prior to BY 1991, distinguishing adipose fin clips were not applied to all hatchery progeny at all facilities; therefore, unknown proportions of unmarked hatchery-origin adults contributed to initial supplementation progeny (BY 1991 – 1995). From BY 1996-2002 all crosses were made with known-origin fish to create supplementation fish. As soon as supplementation fish began returning as adults in 1995, some were used in the supplementation broodstock and some were passed as treatments. Hatchery methods followed accepted standard practices (for an overview of standard methods, see Leitritz and Lewis 1976; Piper el al. 1982; Erdahl 1994; Bromage and Roberts 1995; McDaniel et al. 1994; Pennell and Barton 1996).

Juvenile Releases and Adult Treatments

Hatchery produced juveniles of the above supplementation crosses were differentially marked and released into supplemented streams at the prescribed life stage and up to the prescribed numerical level (Bowles and Leitzinger 1991). We defined age-0 supplementation juveniles as presmolts and age-1 supplementation juveniles released in the spring as smolts. Juveniles in each supplementation juvenile release were also marked with PIT tags in numbers adequate to estimate survival to LGR, which demarcates exit from all potential freshwater rearing habitats.

The nine weir-controlled supplemented streams followed population-specific prescriptions for releasing supplementation and natural-origin adults upstream into study reaches by origin and sex (Bowles and Leitzinger 1991). No non-treatment hatchery adults were to be intentionally released into study reaches. Typically, from study initiation through BY 1995 one-third of unmarked females and males were to be released for natural spawning, with two-thirds retained for use as broodstock to create supplementation progeny. From BY1995 – BY2002 ≥ two-thirds of natural-origin adults were to be released for natural spawning, with the remainder to contribute to supplementation progeny. Supplementation adults returning in excess of broodstock needs were released for natural spawning but were not to exceed the number of natural-origin adults, by sex; and fish surplus to that need would be used in the harvest mitigation (i.e., general production) broodstock. Treatments ended with the return of age-5 BY 2002 supplementation adults in 2007.

Juvenile Monitoring

We operated rotary screw traps (RST), floating scoop traps, or juvenile fish weirs on 18 streams during Phase 1 and Phase 2, and on 15 streams during Phase 3, to collect juvenile Chinook Salmon emigrating downstream to estimate cohort abundance and survival to LGR. We also collected life history information, such as size at emigration and the timing of peak movements (Appendix D). Initial deployments of RST were delayed in some streams for one to five years, and RST were phased in across all study sites to replace scoop traps and juvenile weirs. Prior to 1998 some RST were not operated during summer, but since 1998 we deployed RST as early in the spring as possible and fished them as continuously as river conditions allowed until ice-up in the fall. Trap operations were designed to maximize collection efficiency and are described in Venditti et al. (2014).

Fish were implanted with passive integrated transponder (PIT; Prentice et al. 1990) tags following established protocols (Kiefer and Forster 1991; PIT Tag Steering Committee 1992; CBFWA 1999). Project specific protocols changed somewhat over the study, but changes were made wholesale across study sites to maintain as much consistency as possible (Appendix D).

Minimum seasonal tagging goals were established to ensure adequate data to estimate emigration from natal streams and survival to LGR by life stage. From 1992-1996, a minimum tagging goal of 300 fall and 100 spring emigrants at RST per stream was established to ensure adequate detections for estimating survival to LGR (Bowles and Leitzinger 1991). Beginning in 1997 program cooperators agreed to increase the minimum tagging goal to 700 summer, 500 fall, and 300 spring emigrants at RST per stream to improve survival estimates. By working cooperatively with other projects (e.g., Comparative Survival Studies; Project Number 1996-020-00), larger numbers of PIT tags were often available in the later years of ISS. We strove to tag all spring emigrants at RST, and tags for summer and fall emigrants at RST were allocated systematically to spread tags out over the tagging season. Tag files were checked for accuracy then uploaded to PIT Tag Information Systems (PTAGIS) (http://www.ptagis.org/).

ANALYTICAL METHODS

Our analytical approach evolved from Bowles & Leitzinger (1991) through Lutch et al. (2003) and we finalized the methods with a linear mixed model approach, which incorporated all proposed analyses into a single technique. The full model for Objectives 1 and 2 incorporates suggestions made by ISRP (2003, 2005) after reviewing the ISS Prototype Analysis and Updated Study Design (Lutch et al. 2003, 2005). In ISRP's response, they specifically requested ISS cooperators to include the effect of differing levels of treatments and the effects of "de-facto" supplementation through a non-treatment hatchery fish (i.e., stray) term. The full model used in the analysis now combines the mixed-model ANOVA and regression analysis identified in the Updated Study Design (Lutch et al. 2005). Basin-level analyses provide statewide inference to the positive or negative effect of supplementation on abundance and productivity measures. Intensive studies use detailed weir data to investigate the effect of supplementation and general production female spawners on abundance with a regression approach (Draper & Smith 1998). To examine the effects of supplementation for both basin-level and intensive-studies, linear mixed-effect models (LMM; Littell et al. 2006) were used to analyze changes in abundance and productivity across time due to supplementation efforts. Mixed effect models are a common and practical approach to evaluating ecological studies (Bolker et al. 2009) as they provide a meaningful way to explain the natural hierarchy in biological systems (Grueber et al. 2011) and to account for dependence among repeated measurements (Littell et al. 2006).

For each research question, we fit a suite of models using maximum likelihood (ML) estimation in R (R Core Team 2014) using "lme4" (Bates et al. 2014) and ranked them with information theoretics (Akaike 1973). Definitions of all model variables used in the analysis can be found in Appendix A. Fitting multiple models is a preferred analysis technique for observational ecological studies (Burnham & Anderson 2002; Elliott & Brook 2007) and allows the examination of multiple alternative hypotheses at once to ultimately select a hypothesis that best fits the data. Model ranking was conducted with a modified Akaike information criterion (AICc) (Burnham & Anderson 2002). After each model was ranked from the lowest to highest AICc, the difference in AICc values (Δ_{AICc}) from the top ranked model was calculated, along with model probabilities (Akaike weights) to assess model selection uncertainty (Burnham & Anderson 2002). After models were ranked with ML methods, each model was then re-fit using restricted maximum likelihood (REML) to estimate coefficients and account for the biased ML variance estimates (Burnham & Anderson 2002; Symonds & Moussalli 2011; Littell et al. 2006).

Multi-model inference was performed across the full model set using ML based model probabilities and the REML coefficients, because of uncertainty associated with selecting the highest ranked model (i.e., model probabilities were very similar). Including all models in the set shrinks averaged coefficients towards zero, providing a conservative coefficient estimate (Burnham & Anderson 2002; Grueber et al. 2011). We used model-averaged results to provide inference on the positive or negative effect of supplementation. Strong inference is assumed when model coefficient confidence intervals do not overlap zero, and weak inference is assumed when confidence intervals overlap zero (Burnham & Anderson 2002; Bolker et al. 2009).

We assessed model performance in two different ways. First, for each ranked model, the proportion of variance explained by fixed effects (marginal R^2) and the proportion explained by both fixed and random terms (conditional R^2) were calculated to decompose the variation explained into fixed and random model components (Nakagawa & Schielzeth 2013). We report marginal and conditional R^2 for the top model. Second, we examined model fit and assumption violations for independence, homogeneity, and normality by visually inspecting residuals from the full model in diagnostic plots (Burnham & Anderson 2002). No assumption violations were observed from residual plots, so we continued with this analytical approach.

Basin-Level Analyses of Abundance and Productivity

Analyses of abundance and productivity use the same model set with identical predictors to evaluate changes across time by only switching model response variables. Changes in abundance (Objective 1) were examined at four different life stages: redd abundance, emigrants at RST, smolts at LGR, and natural-origin progeny redds. Progeny redds are those produced by natural-origin females in the generation subsequent to supplementation females present on the spawning grounds. Three response variables provided inference on shifts in productivity (Objective 2): emigrants at RST per redd, smolts at LGR per redd, and natural-origin adult progeny per parent redd.

The LMM structure employed for the basin-level analyses followed Piepho and Ogutu's (2002) methods with modifications made by Dr. Kirk Steinhorst (Professor Emeritus Department of Statistics, University of Idaho) The full model contains terms to estimate mean changes in supplemented streams across three distinct time-periods while accounting for natural changes in population abundance and productivity using reference streams (Equation1.1). First, the model estimates the differences between streams by establishing a baseline relationship using two random effects, geographic group and stream. Using the baseline relationship, the model then estimates a common mean condition for all streams in Phase 1, regardless of treatment type. Next, the model estimates the average increase or decrease of supplemented streams in Phase 2 and Phase 3 by examining the change in the baseline stream relationship. Thus, the Phase 1 relationship between reference and supplemented streams is the foundation of the analysis and is assumed to remain constant throughout the study period; therefore, any differences between stream type during Phase 2 or Phase 3 are due to supplementation.

$$y_{ijt} = \mu + \beta_1 p1_{jt} + \beta_2 T_{jt} + \beta_3 p3_{jt} + \beta_4 p3t_{jt} + \beta_5 S_{jt} + g_i + s_{j(i)} + a_t + \epsilon_{\mathrm{ijt}} \text{ (Equation1.1)}$$

The model includes a natural-log-transformed response variable (y_{ijt}) for the j^{th} stream in the i^{th} geographic group for year t. Fixed effect explanatory variables include;

μ = mean response level (intercept) for reference streams in Phase 2,
β_1 = mean response effect for all streams in Phase 1 ($p1_{jt}$),
β_2 = partial slope effect of ISS treatments (T_{jt}) during Phase 2,

β_3 = mean response effect for reference streams in Phase 3 ($p3_{jt}$),
β_4 = mean response difference for supplemented streams in Phase 3 ($p3t_{jt}$),
β_5 = partial slope effect for non-treatments (S_{jt}).

Explanatory terms for Phase 1 ($p1_{jt}$), Phase 3 ($p3_{jt}$) and Phase 3 treatment ($p3t_{jt}$) were indicator variables, equaling 1 if year t of stream j was in Phase 1, Phase 3, and if the observation was a supplemented stream in Phase 3, and 0 otherwise. Johnson, Lolo, Newsome, and Eldorado creeks were used to estimate Phase 1 and Phase 2 coefficients but were removed from Phase 3 estimation due to continued supplementation activities in these streams. Treatments (T_{jt}) were supplied to the model as the natural log transformed number of supplementation adult females allowed to spawn naturally. Using adults as our treatment variable limited the analysis to all reference streams and only supplemented streams with weirs that had estimates of supplementation adult females on the spawning grounds. Removing the supplemented streams without weirs (N = 3, Legendary Bear, Fishing, and Pete King creeks) from the analysis theoretically reduced the power to detect a supplementation effect because of a smaller sample size.

The non-treatment hatchery variable (S_{jt}) was included as the arcsine square-root transformation of the proportion of non-treatment hatchery fish (both sexes combined) estimated on the spawning grounds. Non-treatment hatchery fish in supplemented streams are either general production (i.e., harvest mitigation) fish or supplementation fish that did not return to their release location. In reference streams, non-treatment hatchery fish consist of all hatchery-origin fish including supplementation fish. A proportion of non-treatment fish on the spawning grounds, calculated from carcass surveys, was the only quantitative measurement available to represent “de-facto” supplementation in the basin-level analyses. Introducing the angular transformed proportion, to create an approximately normally distributed predictor, in the basin-level model complicated the interpretation of the effect of non-treatment fish on the response variable. As such, we use the non-treatment term as a nuisance parameter that is included solely to account for variation in the response attributed to differing levels of “de-facto” supplementation. An interpretation of non-treatment fish on the spawning grounds will be provided from the intensive study results.

To statistically block and account for known variation contained within the data and random noise ($\epsilon_{ijt} \sim N(0, \sigma^2)$) the additional error terms were included in the basin-level model (Equation 1.1) as random effects,

$$g_i \sim N(0, \sigma_g^2),$$
$$s_{j(i)} \sim N(0, \sigma_s^2),$$
$$a_t \sim N(0, \sigma_a^2),$$

where g_i is a random term for group i, accounting for variation due to geographic areas of study streams, $s_{j(i)}$ is a random term for stream j within group i, and a_t is a random term for annual observation year t. Estimated variation across groups, streams within groups, year and unexplained noise equal σ_g^2, σ_s^2, σ_a^2 and σ^2, respectively.

The basin-level model used the expected value of reference streams at each phase as the evaluation point to judge supplementation success during the treatment and post-treatment periods. By parameterizing the model as in Equation 1.1, we could differentiate supplemented streams and estimate positive or negative treatment effects in Phase 2 or Phase 3 with the sign of the β_2 and β_4 coefficients, respectively (Figure 3). Decomposing the model into its parts, the expected marginal response for reference and supplemented streams during Phase 1 becomes

$$E[y_{ijt}] = \mu + \beta_1 p1_{jt} + \beta_5 S_{jt} .$$

During Phase 2, the expected response for reference streams reduces to the y-intercept and the non-treatment hatchery fish term only,

$$E[y_{ijt}] = \mu + \beta_5 S_{jt} .$$

Calculating the expected response for supplemented streams in Phase 2 includes the additional treatment term $\beta_2 T_{jt}$.

$$E[y_{ijt}] = \mu + \beta_2 T_{jt} + \beta_5 S_{jt}$$

The Phase 3 expected response for reference streams can be shown as

$$E[y_{ijt}] = \mu + \beta_3 p3_{jt} + \beta_5 S_{jt} .$$

Then, supplemented streams in Phase 3 are adjusted from reference streams by the additional term $\beta_4 p3t_{jt}$.

$$E[y_{ijt}] = \mu + \beta_3 p3_{jt} + \beta_4 p3t_{jt} + \beta_5 S_{jt}$$

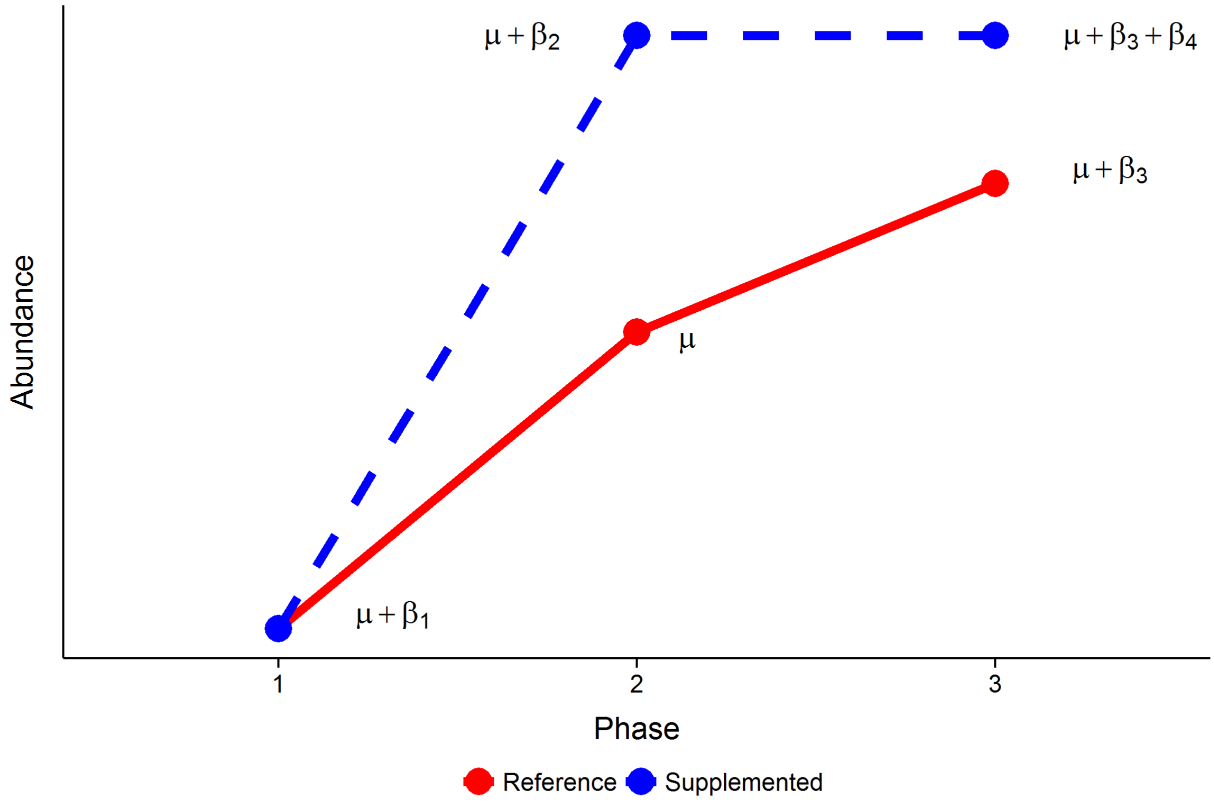


Figure3. A hypothetical result shows how the full model (Equation 1.1) in the basin-level analysis shifts between phases with model coefficients β_1 (phase 1) and β_3 (phase 3) for both reference and supplemented streams. And how stream type differences are made with the β_2 coefficient for phase 2 and the β_4 coefficient for phase 3.

The complete model set was formed from nested models, contained within Equation 1.1, and together they represented competing hypotheses for each response variable under Objectives 1 and 2. Six *a priori* competing hypotheses were considered as biologically plausible to explain the effects of supplementation in the long-term studies. Three main variations of hypotheses include an immediate and persistent supplementation effect, an immediate supplementation effect only during the treatment period, and no treatment effect detected (Figure 4). Each hypothesis variant was then combined with a non-treatment hatchery fish term to estimate the effect of non-treatment hatchery fish on the response variable (Table 3).

Table 3. Six *a priori* models to evaluate changes in abundance and productivity across the three study phases.

Model	Hypothesis
1	Immediate and persistent supplementation effect, non-treatment effect
2	Immediate supplementation effect, non-treatment effect
3	No supplementation effect, non-treatment effect
4	Immediate and persistent supplementation effect, no non-treatment effect
5	Immediate supplementation effect, no non-treatment effect
6	No supplementation effect, no non-treatment effect

To provide an interpretation of model averages, we calculated the benefit of supplementation in an average stream in an average year. This response is illustrated by marginal plots showing the mean response of reference and supplemented streams after averaging across the random effects of group, stream, and year (Littell et al. 2006). To calculate expected responses across each study phase we assumed the proportion of non-treatment hatchery fish on the spawning grounds equaled zero. To visualize the average supplementation response in Phase 2 we set the treatment level at the observed average number of supplementation females on the spawning grounds in the Clearwater and Salmon basins. To provide a more intuitive interpretation of the treatment effect, we calculated the proportional response by increasing the adult female treatment by an arbitrary value of 25.0% and performed a back transformation of the natural-logged transformed response and treatment variable (1.25^(β_2). A proportional response in Phase 3 is shown using the back transformation of the natural-logged transformed response variable and stream type classification (exp^(β_4)).

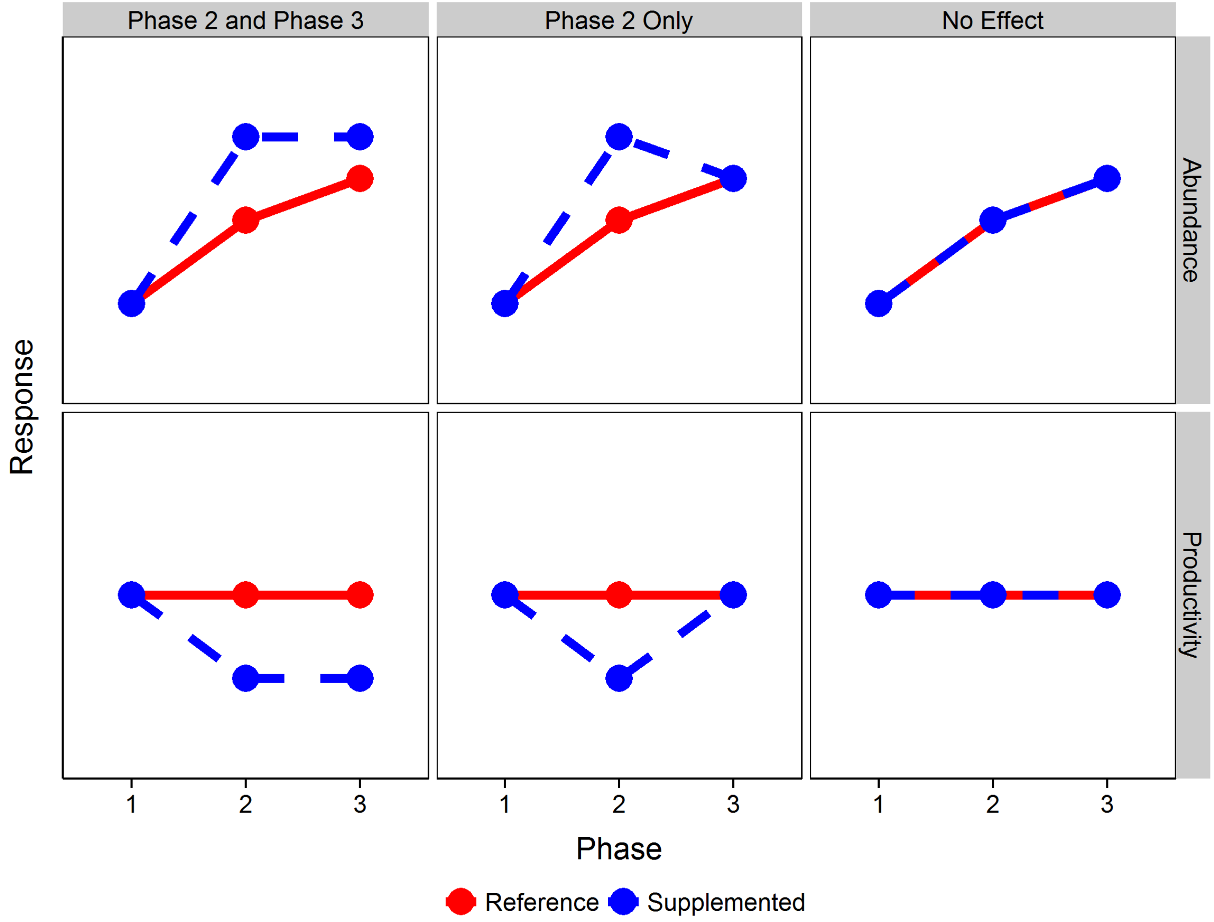


Figure 4. Hypothetical representations of three primary variations of the competing models used in the basin-level analyses for abundance and productivity. These hypotheses were evaluated using models that both included and excluded an additional fixed effect term for non-treatment adults on the spawning grounds.

Intensive Analyses of Supplemented Streams with Weirs

To satisfy Objective 3, we used intensive studies focusing on data collected during Phase 2 and Phase 3 in supplemented streams with weirs (N = 9, see Table 2). Five research questions were broken into two sections: (1) the relationship between the numbers and type of juveniles released to explain the expected number of supplementation brood year returns at a weir, and (2) the change in abundance at four distinct life stages relative to the origin of female spawners. Following a life-cycle approach allows a more complete understanding of the effects of supplementation on Chinook Salmon population measures. In addition, it enabled us to analyze statistically if population performance at various stages in the life cycle is affected by female origin.

Supplementation Return

To estimate the relationship between juveniles released and brood year adult supplementation fish returning we constructed the full model (Equation1.2) as,

$$y_{jt} = \mu + \beta_1 R_{jt} + \beta_2 L_{jt} + s_j + a_t + \epsilon_{jt} \qquad \text{(Equation 1.2)}$$

where y_{jt} represents the natural-log-transformed total number of supplementation adults returning to a weir in stream *j* for brood year *i*. Fixed effects in Equation 1.2 included the mean effect (μ), the continuous variable R_{jt} for natural log transformed total number of juveniles released, and the discrete variable L_{jt} for life stage of juveniles released, either parr/presmolt or smolt. Random effect terms included a stream effect, $s_j \sim N(0, \sigma_s^2)$, year effect, $a_t \sim N(0, \sigma_a^2)$, and unexplained error, $\epsilon_{jt} \sim N(0, \sigma^2)$.

From the full model, three additional nested models were formed to test competing hypotheses and allow multi-model inference. Competing hypotheses include: (1) the rate of increase in returns of supplementation adults is equal for presmolt and smolt release but life-stages operate at different scales, (2) the rate of return depends only on the number of juveniles released, (3) return is equal across all juvenile release numbers but differs by life stage, and (4) the return does not depend on release number or life stage.

Population Abundance

Intensive studies of supplementation effects on abundance were completed at the same four life stages examined with the basin-level analyses: redds, emigrants at RST, smolts at LGR, and adult progeny. The intensive analyses focused on cohorts receiving supplementation treatments. Weir control allowed for a direct comparison among natural-origin, supplementation, and non-treatment hatchery females in terms of their effect on population response at each life stage using their true abundances as the predictor. Similar to Objectives 1 and 2, a common model set was fit to estimate the rate of change in abundance at each life stage by switching the response variable.

To estimate the rate of change in abundance attributed to spawners of different origin, we began with the full model (Equation 1.3) written as:

$$y_{jt} = \mu + \beta_1 N_{jt}^{F} + \beta_2 T_{jt}^{Ratio} + \beta_3 S_{jt}^{Ratio} + s_j + a_t + \epsilon_{jt,} \qquad \text{(Equation 1.3)}$$

where y_{jt} is the natural log transformed response variable of redds, emigrants at RST, smolts at LGR or natural-origin progeny returns to the weir for stream *j* in year *t* and the mean effect is represented by μ. The term N_{jt}^{F} represents the natural logged transformed number of natural-origin females on the spawning grounds. Thus, β_1 represents the proportional increase in the response variable due to a proportional increase in natural-origin spawning females. Change in abundance due to an increase in supplementation and non-treatment hatchery females was estimated with β_2 and β_3, respectively, where T_{jt}^{Ratio} and S_{jt}^{Ratio} is the ratio of supplementation or non-treatment hatchery females to natural-origin females on the spawning grounds. Estimating the change in abundance attributed to different supplementation ratios provides a tool for weir management.

The model set included four competing hypotheses to explain the variation in the data (Table 4). The first hypothesis included terms for natural-origin, supplementation, and non-treatment hatchery female spawners, suggesting each origin contributes to changes in abundance. The second and third hypotheses include natural-origin and either supplementation or non-treatment hatchery females terms, indicating only two origins contribute to abundance changes. The fourth hypothesis predicts that the variation in abundance is explained only by natural-origin females.

Table 4. Four *a priori* models to estimate changes in abundance at four distinct life stages due to the origin of female spawners; natural-origin, supplementation and non-treatment hatchery fish.

Model	Hypothesis
1	Abundance change detected from all three spawner origins
2	Abundance change detected from natural-origin and supplementation spawners
3	Abundance change detected from natural-origin and non-treatment hatchery spawners
4	Abundance change detected only from natural-origin spawners

FIELD RESULTS

Overview

This section contains a summary of field data collected pertaining to supplementation treatments, non-prescribed treatments, and response variables used in the analysis. Data collection began in 1992 and concluded with juvenile trapping operations in 2014. Prescribed treatments reported included juvenile releases and adult female Chinook Salmon released above weirs to spawn naturally. Reported field results used as response variables in the analysis include redd counts, adult brood year returns, an index of emigrants at RST leaving the natal reaches, and an index of smolt abundance at LGR.

Treatments

Production of Supplementation Fish

Production of supplementation broodstocks was greatly affected by low adult returns in Phase 1. This prevented the creation of localized broodstocks in the Clearwater basin, so supplementation juveniles were from mitigation programs. In the Salmon basin, low adult returns resulted in juvenile releases smaller than prescribed in most supplemented streams. Therefore, fewer supplementation adults returned in Phase 2, creating the dilemma of simultaneously making treatments and the next generation of supplementation juveniles.

Juvenile fish were released to produce adults for supplementation treatments. Over the course of the study, 111 juvenile releases were made totaling 10,971,116 fish. Individual releases averaged 98,839 juveniles with the smallest and largest releases occurring in the

South Fork Salmon River (Figure 5). Four reference streams, American River, Crooked Fork Creek, East Fork Salmon River and West Fork Yankee Fork, received three or fewer small juvenile releases.

As part of program objectives, adult supplementation activities focused on releasing females to spawn naturally in study streams in both the Clearwater and Salmon basins. Adult supplementation females returning from juvenile releases spawned naturally in 71 stream-year combinations; thus only 64% of the juvenile releases yielded any returning adults. Nine streams across both basins received adult female treatments, averaging 61 females per year (SD = 71) and ranging from 2 - 320 (Table 5). The average treatment level observed in the Clearwater was 39 additional females (SD = 58.2) on the spawning grounds and 76 additional females (SD = 75.6) in the Salmon basin. Newsome Creek, Red River, and Upper Salmon River received the smallest adult treatments, with only two supplementation females in one year, while the Upper Salmon River also had the largest treatment of 320 additional females (Table 5). Distributions of supplementation females released across both basins was heavily skewed and weighted towards smaller treatments, potentially reducing a measurable response of supplementation (Figure 6).

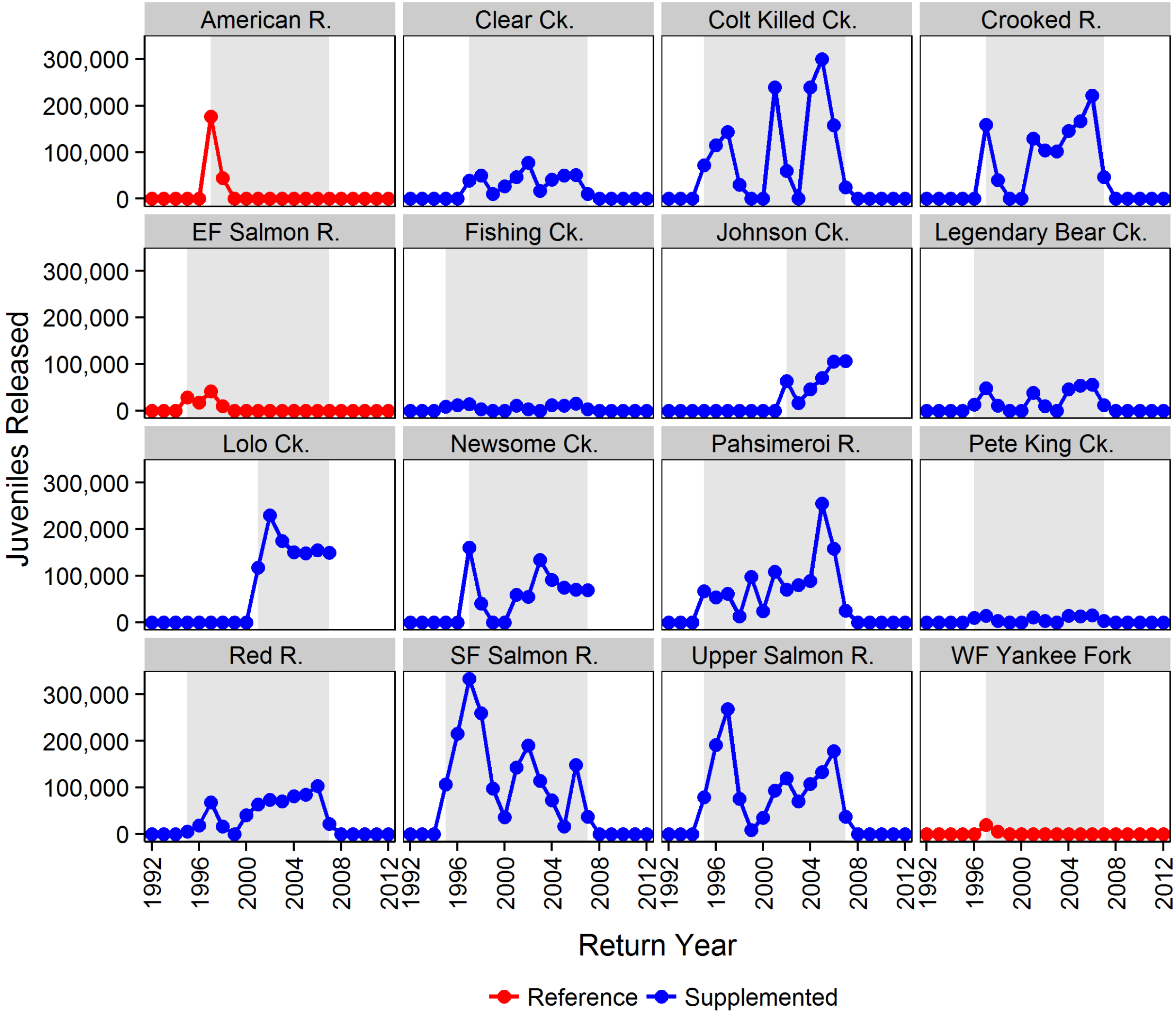


Figure 5. Number of juveniles released (parsed into estimated return year) ranged from a low of 2,565 to a high of 333,334 across ISS supplemented streams. The gray portion of the figure indicates Phase 2 of the ISS study, a period of supplementation adult returns.

Table 5. Summary of supplementation females released to spawn naturally in study streams (N = number of release years). Includes years with zero females released, but excludes years when weirs were not operated.

Stream	**N**	**Average**	**SD**	**Minimum**	**Maximum**
Clear Creek	6	14	13	0	35
Crooked River	11	22	30	0	95
Johnson Creek	6	59	51	23	154
Lolo Creek	6	93	102	15	284
Newsome Creek	6	26	43	0	112
Pahsimeroi River	13	70	79	0	255
Red River	13	6	12	0	44
South Fork Salmon River	13	84	64	8	176
Upper Salmon River	13	69	96	0	320
Combined	87	50	68	0	320

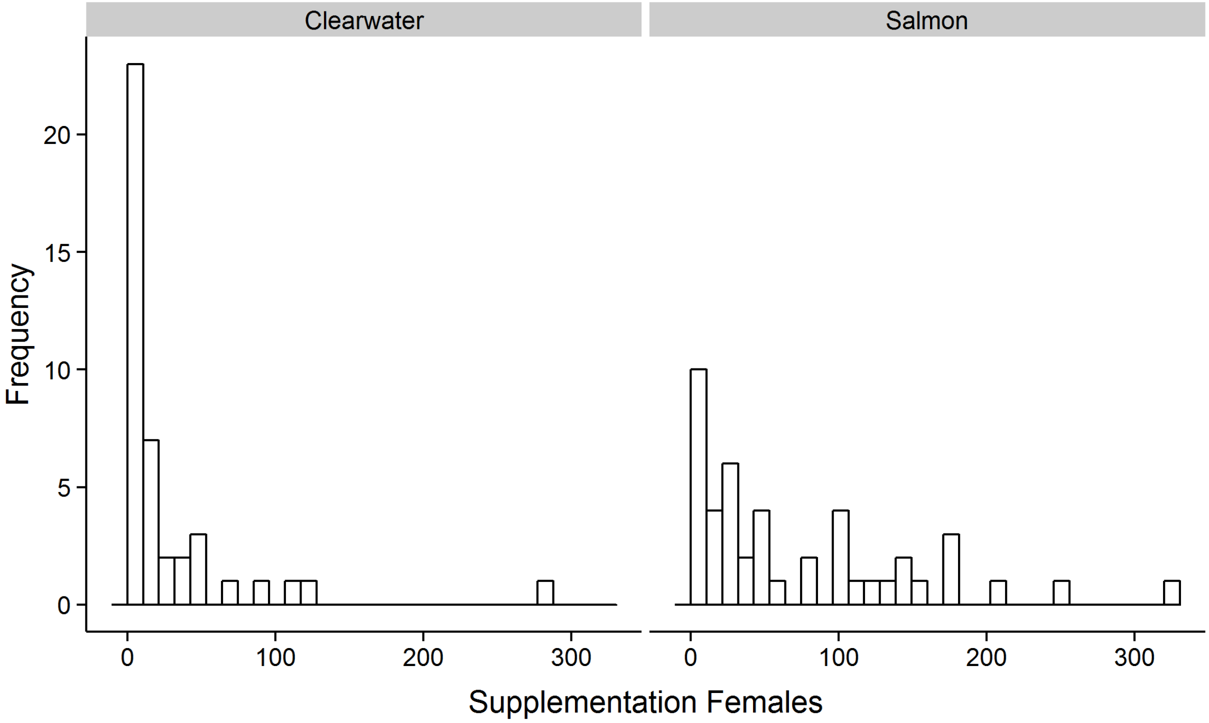


Figure 6. The distribution of supplementation females allowed to spawn naturally on the spawning grounds across the Clearwater and Salmon River basins.

In general, abundance of natural-origin and supplementation females on the spawning grounds had similar trends throughout Phase 2 (Figure 7). In the Clearwater basin, non-treatment hatchery females followed the same trend as natural-origin and supplementation females. We omitted the Red River data, because the large amount of dropout below the weir resulted in few fish at the weir. Abundance of non-treatment hatchery females on the spawning grounds in the Salmon River was typically low except in the South Fork Salmon River prior to the installation of a more efficient weir in 2007.

Our observed treatment rate, measured as the ratio of supplementation females to natural-origin females released above a weir for natural spawning averaged 0.72 (0.0 – 5.0) across treatment years and streams (Table 6), moderately less than our prescription of 1.0. The average ratio ranged from 0.39 in the Upper Salmon River to 0.96 in Clear Creek and the Pahsimeroi River. Early in Phase 2 (1996-1999), abundance was low for both supplementation- and natural-origin adults, so passing or keeping one or two females had large effects on the potential treatment. This was particularly acute in the Clearwater basin, because abundances were always lower there. Later in Phase 2 (2000-2007), the number of supplementation-origin females often was lower than natural-origin, resulting in supplementation ratios lower than desired. For example, this occurred in 3 years in the Pahsimeroi and Crooked rivers. When supplementation-origin females were abundant, they were often passed in greater number resulting in higher than average treatment-ratios and in some cases higher than prescribed. For example, this occurred in 2 years in the Pahsimeroi and Crooked rivers. In 2007, only 5-year-old supplementation females were available, so the supplementation ratios were always low in this year.

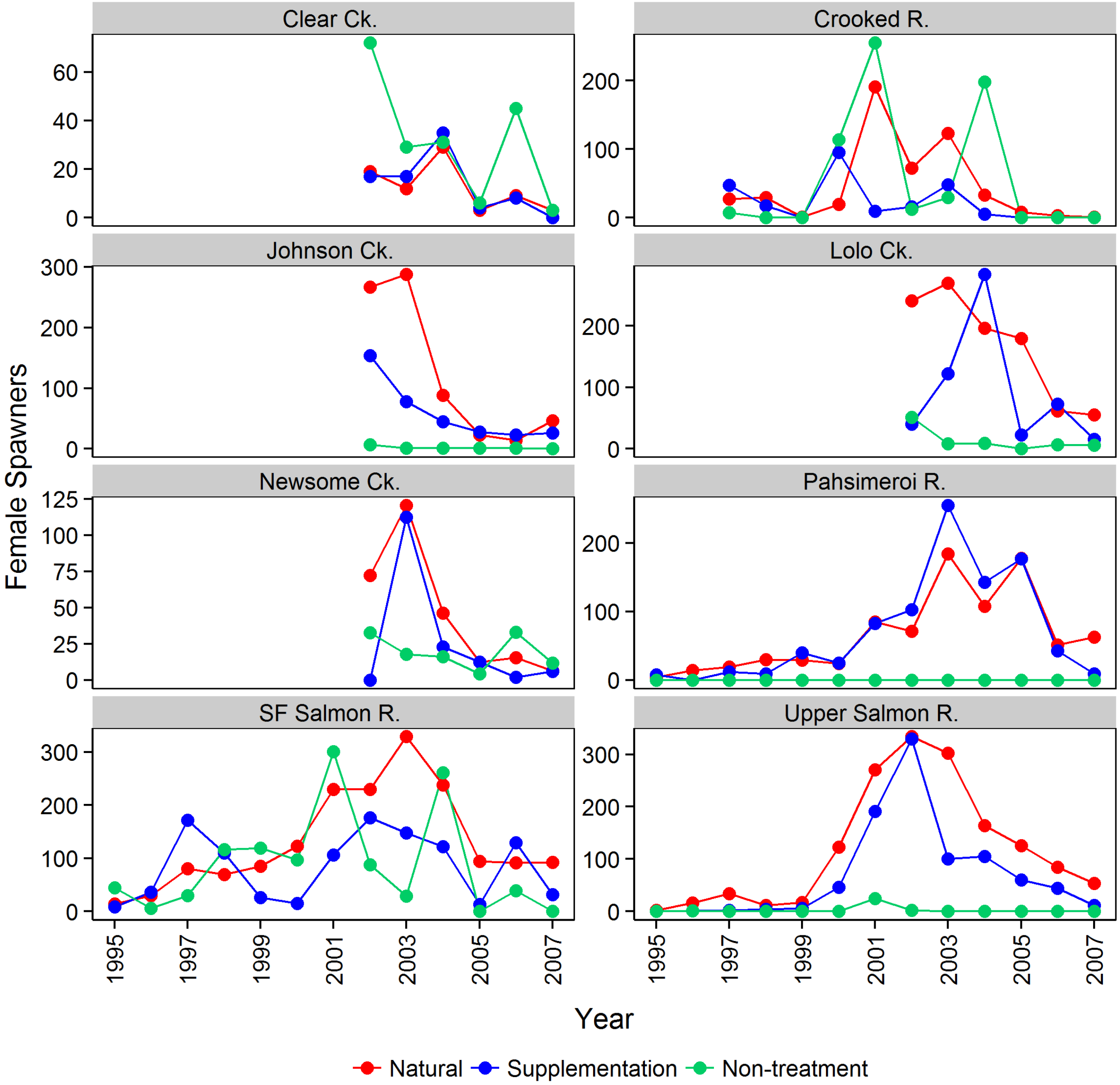


Figure 7. Adult females by origin released upstream of weirs in the Clearwater and Salmon river basins during Phase 2. Non-treatment hatchery returns are general production hatchery females. Note: Y-axis scales differ between panels.

Table 6. Summary of supplementation ratios (supplementation females:natural-origin females) upstream of weirs (N = number release years). Includes years with zero females released, but excludes Red River, which was omitted from the intensive analysis and return years when weirs were not operated.

Stream	**N**	**Average**	**SD**	**Minimum**	**Maximum**
Clear Creek	6	0.96	0.52	0.00	1.42
Crooked River	11	0.74	1.50	0.00	5.00
Johnson Creek	6	0.80	0.52	0.27	1.64
Lolo Creek	6	0.61	0.56	0.12	1.45
Newsome Creek	6	0.59	0.45	0.00	1.00
Pahsimeroi River	13	0.96	0.57	0.00	2.00
South Fork Salmon River	13	0.77	0.63	0.12	2.15
Upper Salmon River	13	0.39	0.28	0.00	0.99
Combined	74	0.72	0.74	0.00	5.00

Non-Treatment Adults

Proportions of non-treatment adults were highly variable between basins and streams. The Salmon basin averaged 5.5% (SD = 14.4%) and the Clearwater basin averaged 37.4% (SD = 35.4%) across the study periods. In most streams, rates of these fish on the spawning grounds were fairly constant across the study years. Streams displaying highly variable rates of non-treatment proportions were influenced mainly by low escapement and/or low carcass collection (Figure 8).

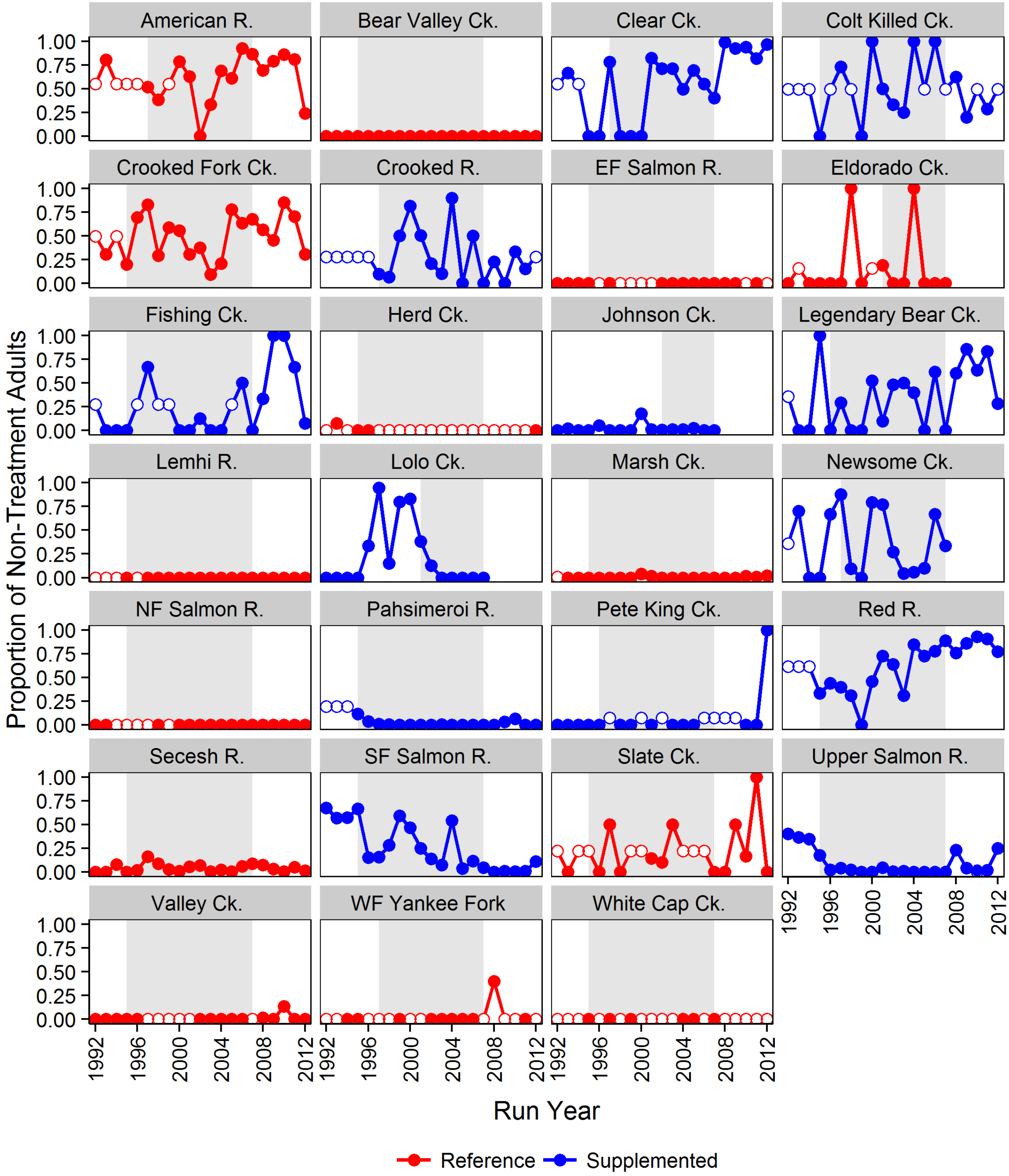


Figure 8. The proportion of non-treatment adults found on the spawning grounds by return year across the study period by stream type. The gray portion of the figure indicates Phase 2 of the ISS study, a period of supplementation adult returns. Open circles represent years with zero carcasses collected and average proportion was used for the basin-level analysis.

Response Variables

Redd Counts

Redd counts were completed annually between 1992 and 2012 (Figure 9). We were not able to use Phase 3 data due to continued supplementation activities in Eldorado Creek, Lolo Creek, Newsome Creek, and Johnson Creek. Occasionally redd counts were not completed in some streams in some years due to safety concerns (e.g. forest fires, flight restrictions). These occurred infrequently enough that we assumed the missing data points would not affect overall results.

Average redd abundance for supplemented and reference streams increased across phases with the exception of supplemented streams in the Salmon basin in Phase 3 (Figure 10). Redd abundance in reference streams increased linearly across phases for both basins. Redd abundance in supplemented streams increased into Phase 2 and plateaued (Clearwater) or decreased slightly (Salmon) into Phase 3 (Figure 10). The decrease in the Salmon basin was driven by a decrease in redd production in the South Fork Salmon River study reach (mean = 344 redds in Phase 2 versus mean = 273 redds in Phase 3), despite remaining the largest population within our study.

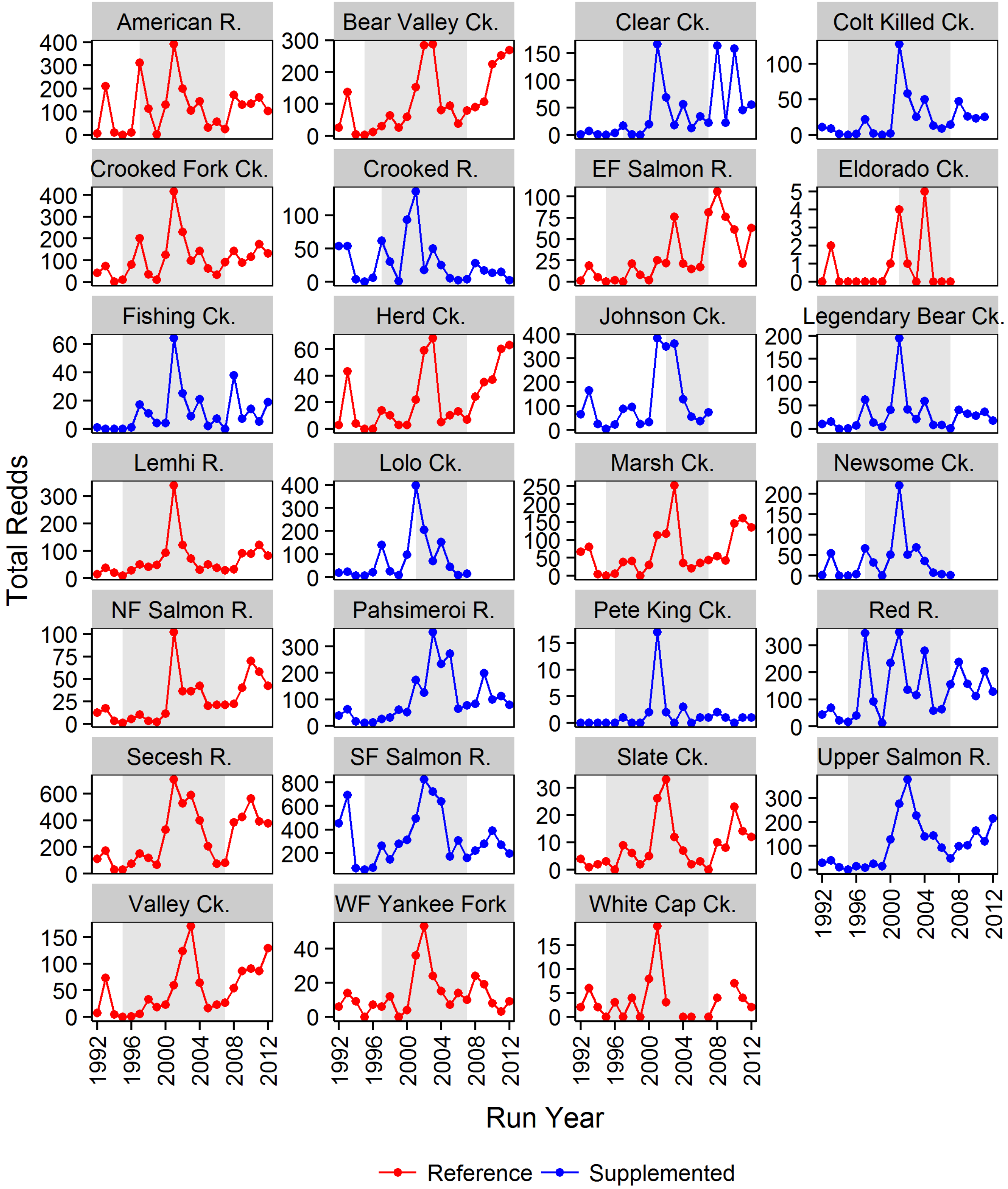


Figure 9. Total redds counted on the spawning grounds by return year across the study period. The grey portion of the figure indicates Phase 2 of the ISS study, a period of supplementation adult returns. Note: Y-axis scales differ between panels.

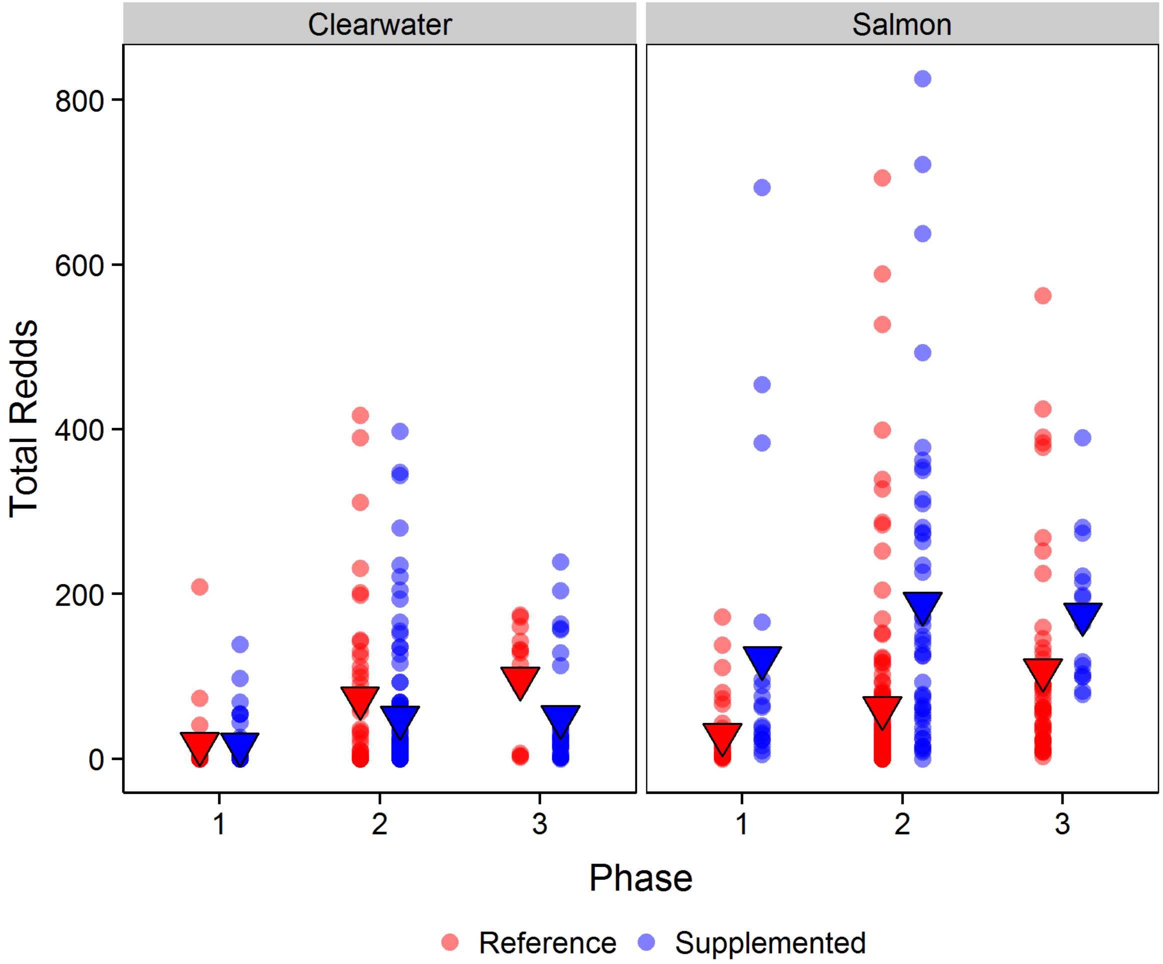


Figure 10. Average total redds (triangles) in supplemented and reference streams for each basin across all phases. Filled circles represent annual estimates.

Juvenile Emigration

Juvenile data were collected in 16 study streams for brood years 1992 to 2012. Juvenile emigrant at RST estimates generally tracked redd abundance (Figure 11). However, our index of juvenile abundance (sum of fall and spring emigrant abundance estimates) was more variable than redds because of measurement error at RST and the influence of environmental stochasticity on the life stage (e.g., fire, flow, temperature). In both the Clearwater and Salmon basins, fall emigrants at RST made up the largest portion of the index. Overall, emigrant estimates were complete throughout the study period; however, estimates could not be generated in some cases due to late inclusion into the study, environmental conditions (e.g., high water), and few juvenile captures. Additionally, screw traps were not operated in three years after years of zero redd counts (1995 and 1999 in Marsh Creek and 1995 in the upper Salmon River). Omissions occurred in both high and low abundance populations (see Figure 11); therefore, they should not bias results but will add uncertainty.

Average total emigrants at RST differed by basin, phase, and stream treatment type. Overall, streams in the Clearwater basin averaged 26,008 (SD = 47,081) emigrants at RST and Salmon basin streams averaged 30,379 (SD = 28,605) emigrants at RST. In the Clearwater basin, reference and supplemented streams had an inverse relationship (Figure 12). Average emigrants at RST in reference and supplemented Salmon basin streams increased from Phase 1 to Phase 2. Reference streams then continued to increase into Phase 3, while supplemented streams declined slightly (Figure 12).

The number of smolts at LGR from study streams remained fairly constant throughout the study period (Figure 13). Unlike redds and emigrants at RST, smolts at LGR did not generally display an increase during Phase 2. Notable exceptions to this include Lolo Creek and the Pahsimeroi and upper Salmon rivers. In Lolo Creek, smolts at LGR increased sharply toward the end of Phase 1 and then declined just as sharply through Phase 2. The Pahsimeroi River showed steadily increasing numbers of smolts at LGR over the entire study period. In the upper Salmon River, smolts at LGR peaked during Phase 2 and then declined somewhat during Phase 3 and appear to stabilize at a level intermediate between numbers observed in Phase 1 and Phase 2 (Figure 13).

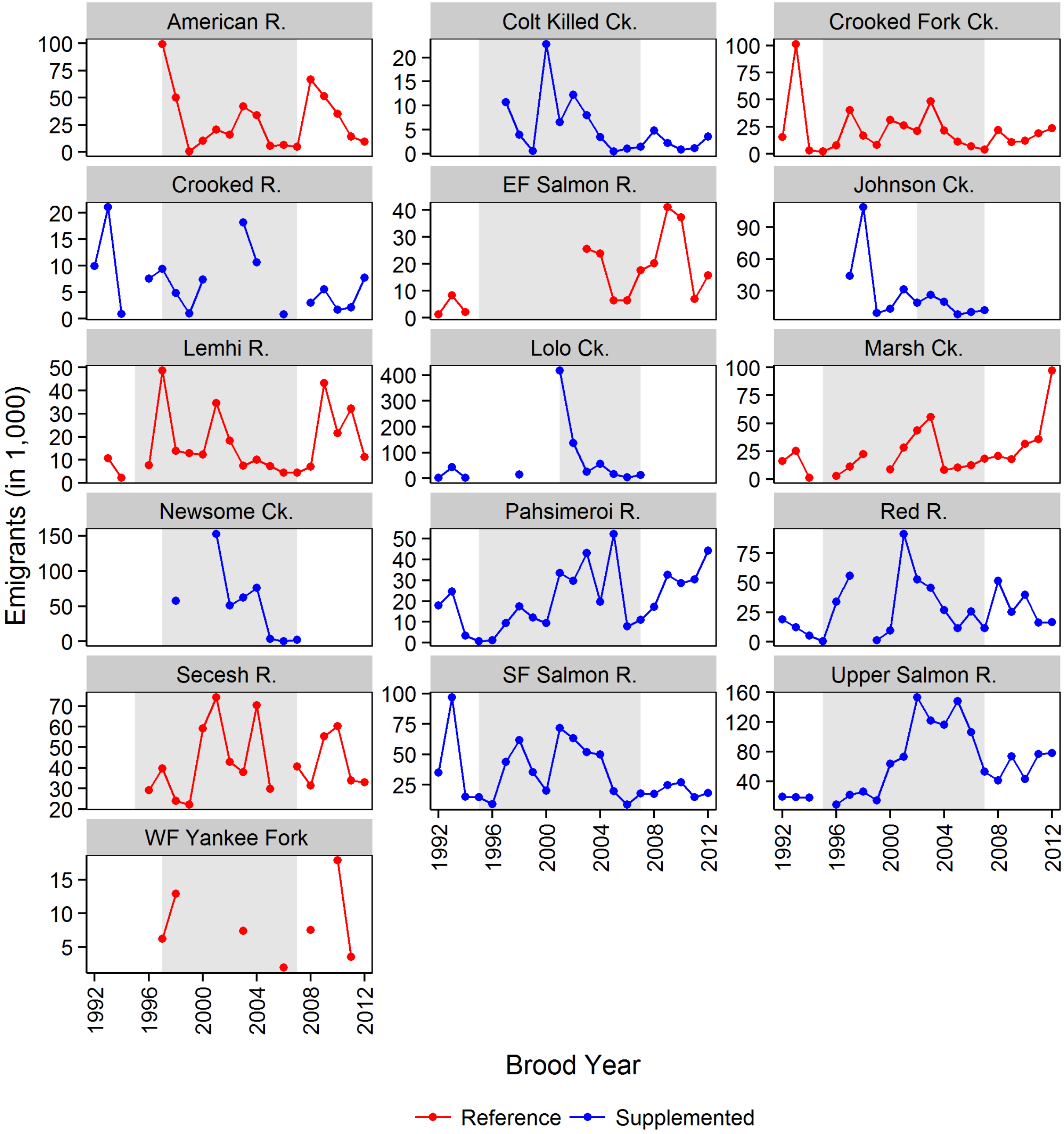


Figure 11. The estimated number of natural-origin fall and spring emigrants at ISS rotary screw traps by brood year. The grey portion of the figure indicates Phase 2 of the ISS study, a period when supplementation adults contributed to production. Note: Y-axis scales differ between panels.

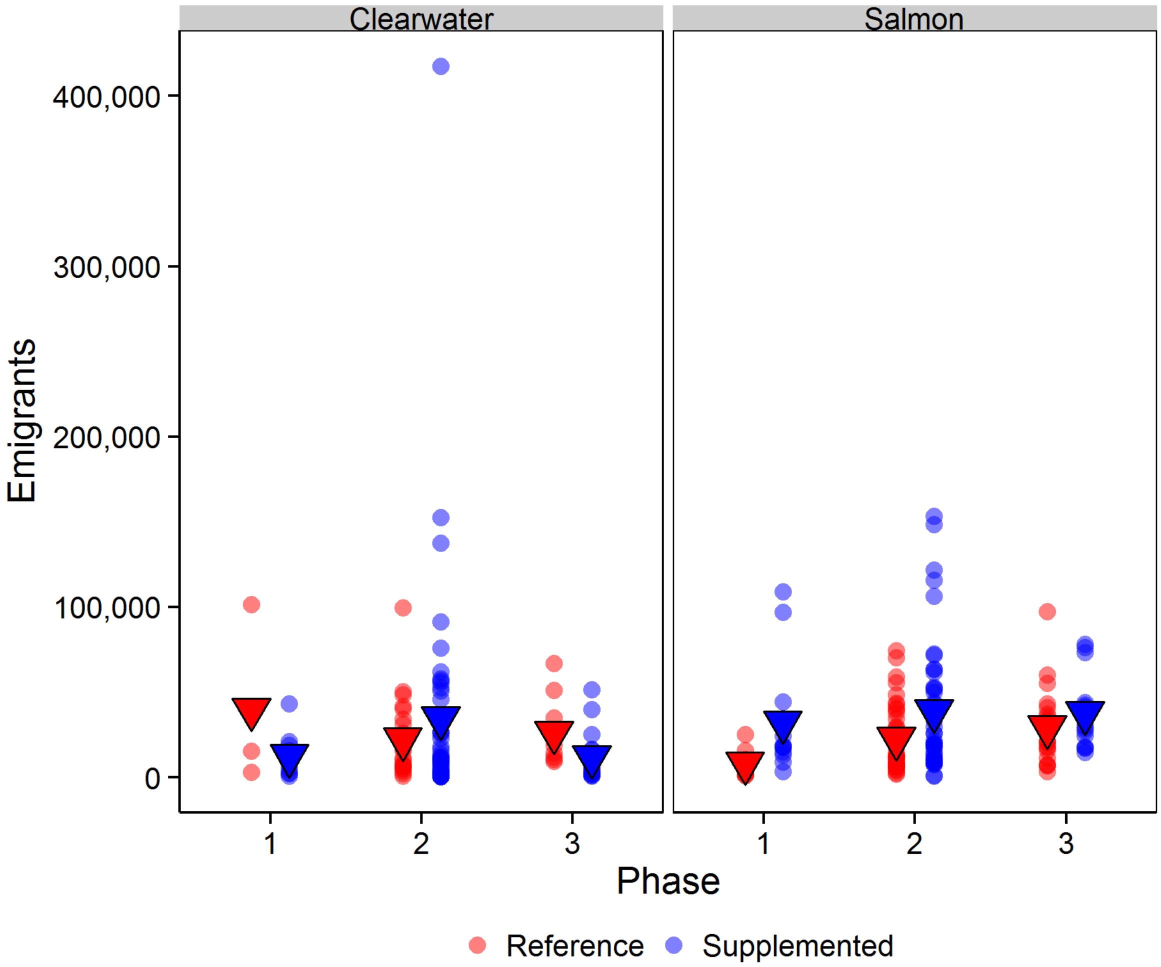


Figure 12. Average total estimated natural-origin emigrants at rotary screw traps (triangles) in supplemented and reference for each basin across all phases. Filled circles represent annual estimates.

The average abundance of smolts at LGR showed a similar pattern as estimated emigrants at RST across all phases (Figure 14). The only difference is supplemented streams in the Salmon basin increased smolts at LGR abundance from Phase 2 to Phase 3 instead of a slight decline. The average number of smolts at LGR from Clearwater basin streams was 6,466 (SD = 7,707) and from Salmon basins streams was 8,359 (SD = 7,060).

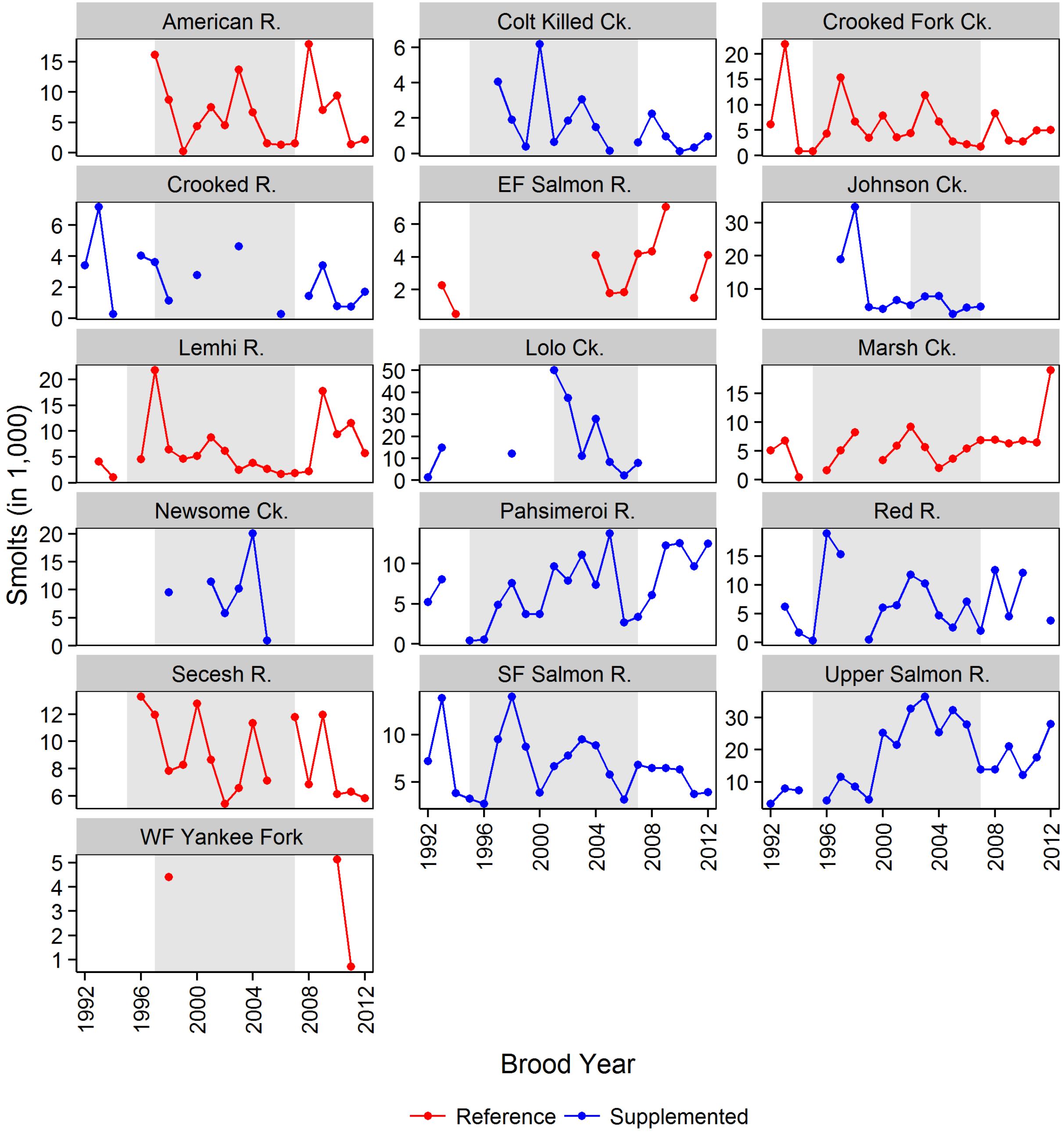


Figure 13. The number of smolts at LGR by brood year from study streams (includes both fall and spring emigrants at rotary screw traps). The gray portion of the figure indicates Phase 2, when supplementation adults contributed to production. Note: Y-axis scales differ between panels.

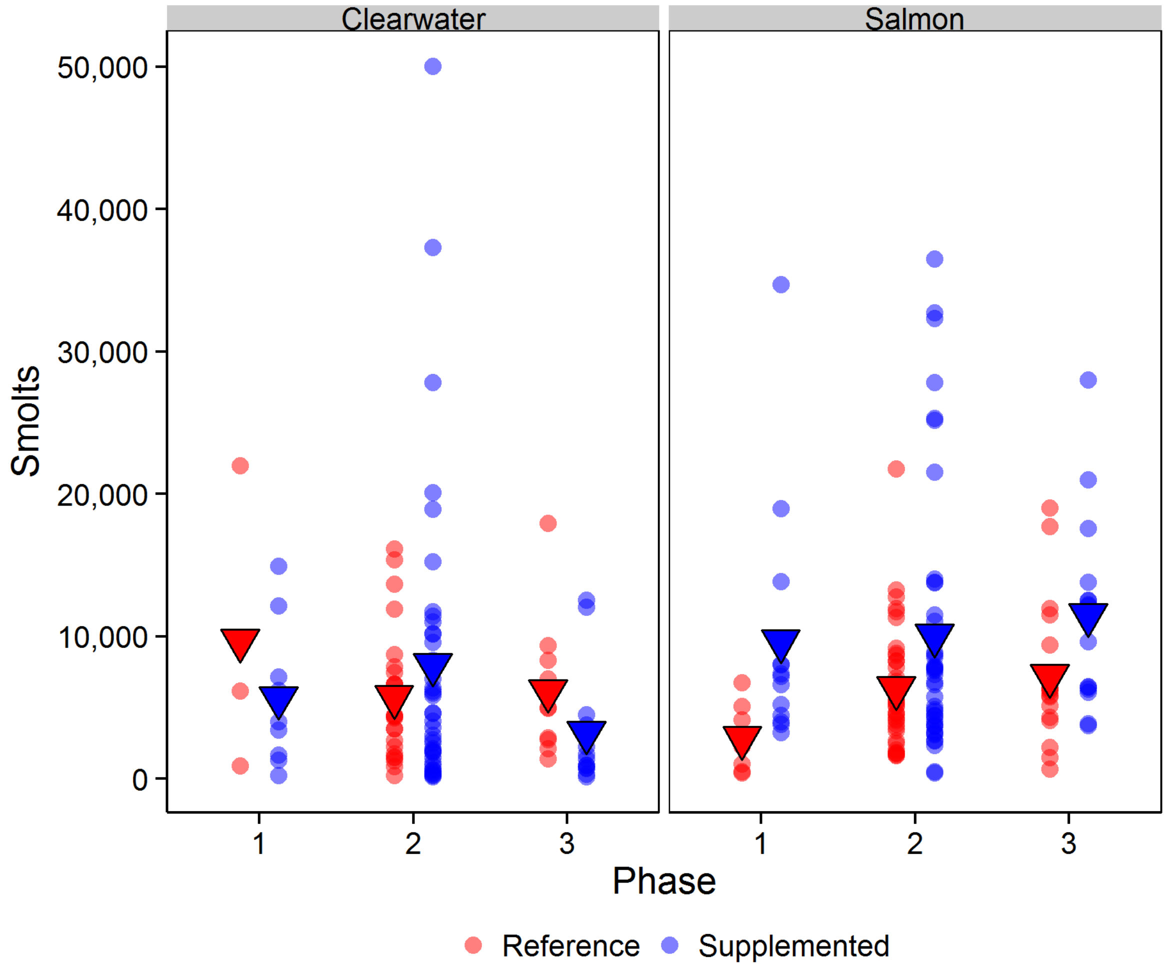


Figure 14. The number of smolts at LGR by phase from study streams (includes both fall and spring emigrants at rotary screw traps). Triangles represent the average number within phase, stream type, and basin. Filled circles represent brood year estimates.

Adult Progeny Returning to Weirs

Supplementation adults returned to ISS weirs starting in return year 1995 and continuing through 2007, representing brood years 1993-2002. These returning supplementation fish were used for broodstock and adult treatments. Low adult returns during the early years of the program (1991 – 1996) affected our ability to meet project goals. Low returns forced a compromise between passing sufficient supplementation adults to provide a detectable treatment effect with the concurrent need to pond sufficient adults to create the next cohort of supplementation juveniles.

Natural-origin and supplementation adult returns by brood year (both male and female) in the Clearwater and Salmon basins showed similar trends with natural-origin returns typically more numerous than supplementation returns. In both basins, adult returns of either origin were low in the early years resulting in the previously mentioned need to balance releases against ponding fish for broodstock needs. Crooked River was an exception where more supplementation Chinook Salmon returned than natural-origin fish in all years.

ANALYTICAL RESULTS

Overview

In this section, we present our modeling results for the basin-level and intensive analyses. Basin-level results include expected changes in abundance and productivity due to supplementation through the life cycle. Inference is based on model parameters. We illustrate the expected size of the supplementation effect on both abundance and productivity measures by varying the parameter of interest while setting all other parameters to their average. Next, we provide a measure of model fit to assess how well our models explained the data. Results from the intensive analyses of treatment streams with weirs demonstrate 1) the response of supplementation adult returns from the release of fall and spring hatchery juveniles; and 2) the effect of spawning females of different origins on abundance measures through the life cycle. Finally, we provide information to assess how well intensive models explained the data. Detailed results of model rankings, averaged estimates, and random effect variance estimates from basin-level and intensive analyses are presented in Appendices B and C.

Basin-Level Analyses of Abundance and Productivity

Population Abundance

Expected abundance at all four life stages generally increased across study phases for both reference and supplemented streams (Figure 15). In the Clearwater basin, there were differences through the life cycle. Expected smolt abundance remained flat and adult progeny declined in supplemented streams in Phase 3. In the Salmon basin, increases with study phase were more consistent. However, there was a lot of variability around the expected abundances. The thin lines in Figure 15 represent average abundance from each stream and phase, illustrating the inherent variability across study streams.

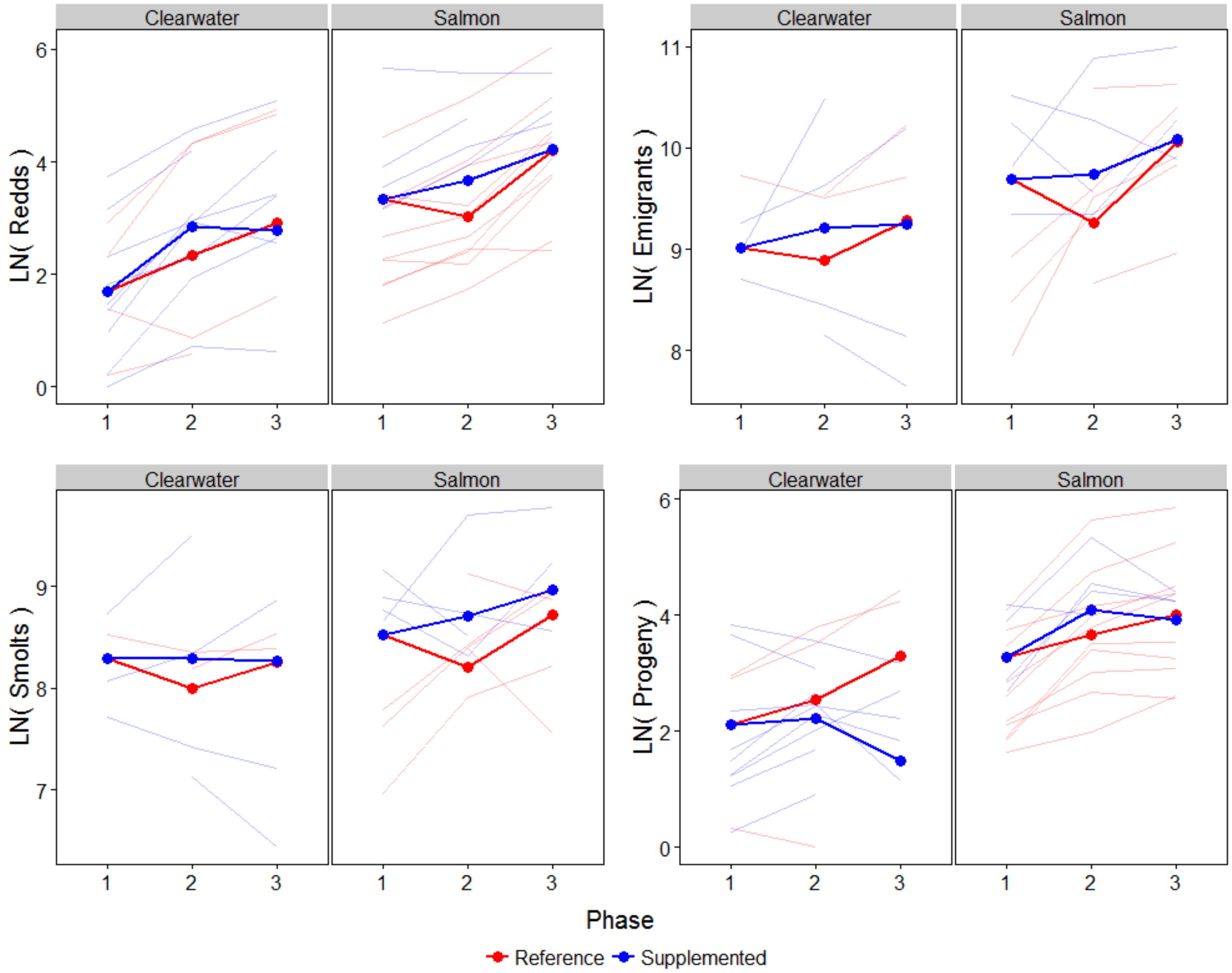


Figure 15. Bold lines indicate abundance during each phase at four life stages assuming an average adult female treatment (Clearwater = 39, Salmon = 76) in supplemented streams relative to reference streams as estimated from model-averaged coefficients. The baseline difference between reference and supplemented streams is removed from each phase estimate, resulting in Phase 1 being equal for both stream types. The remaining difference between reference and supplemented streams in Phase 2 and III represent the change from the baseline relationship. The thin lines are each stream's average abundance by study phase.

In the Clearwater basin during Phase 2, the point estimates of supplementation effect size decreased across the four life stages. We detected a positive change in total redds in Phase 2 (β_2 = 0.17; SE = 0.08; Equation 1.1) and this was the only life stage where the coefficient CI did not overlap zero (Figure 16; Appendix B). Increasing adult female treatment by 25.0% would increase redds by 3.9% on average ($1.25^{0.17} = 1.039$). Clearwater streams also showed positive increases in emigrants at RST (β_2 = 0.11; SE = 0.11) and smolts at LGR (β_2 = 0.10; SE = 0.09) during Phase 2 (Appendix B. Basin-level Output). Using the same arbitrary increase in adult female treatments of 25.0% and corresponding β_2 coefficients, emigrants at RST would increase by 2.5% and smolts at LGR would increase by 2.3%, slightly less than the expected increase for redds. A negative effect for adult progeny returns was estimated in the Clearwater during Phase 2 with a 2.4% decrease (β_2 = -0.11; SE = 0.08) when female treatments increased by 25.0% (Figure 16).

During Phase 3 in the Clearwater basin, point estimates of the supplementation effects were similar with one exception. Confidence intervals with respect to redd abundance (β_4 = -0.12; SE = 0.26; Equation 1.1), emigrants at RST (β_4 = -0.04; SE = 0.20), and smolts at LGR (β_4 = 0.01; SE = 0.16; Figure 16) all overlapped zero. However, CIs around the adult progeny estimate did not overlap zero, demonstrating a negative supplementation effect, although the width of the CI suggests the estimate is imprecise. The estimate is imprecise due to few Phase 3 adult progeny response observations in reference streams (N = 4 stream/year combinations) in this basin. This effect was estimated to reduce adult progeny by 83.5% (β_4 = -1.8; SE = 0.51; $1 - \exp^{-1.8} = 0.835$) relative to reference streams (Figure 16).

In the Salmon basin during Phase 2, point estimates of supplementation effects were small and positive, but CIs for these estimates did not overlap zero (Figure 16). All point estimates were similar: by life-stage, coefficient values were redds (β_2 = 0.17; SE = 0.04), emigrants at RST (β_2 = 0.13; SE = 0.06), smolts at LGR (β_2 = 0.14; SE = 0.06), and adult progeny (β_2 = 0.12; SE = 0.05). Increasing adult female treatment by 25.0% would increase redds by 3.9% ($1.25^{0.17} = 1.039$). For the same increase in adult female treatment rates, expected abundance increase was slightly lower at the emigrant at RST, smolt at LGR, and adult progeny life stages with 2.9%, 3.2%, and 2.7% increases, respectively. The smallest effect size occurred at the life-cycle evaluation point furthest in time from the treatment action, natural-origin adult progeny returns.

During Phase 3 in the Salmon basin, CIs about the treatment effects overlapped zero (Figure 16). Abundance in supplementation and reference streams in Phase 3 returned to approximately their Phase 1 relationship (i.e., $\beta_4 \approx 0_)$; Equation 1.1) for redds (β_4 = 0.03; SE = 0.15), and emigrants at RST (β_4 = 0.03; SE = 0.16). The number of smolts at LGR was 28.4% higher in supplemented streams (β_4 = 0.25; SE = 0.31). Expected adult progeny returns in Phase 3 were 8.6% lower (β_4 = -0.09; SE = 0.22) relative to reference streams.

Population Productivity

Productivity measures predominantly decreased during the study (Figure 17). The expected number of emigrants at RST per redd in both basins and stream types declined sharply from Phase 1 to Phase 2 and remained similar between Phase 2 and Phase 3. Expected number of smolts at LGR per redd followed the same pattern except supplemented streams in the Salmon basin had a near linear decline from Phase 1 to Phase 3. Adult progeny per parent estimates showed different trends between basins but supplemented and reference streams were consistent within basins. In the Clearwater basin, adult progeny declined almost linearly from Phase 1 to Phase 3 in both supplemented and reference streams. In the Salmon basin, adult progeny per parent increased from Phase 1 to Phase 2 and then declined in Phase 3 for both stream types (Figure 17). In general, streams in Phase 3 experienced the lowest productivity for all life-stages in both Clearwater and Salmon basin during the course of the project. Expected productivities show approximately the same value (at all life stages) in reference and supplemented streams during Phase 3.

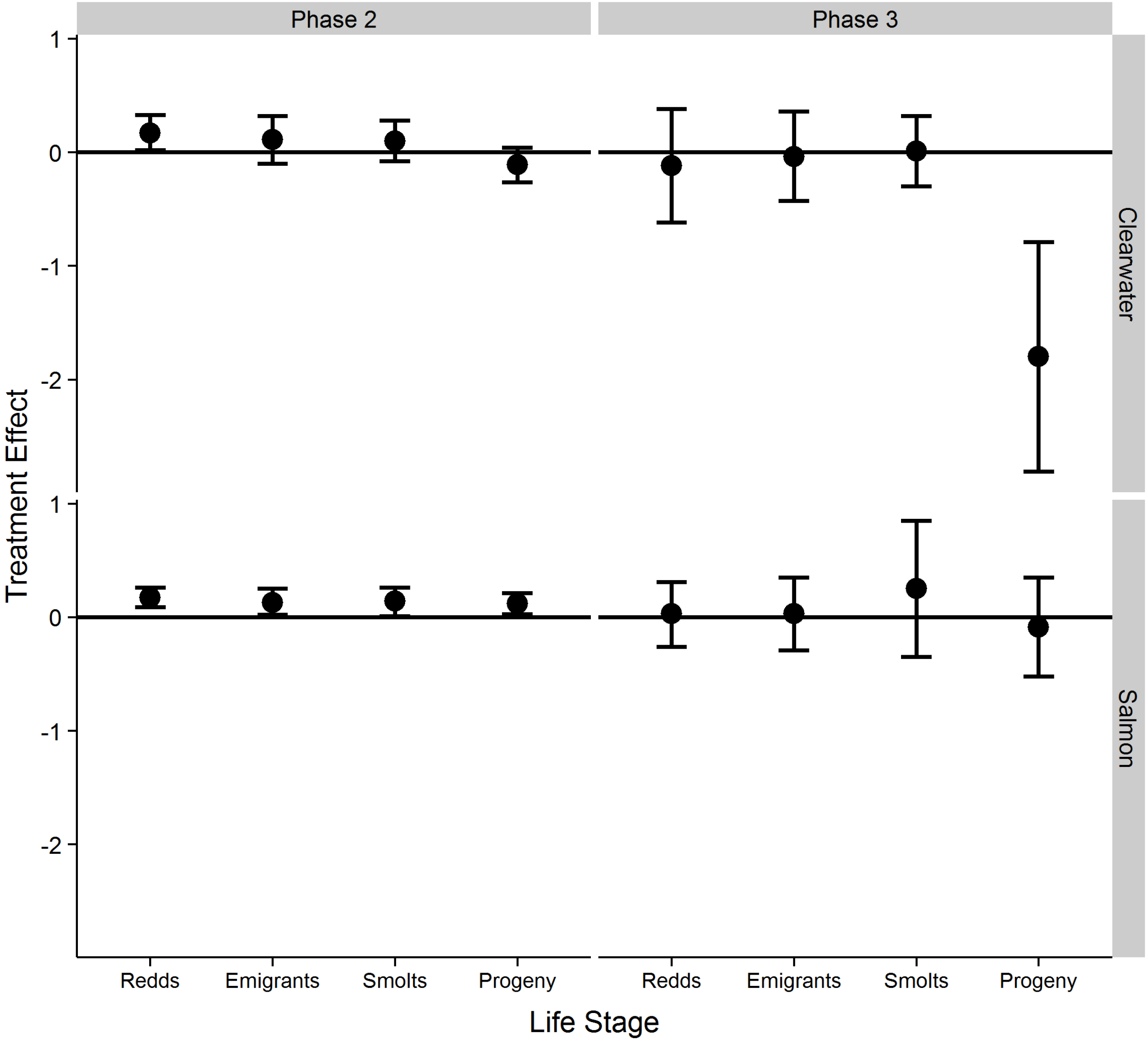


Figure 16. Model-averaged coefficient estimates for the Phase 2 (β_2) and Phase 3 (β_4) supplementation effects in Equation 1.1 on abundance response variables by life stage using adult females as a treatment. Inference of a supplementation treatment effect is evident by 95% confidence intervals not overlapping zero, while no evidence is indicated by intervals overlapping zero.

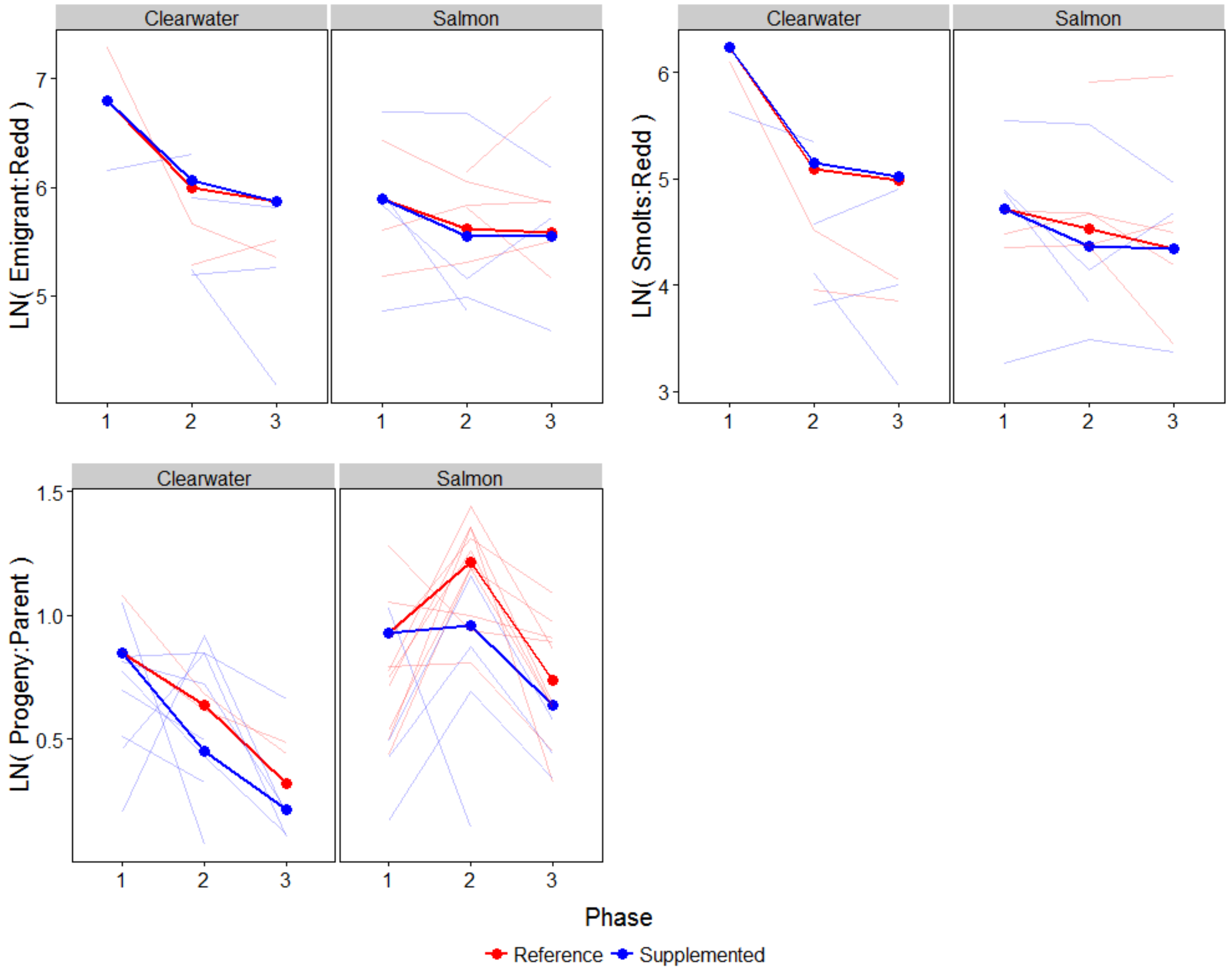


Figure 17. Bold lines indicate productivity during each phase at four life stages assuming an average adult female treatment (Clearwater = 39, Salmon = 76) in supplemented streams relative to reference streams as estimated from model-averaged coefficients. The baseline difference between reference and supplemented streams is removed from each phase estimate, resulting in Phase 1 being equal for both stream types. The remaining difference between reference and supplemented streams in Phase 2 and III represent the change from the baseline relationship. The thin lines are each stream's average productivity by study phase.

In the Clearwater basin, CIs for all treatment effects in Phase 2 and Phase 3 overlapped zero (Figure 18). Phase 2 effects for emigrants at RST per redd (β_2 = 0.02; SE = 0.06; Equation 1.1) and smolts at LGR per redd (β_2 = 0.02; SE = 0.06) were estimated at less than a 1.0% increase with a 25.0% increase in adult female treatments. Emigrants at RST per redd values in Phase 3 (β_4 = 0.01; SE = 0.11) were increased by approximately 1.0% with a 25.0% increase in adult female treatments in supplemented streams as compared to references, and smolts at LGR per redd (β_4 = 0.04; SE = 0.18) were 4.1% higher than in reference streams. Treatment coefficient values were negative during both phases (β_2 = -0.06; SE = 0.05; β_4 = -0.10; SE = 0.23) for adult progeny per redd, translating to a 1.3% reduction for a 25% increase in adult female treatments in Phase 2 and a 9.5% reduction in supplemented streams relative to reference streams in Phase 3.

In the Salmon basin, CIs around all productivity coefficients overlapped zero except one (Figure 18). Point estimates of these coefficients suggest supplemented streams in the Salmon basin experienced a decrease in productivity through the life cycle in Phase 2 and Phase 3, but only the Phase 2 adult progeny per parent estimate had a CI that did not overlap zero. The Phase 2 reduction in productivity resulted in decreases of 0.4%, 1.1%, and 1.5% for a 25.0% increase in adult female treatments for emigrants at RST per redd (β_2 = -0.02; SE = 0.03), smolts at LGR per redd (β_2 = -0.05, SE = 0.05), and adult progeny per parent (β_2 = -0.07, SE = 0.03). Estimated Phase 3 supplementation effects on emigrants at RST per redd (β_4 = -0.03, SE = 0.11), smolts at LGR per redd (β_4 = -0.01, SE = 0.11), and adult progeny per redd (β_4 = -0.10, SE = 0.17) suggest productivity would decrease by 3.0%, 1.0% and 9.5%, respectively.

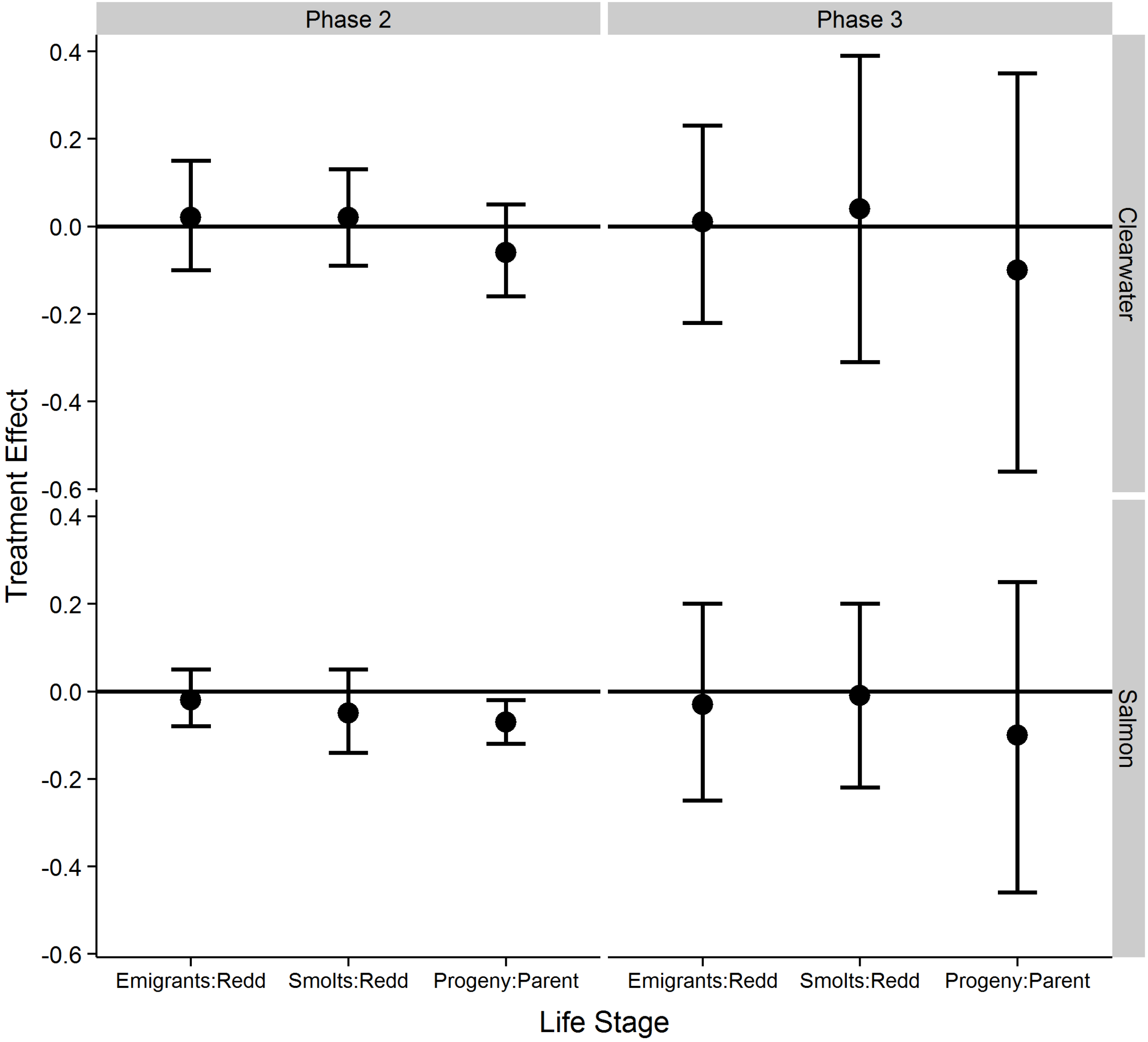


Figure 18 Model-averaged coefficient estimates for the Phase 2 (β_2) and Phase 3 (β_4) supplementation effects in Equation 1.1 on productivity response variables by life stage using adult females as a treatment. Inference of a supplementation treatment effect is evident by 95% confidence intervals not overlapping zero, while weak or no evidence is indicated by intervals overlapping zero.

Effects of Non-treatment Hatchery Fish

The proportion of non-treatment hatchery adults (both sexes combined, including jacks) spawning in study streams was associated with an increase in redd abundance, but this effect declined throughout the life cycle (Figure 19). The pattern and direction of effects were consistent in magnitude across basins for the abundance responses but differed for productivity measures. The redd response variable had the strongest relationship with the non-treatment hatchery proportion with an effect size in the Clearwater basin of β_5 = 0.60 (SE = 0.20; Equation 1.1) and in the Salmon basin of β_5 = 0.66 (SE = 0.28); the CIs on these estimates did not overlap zero. Non-treatment hatchery effects on the abundance of emigrants at RST were slightly smaller than redds with an estimate in the Clearwater basin of β_5 = 0.35 (SE = 0.40) and in the Salmon basin of β_5 = 0.41 (SE = 0.42). The effect continued to decline on smolts at LGR and adult progeny in the Clearwater basin with estimates of β_5 = 0.11 (SE = 0.25) and β_5 = 0.09 (SE = 0.17), respectively. The Salmon basin showed similar declines to β_5 = 0.08 (SE = 0.23) and β_5 = 0.08 (SE = 0.19) for smolts at LGR and adult progeny, respectively. Of the latter four coefficient estimates, all had CIs overlapping zero.

In both basins, non-treatment hatchery effects on most productivity coefficient estimates were negative (Figure 19). The estimated effects in the Clearwater basin were β_5 = -0.43 (SE = 0.37), β_5= -0.92 (SE = 0.38) and β_5 = -0.01 (SE = 0.07) for emigrants at RST per redd, smolts at LGR per redd, and adult progeny per parent, respectively. The estimated effects in the Salmon basin were β_5 = -0.04 (SE = 0.16), β_5 = -0.04 (SE = 0.16), and β_5 = -0.37 (SE = 0.18) emigrants at RST per redd, smolts at LGR per redd, and adult progeny per parent, respectively. Of these estimates, only smolts at LGR per redd in the Clearwater and adult progeny per redd in the Salmon basin did not have CIs overlapping zero. A more thorough interpretation of the effects of non-treatment hatchery fish will be presented in the Intensive Analyses of Study Streams with Weirs section, below.

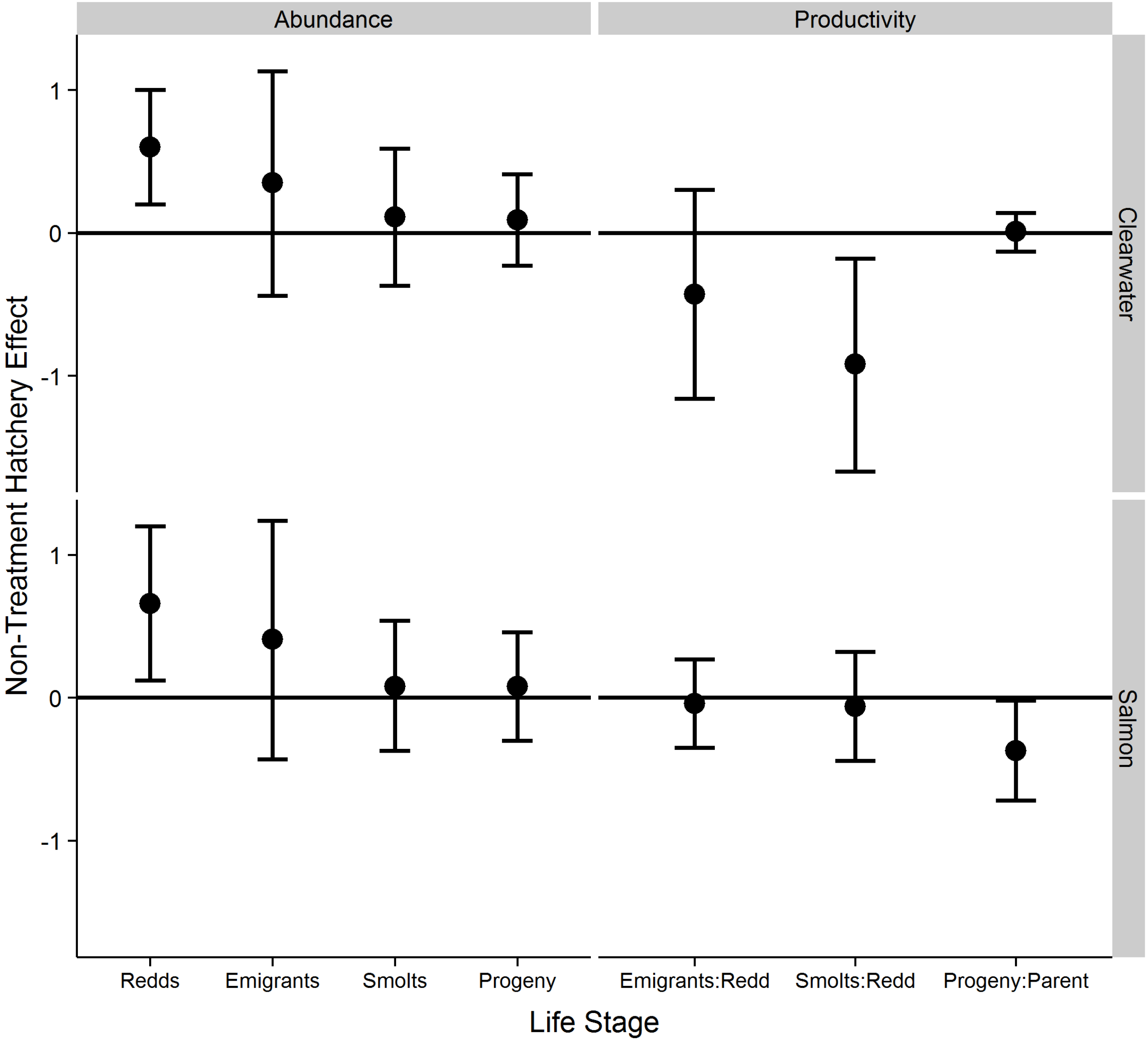


Figure 19. Model-averaged coefficient estimates for the effect of non-treatment hatchery adults in Equation 1.1 on abundance and productivity response variables by life stage. Inference of an effect is evident by 95% confidence intervals not overlapping zero, while no effect is indicated by intervals overlapping zero.

Variance Explained

The models explained a large proportion of the variance in the data. Conditional R^2 averaged 58.1% for the Clearwater and 66.3% for the Salmon datasets and ranged from 17.2-82.4% and 53.4-83.7%, respectively. However, the amount of variation explained by fixed effects (marginal R^2) was small compared to the amount explained by random effect portions of each model. Examining the Clearwater datasets, marginal R^2 averaged 12.1% and ranged from a low of 3.3% for smolts at LGR to a high of 34.2% for smolts at LGR per redd data. Marginal R^2 values in the Salmon River averaged 9.2% and ranged from a low of 4.4% for adult progeny data to a high of 15.2% for smolts at LGR. Using the average variation explained across all response variables, fixed effects accounted for a small proportion of all explained variation: 20.8% (0.121/0.581) for the Clearwater and 13.9% (0.092/0.663) for the Salmon.

The random terms accounting for the largest amount of variance in abundance and productivity analyses were consistent across the two basins. The year term explained most of the variation in the emigrants at RST, smolts at LGR, and adult progeny per parent responses. Total redd and adult progeny variation was driven by the stream within group term in the Clearwater basin and group term in the Salmon basin. This suggests that streams within Clearwater geographic groups have different levels of spawner abundance, where the Salmon basin has similar numbers of spawners within a group. The unexplained residual variance term was largest in the emigrants at RST per redd and smolts at LGR per redd analyses, potentially because the important year effect on juvenile abundance and stream effect on redds canceled each other when examining the quotient of emigrants at RST or smolts at LGR per redd.

Intensive Analyses of Supplemented Streams with Weirs

Supplementation Return

A significant relationship was found between supplementation juveniles released (β_1 = 1.02, SE = 0.29; Equation 1.2) and corresponding adult returns (Table 7; Figure 20). The estimated rate of adult returns increased by 25.6% for an additional 25.0% release of supplementation juveniles. Adult returns were 63.2% higher for supplementation juveniles released as smolts in the Salmon basin (β_2 = 0.49, SE = 0.66; Equation 1.2) compared to supplementation juveniles released as presmolts in the Clearwater basin if equal numbers of juveniles were released. However, confidence intervals overlapped zero (Table 7).

Table 7. Parameter estimates from model averaging using juveniles released (R_{jt}) and life-stage (L_{jt}) to predict supplementation brood year return.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
Intercept	-7.53	3.37	-14.14	-0.93
R_{jt}	1.02	0.29	0.45	1.59
L_{jt}	0.49	0.66	-0.81	1.79

The model explained approximately 66.3% of the variation (conditional R^2). Most of the variation was attributed to the year term with unexplained residual variance accounting for a similar amount. Fixed terms in the basin-level model (intercept, juveniles released, release stage) accounted for 29.0% of the variation (marginal R^2).

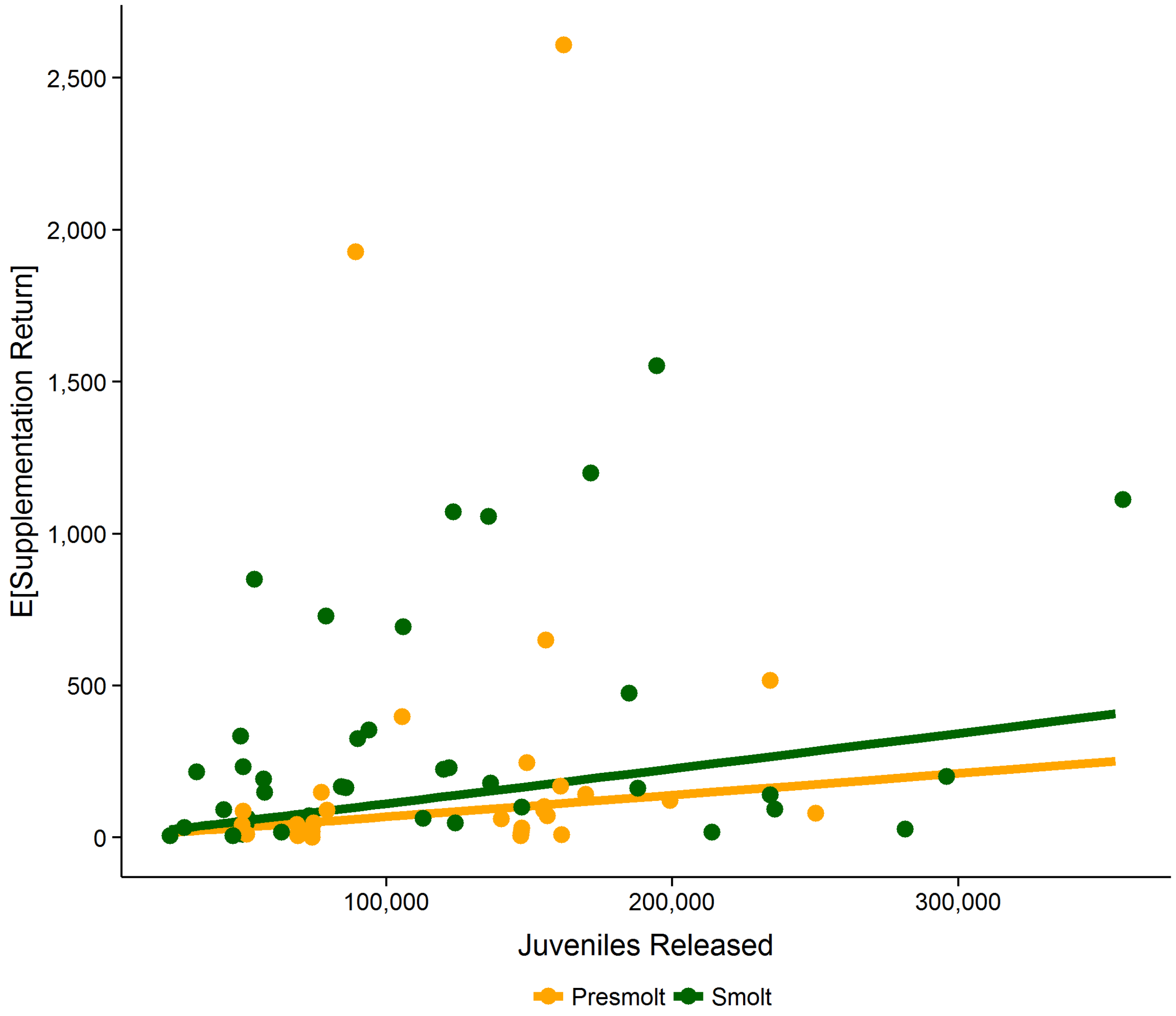


Figure 20. Expected brood year returns of ISS supplementation fish regressed upon the numbers of juveniles released show a positive trend for both supplementation-origin presmolt and smolt release groups.

Population Abundance

Population abundance at all life stages increased with the addition of female spawners, but the rate of increase varied depending on origin and diminished through the life cycle (Figure 21; Appendix B). Natural-origin females were the most effective at increasing redd abundance followed by supplementation and then non-supplementation hatchery females. Natural-origin females in the Clearwater basin constructed redds at a rate slightly less than 1:1 (β_1 = 0.86, SE = 0.13; Equation 1.3), assuming all parameters were held at their averages. Natural-origin females in the Salmon basin were found to construct redds at a 1:1 ratio (β_1 = 1.02, SE = 0.05). Supplementation females in the Clearwater basin constructed redds at a rate much less than 1:1 (β_2 = 0.58, SE = 0.45), while supplementation females in the Salmon basin were more effective (β_2 = 0.72, SE = 0.18). Non-treatment hatchery females in the Clearwater basin constructed redds at a low rate (β_3 = 0.03, SE = 0.15), while those in the Salmon basin were more effective (β_3 = 0.24, SE = 0.25). For the estimates above, the effects of natural-origin females in both basins and supplementation females in the Salmon basin had CIs that did not overlap zero.

The effectiveness of females by origin on emigrants at RST was similar to that observed for redds (Figure 21). The change in emigrants at RST was similar across the two basins for natural-origin female spawners (Figure 21; Clearwater: β_1 = 0.77, SE = 0.17; Salmon: β_1 = 0.76, SE = 0.09; Equation 1.3). The effects of supplementation females was lower in the Clearwater basin (β_2 = 0.04, SE = 0.21) than in the Salmon basin (β_2 = 0.35, SE = 0.37). Non-treatment hatchery spawners had a negative effect on emigrants at RST in the Clearwater basin (β_3 = -0.12, SE = 0.28) and a positive effect in the Salmon basin (β_3 = 0.62, SE = 0.47). For the estimates above, only the effects of natural-origin females had CIs that did not overlap zero.

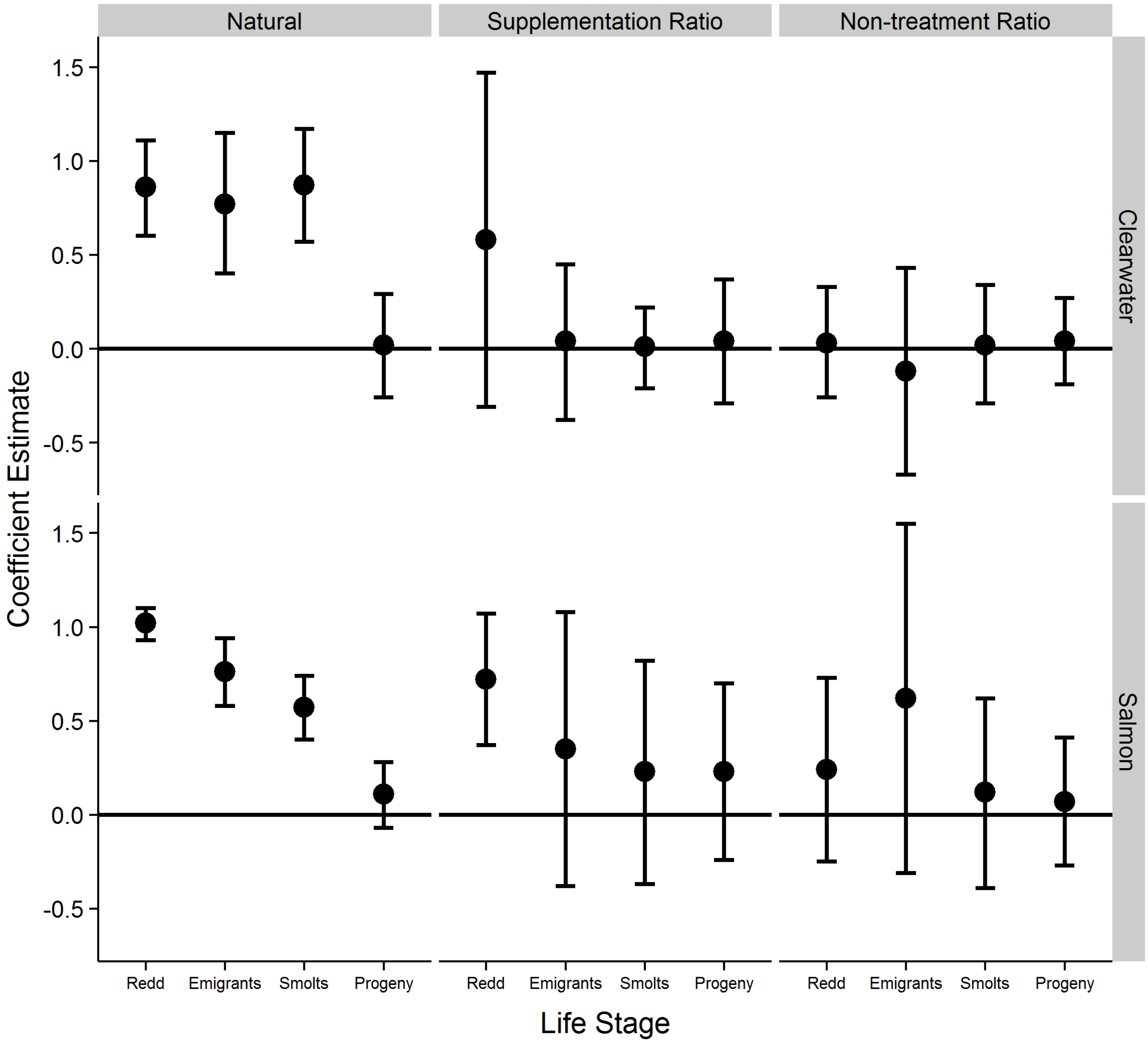


Figure 21. Model-averaged coefficient estimates for the effect of natural females, supplementation ratio, and non-treatment hatchery fish ratio in Equation 1.3 by life stage. Inference of an effect is evident by 95% confidence intervals not overlapping zero.

The effectiveness of females by origin on smolts at LGR was similar to that observed for redds (Figure 21). Assuming an average number of natural-origin female spawners in each respective basin, more smolts at LGR were observed for the Clearwater basin (β_1 = 0.87, SE = 0.15) as compared to the Salmon basin (β_1 = 0.57, SE = 0.09). The effect of supplementation females was smaller in the Clearwater basin (β_2 = 0.01, SE = 0.11) than in the Salmon basin (β_2 = 0.23, SE = 0.30). The effect of non-treatment hatchery females was smaller in the Clearwater basin (β_3 = 0.02, SE = 0.16) compared to the Salmon basin (β_3 = 0.12, SE = 0.26). For the estimates above, only the effects of natural-origin females had CIs that did not overlap zero.

The effectiveness of females on adult progeny was low for all origins (Figure 21). Assuming an average number of natural-origin female spawners in each respective basin, fewer adult progeny were observed for the Clearwater basin (β_1 = 0.02, SE = 0.14) as compared to the Salmon basin (β_1 = 0.11, SE = 0.09). The effect of supplementation females was smaller in the Clearwater basin (β_2 = 0.04, SE = 0.17) than in the Salmon basin (β_2 = 0.23, SE = 0.24). The effect of non-treatment hatchery females was similar in the Clearwater basin (β_3 = 0.04, SE = 0.12) compared to the Salmon basin (β_3 = 0.07, SE = 0.18). For the estimates above, all CIs overlapped zero.

Supplementation ratio had a strong effect on our predicted abundance measures, assuming no non-treatment hatchery females escaped. A greater increase in redds, emigrants at RST, and smolts at LGR abundance response variables was observed when female spawners were 100% natural-origin across both basins (Figure 22). The three response variables continued to increase as the supplementation ratio (supplementation females:natural-origin females) became larger, but the rate of increase began to decline.

The relationship between natural-origin adult progeny and supplementation ratio was weak (Figure 22, bottom right panel). In the Clearwater basin, estimated increases were less than 1.0% for a 25.0% increase in either natural-origin females, or supplementation ratio. Estimates for the Salmon basin were slightly larger, with the largest effect of a 5.3% increase in adult progeny for a 25.0% increase in the supplementation ratio.

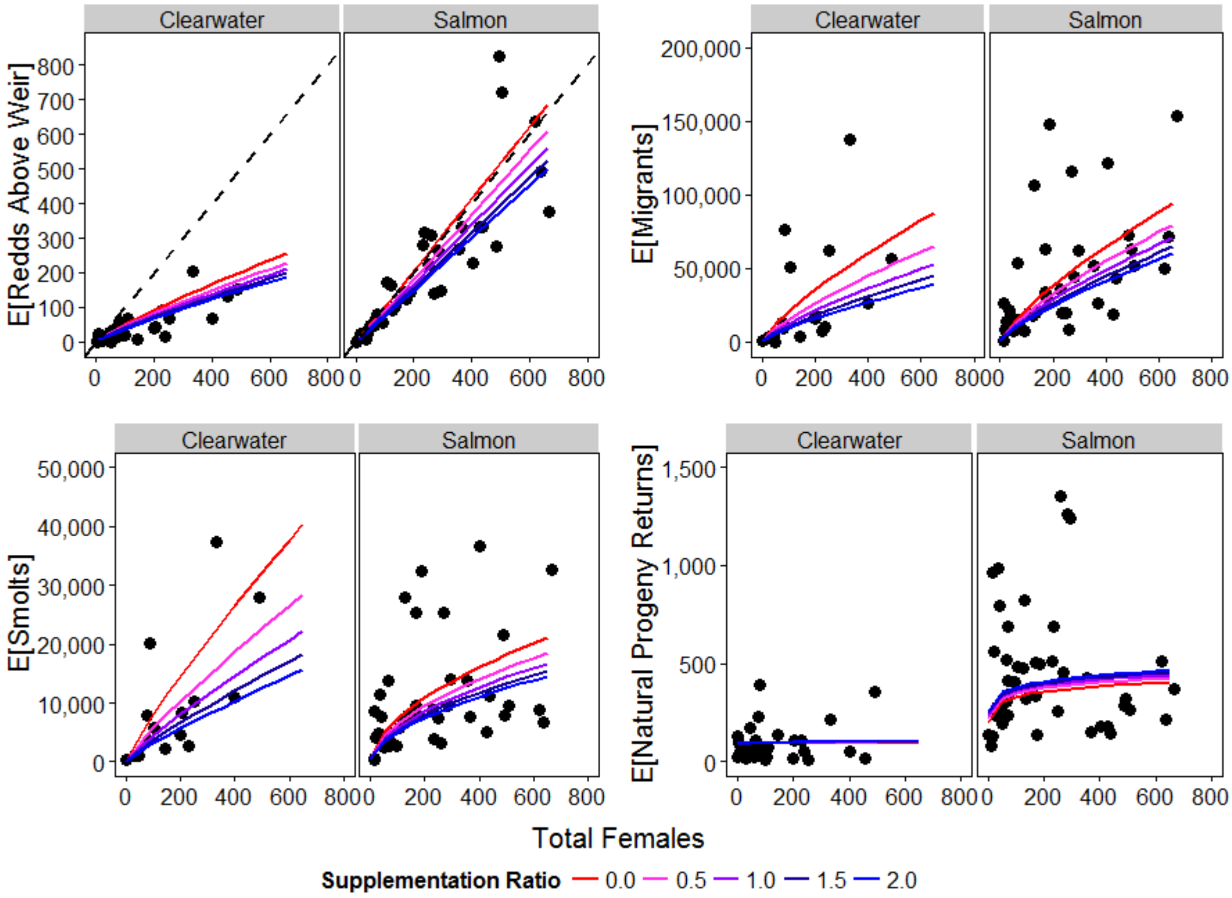


Figure 22. Expected change in response variables relative to differing supplementation ratios of supplementation to natural-origin females released onto the spawning grounds.

Variance Explained

The models used in the intensive analyses of supplemented streams with weirs explained a large proportion of the variance in the data, particularly for the freshwater life stages. Conditional R^2 ranged from 80.5% (redds) to 89.9% (adult progeny) for the Clearwater datasets and from 78.7% (smolts at LGR) to 94.4% (redds) for the Salmon dataset. In this suite of analyses, the fixed effects explained most of the variance. In general, marginal R^2 values declined progressively through the life cycle. In the Clearwater basin, marginal R^2 values were 68.2% for redds, 50.0 % for emigrants at RST, 72.1% for smolts at LGR, and 1.2% for adult progeny. Marginal R^2 values for the Salmon River datasets were 90.4% for redds, 56.9% for emigrants at RST, 43.3% for smolts at LGR, and 7.6% for adult progeny. This indicates that fixed effects (things a supplementation program can control) are important predictors of abundance during the freshwater portion of the life cycle, but random effects (those outside of programmatic control) drive adult returns.

DISCUSSION

Supplementation resulted in a population boost that did not persist in the post-supplementation phase. Abundance, as measured by redd counts, increased across both basins but supplemented streams increased more than reference streams during the treatment phase. The observed abundance increase diminished through the life cycle (emigrants at RST, smolts at LGR, adult progeny) and this trend was consistent across both the Clearwater and Salmon basins. We observed similar overall patterns when addressing effects of non-treatment hatchery fish on redd abundance, but positive effects of these fish were not observed in juvenile life stages or in adult progeny. After supplementation treatments ceased, abundance and productivity at each life stage in treated and reference streams returned to their Phase 1 relationship, suggesting supplementation did not have a lasting positive influence on abundance and productivity. With one exception (discussed below), we did not observe negative effects. Random stream, geographic group, and year effects explained the majority of the variation in all models, suggesting factors outside the study design (e.g., hydrosystem, ocean conditions, population life history differences) have a much greater influence on abundances and productivity than factors under the control of supplementation programs (e.g., number of juveniles or adult females released, supplementation ratio, or broodstock type).

The ISS study design was robust enough to allow inference on supplementation and post-supplementation effects. The multiple life stage approach in the ISS study design is one of its primary strengths. While adult, natural-origin progeny represent the ultimate response desired, developing estimates of supplementation effects on other life stages provide important insight into the mechanisms behind that response. Likewise, addressing supplementation across two large basins allows for greater generality of inference. The range of treatment-ratios observed provided statistical power to estimate the increase in population response due to an increase in supplementation ratio. We observed common results across basin and life stages, suggesting the results of ISS have applicability to other systems where supplementation occurs. The inferences made in this report are general but inter-population variability shows supplementation should be customized to the target population.

Below, we revisit the specific objectives and questions this report addresses. In the first section, we review the effects of supplementation on abundance across all populations through the life cycle, and in the second section, we discuss the effects of supplementation on population productivity in all populations. These are our basin-level analyses. In the third section, which is intensive studies of supplemented streams with weirs, we discuss the relationship between juvenile release life stage and adult returns, and investigate population response to passage at weirs of females by origin type. The results are then reviewed with reference to salmon population dynamics and evolution. Finally, we provide management recommendations to guide future use of supplementation and identify areas for further research.

Basin-level Analyses of Abundance and Productivity

Population Abundance

There are many ways supplementation could be accomplished and the results investigated. Although supplementation programs differ greatly from conventional hatchery programs in their focus on recovery of wild populations, in the scale of production, and in the mode of its deployment, they differ only subtly in many of the fish culture and husbandry methods used (ISAB 2003). Studies on aspects of the individual performance of hatchery fish in the wild are becoming more common in the literature (e.g., relative fitness [Araki et al. 2008] or life history [Knudsen et al. 2006, Hoffnagle et al. 2008]) but demographic evaluations of supplementation programs have been more limited (e.g., Sharma et al. 2006, Berejikian et al. 2008). This study addresses demography across multiple watersheds and life stages, which provides unique insight into supplementation and its effects.

The strongest response to treatment observed by ISS was the immediate production of redds resulting from passage of females into spawning reaches. During treatment, we observed positive effects on abundance across all life stages in the Salmon basin, but only on redd production in the Clearwater basin. Response of the reference streams showed that abundance increased in all study streams across phases but, on average, the increase was greater in supplemented streams during the treatment phase.

During Phase 3, differences between supplemented and reference streams were largely negligible, but there are two notable exceptions to this pattern. First, in the Clearwater basin, we observed a negative treatment effect of supplementation on the abundance of adult progeny. This negative effect was driven by a large increase in redd counts and a low proportion of non-treatment hatchery spawners in American River and Crooked Fork Creek during 2013 and 2014, relative to other years. These were the reference streams with the highest abundances in the Clearwater basin (Figure 15, top two fine red lines). Our low- productivity reference streams (Eldorado Creek and White Cap Creek) were not included in Phase 3, because we did not have age data to assign adult progeny to BY. The other exception was the post-treatment increase in the Salmon basin smolt at LGR abundance, which generated the largest positive treatment effect observed in the Salmon basin during either phase, although the bounds on this estimate were large and overlapped zero. Here, the response was driven by smolt at LGR production in the Pahsimeroi River, which may be attributed to habitat restoration programs (e.g., removal of barriers in spawning reaches) in this stream. This effect may be exacerbated by generally declining smolt survival between Phase 2 and Phase 3 in reference streams (see Brood Year Report 2002 and later, citations in Appendix D). Both exceptions are driven by localized factors, but we are not able to definitively identify causative mechanisms with the data available. Regardless, both cases are inconsistent with other responses observed across phases, basins, and life stages.

The presence of non-treatment adults in the spawning populations had a positive effect on abundance. The proportion of non-treatment adults was positively related with redd abundance but this effect declined through the life cycle. However, because of the way we were forced to measure the effects of these fish over all study populations (as a proportion), it is difficult to interpret this effect in real terms. That is, we had no way to estimate the number of hatchery fish straying into the reference streams without expanding the proportion with the redd count, thus putting redd counts on both sides of the equation. Control afforded by weir operations allows direct estimation of non-treatment adult abundance and we address interpretation in the Intensive Studies of Supplemented Streams with Weirs section.

Abundance increases in response to supplementation treatments are commonly observed. Sharma et al. (2006) found that supplementation of a coho population on the Washington (USA) coast increased total adult return and was necessary to maximize adult production unless freshwater and ocean conditions were optimal. The authors concluded that supplementation could slow declines and provide increased capacity for recovery. Chum Salmon populations in the Strait of Juan de Fuca and Hood Canal increased in abundance since supplementation programs were initiated in the 1990s (PNPTT and WDFW 2014). Supplementation of steelhead in the Hamma Hamma River on the Olympic Peninsula increased redds without reducing production of natural-origin fish (Berejikian et al. 2008). In the Yakima River, supplementation increased spring Chinook Salmon redd counts 126% since supplementation began, compared to a 52% increase in an unsupplemented reference stream (Fast et al. 2015).

In the Snake River basin, supplementation programs have had smaller effects on abundance. Scheuerell et al. (2015) did a large-scale analysis of 22 spring/summer Chinook Salmon populations across the Salmon, Grande Ronde, and Imnaha river basins and found that spawner densities increased 0%-8% relative to unsupplemented years. We also found small effects of supplementation: boosting female abundance by 25% resulted in a change in progeny redds of -2.4% to +2.7%. Some evaluations concluded that supplementation sustained a population when returns were critically low but did not result in rebuilding populations (e.g., Cleary et al. 2014; Gallinat and Ross 2015). When hatchery salmon are passed into streams from which they have been extirpated (e.g., the Clearwater River basin prior to ISS), natural reproduction is observed (e.g., Fleming and Petersson 2001; Boe and Crump 2015) and natural-origin populations are re-established (Kline and Flagg 2014; Galbreath et al. 2014; Anderson et al. 2015).

Unless factors causing population depression are ameliorated, abundance increases resulting from supplementation are unlikely to persist. The ISAB (2003) noted that the presence of appreciable numbers of hatchery-origin adults on the spawning grounds in the late 1980s and early 1990s did not prevent declines in the abundance of natural-origin spawning adults in the mid-1990s. Goodman (2004) predicted that increased population size attributable to supplementation alone would likely not persist after the termination of supplementation. However, some Chum Salmon populations continue to increase after cessation of supplementation but management of these populations also addressed harvest and habitat issues, which were believed to be responsible for population declines (PNPTT and WDFW 2014). We found that abundance in ISS study streams continued to increase post-supplementation but that this increase occurred in reference streams as well as supplemented streams. This observation shows the influence of common out-of-basin factors on salmon abundance in the Clearwater and Salmon basins.

Our overall conclusion is that supplementation increased abundance but the effect was short-lived. There also did not appear to be negative short-term effects on abundance after supplementation ceased. Further, the presence of non-treatment adults on the spawning grounds had a positive effect on the number of redds but those effects diminished through the life cycle. To ascertain why these results were observed, we must examine population productivity and responses of the treated populations upstream of weirs.

Population Productivity

We did not observe an effect on emigrants at RST per redd and smolts at LGR per redd (productivity) into the populations in any phase, but there was a negative effect on adult progeny per redd in Phase 2. The expected number of emigrants at RST per redd and smolts at LGR per redd were nearly identical between supplemented and reference streams. All effects were essentially the same in both basins, but only adult progeny per parent redd in the Salmon basin was precise enough to distinguish from zero during the treatment phase. Confidence intervals were much wider for Phase 3 parameter estimates relative to Phase 2 because we estimated Phase 3 parameters based on relatively few years, with a concurrent reduction of the number of streams in the analyses due to management actions.

In contrast to the trend in abundance, population productivity declined across phases in reference and supplemented streams. That is, per capita contribution to juvenile life stages and next-generation adults decreased even as total abundance increased in the study populations. Two non-exclusive potential mechanisms could explain this trend. The first is that these populations may be operating at or near density dependence in the core habitats in which they are spawning (Walters et al. 2013). The second is that domestication effects on hatchery fish may reduce their reproductive capability in the natural habitat relative to natural-origin fish (Christie et al. 2014), thus reducing productivity. We discuss the mechanistic effects of density and domestication on our observations in separate sections below.

Non-treatment adults had a negative effect on population productivity across all phases. Effects in the Clearwater basin were greatest on smolts at LGR per redd. In the Salmon River basin, the effect of non-treatment adults was greatest on adult progeny in the next generation. Five of the six life-stage-by-basin parameters estimated were negative and the effect on adult progeny per parent in the Clearwater basin was virtually zero. While the point estimates had wide CIs, there was an overall pattern of negative effects of non-treatment fish at all life stages.

Studies of productivity or individual reproductive success generally show negative effects of hatchery fish on the spawning grounds and similar results are often found in supplementation evaluations. In general, reproductive performance of hatchery fish in natural environments is less than that of natural-origin fish, although individual study results may be highly variable (Araki et al. 2008; Hess et al. 2012). Productivity of wild salmon and steelhead populations in the Pacific Northwest tends to be reduced in the presence of hatchery fish on the spawning grounds and this effect was not related to type of broodstock (integrated versus segregated) or duration of exposure (Chilcote et al. 2011). Sharma et al. (2006) found an asymptotic relation of smolts to spawners and that natural productivity (smolts/spawner) declined as proportion of supplemental spawners increased.

The literature suggests a tradeoff between the number of supplementation spawners and the demographic benefit that they provide to a natural-origin population (Oosterhout et al. 2005; Fraser 2008), an observation consistent with our findings (Figure 22). Our results show higher adult progeny/parent ratios in reference streams versus supplemented in Phase 2 and Phase 3 although differences are small and bounds overlap zero except during Phase 2 in the Salmon basin. Buhle et al. (2009) found that the density-dependent effects of hatchery Coho Salmon were five times greater than for wild fish and that population productivity decreased as juvenile releases and adult escapement of hatchery fish increased. When implementing a supplementation program, managers should expect productivity reductions as abundance is boosted and the tradeoff of cost versus benefit should be built into the management plan.

In summary, we found small negative effects of supplementation on population productivity during treatment and these were dissipated or obscured by other sources of variability after supplementation ceased. Non-treatment adults had a negative effect on productivity. In the next section, we discuss the intensive studies we conducted to understand these effects and relate them to management prescriptions.

Intensive Analyses of Supplemented Streams with Weirs

We addressed two topics with intensive investigations on supplemented streams with weirs. These topics concern the practical aspects of implementing a supplementation program. The first concerns the life stages at which juveniles are released and the second is how females of different origins perform to affect population abundance at each life stage. These investigations help explain the basin-level results discussed above.

Juveniles must be released in order to get adults with which to supplement, which leads to the question of the most appropriate life stage to release. Despite the large variation in smolt-to-adult return rates during the ISS study (see estimates presented by McCann et al. 2014), we found evidence that releasing more supplementation juveniles resulted in more adults back, and this effect was greater for the smolt release strategy. Unfortunately, the release strategies for supplementation juveniles implemented during ISS were confounded with basin: presmolts were released almost exclusively in the Clearwater basin and Salmon basin releases were mostly smolts. Most release locations in Clearwater basin were distant from hatcheries and access was difficult in the spring, so fall presmolt releases were typically used. Therefore, with our data, it is difficult to interpret the relative return rate of these two supplementation strategies to adults back to the supplemented streams. However, hatchery investigations in the Clearwater basin suggest that adult returns are maximized through smolt releases versus younger life stages (Leth et al. 2010). Additionally, Peery and Bjornn (2004) observed changes in behavior and habitat selection by natural origin Chinook Salmon subyearlings when in the presence of hatchery origin juveniles that would increase their energy demands and exposure to predators.

Some interesting patterns emerged when we addressed the effects of females by origin on population abundance. Natural-origin females were the most effective followed by supplementation and then non-treatment hatchery females. These patterns were similar across life stages and basins, although effects attenuated through the life cycle. Additional supplementation and conventional hatchery females had almost no effect on production in the Clearwater basin, except for the effect of supplementation females on redds. Note that in the Clearwater basin, supplementation fish were general production hatchery (i.e., harvest mitigation fish not intended for conservation purposes) crosses; hence, one should expect their effect should be the same as the non-treatment hatchery females. In the Salmon basin, the abundance of both supplementation and non-treatment hatchery females corresponded to changes in production across life stages but at lower levels than natural-origin females. All positive effects had disappeared or drastically declined by the return of adult progeny in both basins, showing the influence of out-of-basin factors.

The primary difference between basins with respect to these findings is the difference in broodstock origin. Clearwater Hatchery broodstocks were founded from non-endemic fish, primarily from Rapid River Hatchery (Bowles and Leitzinger 1991), which was founded from population originating upstream of Hells Canyon Dam (Reingold 1966; Howell et al. 1985). Shortfalls in broodstock collections in Clearwater Hatchery programs still are addressed with eyed-egg transfers from Rapid River Hatchery. The naturally spawning fish in Clearwater streams are a non-endemic stock, but we found that natural-origin spawners had a greater effect on abundance than supplementation or non-treatment females. Further, Clearwater populations continue to see high proportions of hatchery fish on the spawning grounds, because juveniles were subyearling releases with little or no acclimation (essentially off-site releases). In the Salmon River basin, only local, endemic broodstocks were used to found the hatchery broodstocks used in this study (Howell et al. 1985; Bowles and Leitzinger 1991). Thus, in the Salmon basin, both supplementation and non-treatment hatchery fish may have a greater degree of local adaptation compared to stocks in the Clearwater basin. Interestingly, across both basins the greatest effect per female across all life stages resulted from passage of natural-origin females above the weir. The consistency in the results of the intensive studies across life stages corroborates observations made in the basin-level examinations. Alternatively, performance differences between supplementation adults may be due to effects of the life stage at which they were released as juveniles, although there is no information to support this assumption.

To provide a quantitative examination of these results in a management context, we modeled the effect of passing different levels of supplementation females (i.e., varying the treatment (T) ratio) while excluding all other hatchery fish. When supplementation females were added to the population, there was an increase in the number of redds, emigrants at RST, and smolts at LGR but the slope of that relationship decreased as the T ratio increased (Figure 22). That is, additional fish were produced but not as quickly as T ratio increased (Figure 22, redd, emigrant and smolt panels). Although non-treatment hatchery fish were excluded from this model, given their lower effectiveness, the slope of this relationship should decline faster in their presence. The number of natural-origin adult progeny returns increased slightly in the Salmon basin but this increase was not observed in the Clearwater basin (Figure 22, adult progeny panel). Instantaneous slopes of the observed relationships were greatest at the lowest observed escapements. We make four conclusions: 1) population increases are more effectively generated by increasing the number of natural-origin fish by other means; 2) supplementation ratios should be tied to risk of population failure (e.g., sliding scales); 3) when risk of failure is low, investigate alternative ways to maximize the effectiveness of supplementation fish; 4) whenever possible, supplementation should be implemented using a broodstock integrated with the natural-origin population.

Models used in the intensive analyses performed better than those used in the basin-level analyses. In the intensive analyses, the conditional R^2 averaged approximately 85% for both basins versus 66% in the Salmon and 58% in the Clearwater in the basin-level analyses. Here we were able to measure the population inputs directly (females of all types upstream of weirs), and this reduced the amount of unexplained variance and provided better resolution on the actual supplementation effect. For redds through smolts at LGR, marginal R^2 explained a large fraction of the total variance explained. However, fixed effects explain almost none of the total variance for adult progeny (7.6% in the Salmon basin and 1.2% in the Clearwater). Out-of-basin factors take over once fish pass LGR, because survival past this point is low and highly variable (Copeland et al. 2014; Schaller et al. 2014). This explains, in large part, why supplementation gains are ephemeral.

In summary, we addressed two questions with intensive studies of supplemented streams with weirs. We found evidence that releasing more supplementation juveniles resulted in more adults back and this effect was greatest for smolt releases. Of more interest is the order of effect on population abundance by type of females passed above the weir: natural-origin > supplementation > non-treatment hatchery. Additional fish were produced by passing supplementation females but the rate of increase slowed as supplementation ratio increased. Effects of additional females were greater in the Salmon River, where hatchery broodstocks were derived from the local populations, whereas in the Clearwater River the hatchery broodstocks were derived from and heavily influenced by the non-local Rapid River Hatchery stock.

The smaller scale intensive studies clarified the basin-level analyses. The general pattern of the intensive study results was consistent between basins and was also consistent with results from the basin-level analyses. The effect of the proportion of non-treatment adults on population abundance and productivity is consistent between analyses and the results of the intensive analysis support our interpretation of the basin-level analysis. We also observed that out-of-basin effects had a dramatically larger effect than supplementation. This concordance of results provides a strong weight of evidence that demographic supplementation in natal habitats (as implemented in the ISS study) as a stand-alone tool will contribute little to recovery, but can provide limited demographic benefits. New individuals were created most effectively by additional natural-origin fish but passing supplementation fish did increase population abundance, at least within the freshwater habitat. The mechanisms behind these observations are rooted in salmon population dynamics and fitness/demographic trade-offs.

Density Effects in Study Streams

We observed a possible density effect on production of smolts at LGR from both reference and supplemented streams that influenced population response to supplementation treatments (Figure 23). Wide variability in spawner abundance provided the power to detect these effects. This was previously observed in a subset of our study streams (Walters et al. 2013). Similar results have been reported elsewhere in the Snake River basin (Gallinat and Ross 2015; Cleary et al. 2014; Boe and Crump 2015; Carmichael et al. 2011a, b) and these effects can influence adult-to-adult productivity (ISAB 2015). The high data point from Marsh Creek (Figure 23) illustrates that density functions do not describe a hard ceiling, but rather indicate there is capacity for greater productivity under the right circumstances. Many of the supplemented brood years were to the right of the inflection point, which may have limited our ability to observe stronger treatment effects.

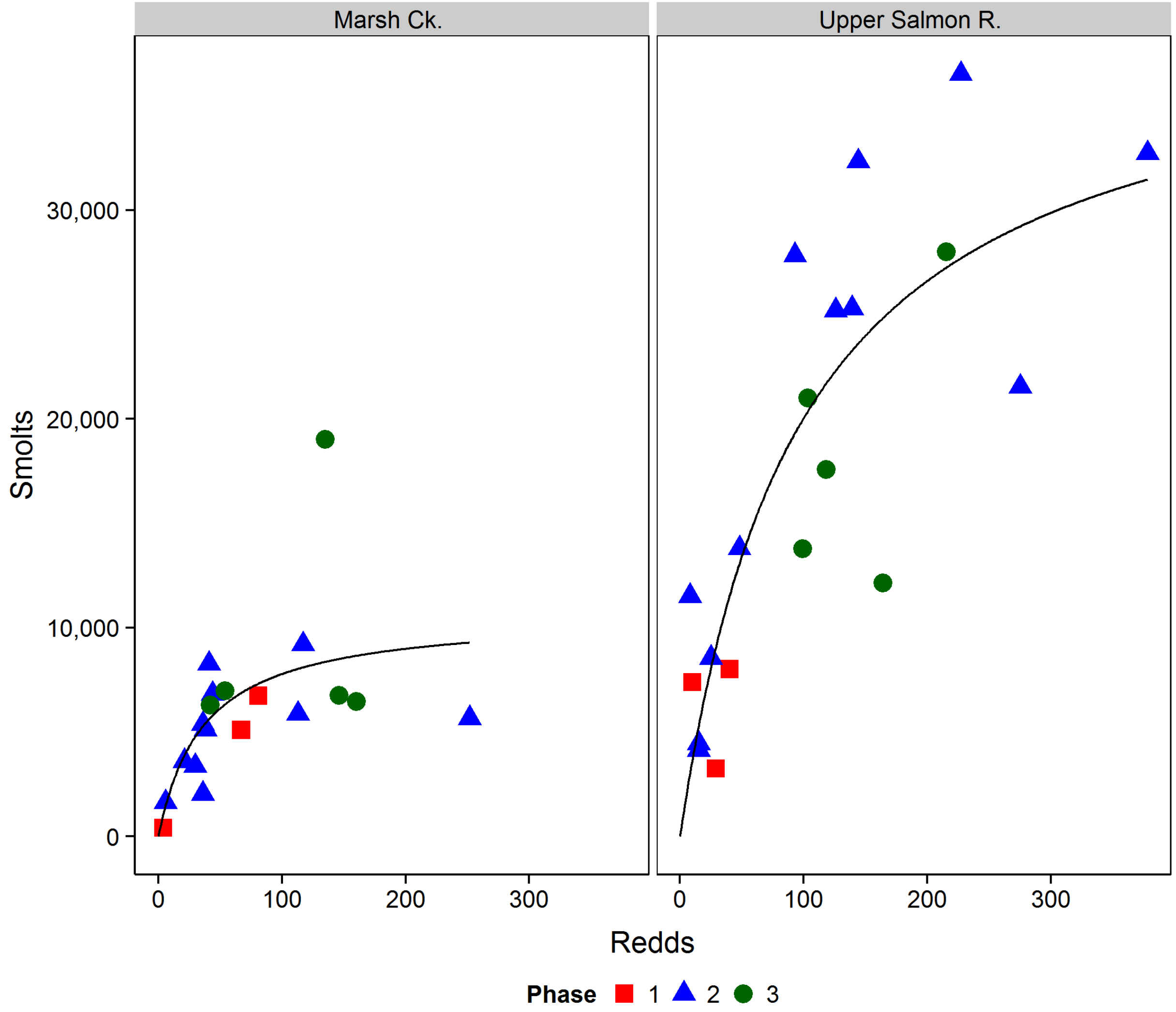


Figure 23. Relationship of redds to natural-origin smolts at LGR in Marsh Creek (reference) and the upper Salmon River (supplemented). The lines represent fitted Beverton-Holt functions.

The hypothesized mechanism is that juveniles emerge and forage together in a relatively small and unproductive space (see Walter & Juanes 1993). It is counterintuitive that density dependence would occur at low abundances, and in the Salmon River basin, there are reaches no longer used by spawning salmon. Hilborn (1985) posited that stressed populations lose the less productive subunits first; surviving subunits are more productive and respond quickly but might not refill the lost subunits. This results in a less resilient and less productive aggregate (Moore et al. 2010). Spawning in the study streams tends to occur in core reaches and spatial distribution expands slowly with abundance (Isaak and Thurow 2006); thus density dependence is possible even at abundances reduced from historical levels (Walters et al. 2013). Loss of marine nutrients in streams with low primary productivity should exacerbate density dependent effects on growth and survival of juveniles (Scheuerell et al. 2005; Sanderson et al. 2009; Kohler et al. 2013). Further, hatchery-origin fish may use resources less efficiently and hence have a different ‘capacity’ than natural-origin fish (Buhle et al. 2009). Based on our results and the literature, we conclude that simply putting fish over the weir is unlikely to have much effect except at low densities. In addition, we suspect re-seeding unoccupied spawning habitat at moderate and higher spawner abundances could help avoid density effects; the testing of such a hypothesis is warranted.

Genetic Aspects of Supplementation

Introgression of natural-origin populations with hatchery spawners may cause loss of population genetic diversity (ISAB 2003), although the results of three Idaho-specific studies have not born this out. The potential for hatchery releases to cause losses among population genetic variation is demonstrated by the genetic homogenization of lower Columbia River Chinook Salmon populations (Utter et al. 1989) and lower Columbia River Coho Salmon populations (Flagg et al. 1995). However, populations can maintain their genetic character in the face of intensive hatchery stocking but introgression is likely when the native population is very depressed (Hansen 2002; Van Doornik et al. 2013). While ISS was not funded to address broad genetic concerns, other investigators have addressed these issues in the study area. Van Doornik et al. (2011) found no changes to heterozygosity or allelic richness in Salmon River Chinook Salmon populations with respect to hatchery operations. In the Middle Fork Salmon River, which has negligible hatchery influence, Chinook Salmon populations retain robust levels of neutral genetic variability despite dramatic declines in abundance (Neville et al. 2007). Narum et al. (2007) examined samples from across the Snake basin and found similar results for stream-type (see Healey 1991) Chinook Salmon populations. Further, genetic structure follows a geographic pattern in the Salmon River basin with no evidence of widespread homogenization caused by hatcheries. The Clearwater is a different case; the local populations are genetically indistinguishable from each other or from the donor stock (Rapid River Hatchery; Narum et al. 2007).

Introgression of natural-origin populations with hatchery spawners may also cause loss of individual fitness (ISAB 2003); therefore, studies of relative reproductive success (RRS) have become common forms of supplementation evaluations. Success of non-native stocks differing in life history from the native stocks have been shown to be poor (e.g., Araki et al. 2007). Studies of segregated broodstocks show that RRS declines with increasing history of domestication in the donor stock (Fleming et al. 2002; Huntingford 2004). However, this result may not apply to integrated broodstocks (e.g., Thériault et al. 2011; Ford et al. 2012). Christie et al.’s review (2014) and work by Waters et al. (2015) suggests that integration can reduce domestication effects. Hatchery males typically have the lowest RRS (Christie 2014), but see Schroder et al. (2010) Further, not all of these effects may be due to genetic inheritance. Williamson et al. (2010) found that decreased fitness of hatchery fish used to supplement the Chiwawa River was due to their homing to poor habitat near their acclimation site and to a smaller body size at return.

Relative reproductive studies have occurred in two ISS study streams. Leth (2005) found that supplementation and natural-origin spawners in the Pahsimeroi River overlapped in spawning distribution and produced emigrants at RST at similar rates. Follow-up results looking at adult-to-adult returns showed that supplementation females produced adult progeny at rates similar to natural-origin females (DAV unpublished data). In Johnson Creek, Hess et al. (2012) found no difference in reproductive success between natural-origin and supplementation fish when only successful spawners were examined. In that case, all supplementation fish were produced from 100% natural-origin broodstock, which was not the approach used in other study treatments. Samples are in hand from certain locales (Sawtooth, and South Fork Salmon) to conduct RRS evaluations to better understand genetic contributions of supplementation fish and link those results to the demographic data collected in this study.

Relative reproductive success studies focus on individual performance, but the performance of populations is of most interest in a management context. Reproductive success in salmon populations often shows a skewed distribution where a few highly successful individuals drive population dynamics (e.g., Anderson et al. 2015). Therefore, population dynamics may become decoupled from individual reproductive success. Thus, non-treatment hatchery and supplementation females had positive effects on population abundance, although less than natural-origin females. The risk is that the lower relative fitness is heritable and may impact subsequent population performance. In the presence of purifying selection, groups of organisms can recover from fitness losses (Estes and Lynch 2003; Szamecz et al. 2014). Potential fitness losses have not materialized in this study, because reference populations show the same productivity patterns as supplemented populations and both returned to their Phase 1 relationship during Phase 3. After natural selection, adult progeny of supplementation spawners may have similar fitness relative to the naturally spawning population (Kitada et al. 2011) and provide a demographic boost (Stark et al. In press).

For supplementation to be an effective conservation tool, managers must balance the tradeoff of demographic boost against genetic fitness costs (Fraser 2008). Theory suggests that the hatchery population is at a different fitness optimum than the wild population and that gene flow between the two components will reduce the fitness of the wild population (Ford 2002). Therefore, genetic risks to the natural-origin population could be reduced if the genetic similarity between hatchery and natural-origin fish is high. The proportionate natural influence (PNI) index was developed to measure this balance (HSRG 2009). It incorporates the effect of natural-origin fish in the hatchery broodstock and the proportion of the naturally-spawning population composed of hatchery fish. This concept has not been well tested beyond theoretic models and the mechanisms behind differences between hatchery and natural-origin fish are just emerging. However, PNI is currently being used to guide implementation of supplementation programs across the Pacific Northwest (HSRG 2014).

When ISS was developed, the PNI index had not been developed, but our results can help guide management. The HSRG (2009) recommended that the proportion of hatchery broodstock comprised of natural-origin fish should be greater than the proportion of the natural-origin spawning population made of hatchery-origin fish (PNI = 0.5) to maintain the genetic characteristics of a locally adapted population and minimize domestication effects. However, for high priority populations, the HSRG (2009) recommended a PNI ≥ 0.67. If the ISS study was implemented as designed during Phase 2, PNI in the Salmon basin would have been 0.5 (50% natural-origin broodstock and 1:1 supplementation to natural-origin fish on the spawning ground) and zero in the Clearwater basin (no natural-origin broodstock). The difference between basins (Figure 15, bottom right panel) shows that supplementation with an integrated local broodstock can provide an increase in abundance over the short term. Salmon River basin populations were integrated from the founding of the hatchery programs until ISS; therefore, long-term PNI in them may be higher than we assume. In the Clearwater basin, neither the segregated Clearwater Hatchery nor the non-endemic Rapid River stocks are adapted to the local environment. Further, with the continued introgression of segregated stocks into natural-origin populations there, it is unlikely local adaptation will occur under the current management program. In light of our results along with Ford (2002) and HSRG (2009, 2014), future supplementation programs should consider current gene flow theory. There is a difference in opinion on the usefulness of the PNI index, so further work needs to be done to assess this index.

Natural-origin fish were generally more successful demographically than segregated hatchery stocks. With large-scale mitigation programs present in the Clearwater basin, genetic risks could be reduced and local adaptation encouraged with localized/integrated broodstocks. A key uncertainty is how quickly populations recover from the influx of segregated hatchery fish with a different fitness optimum (Venditti et al. 2013). Until we have a better understanding of this process, questions regarding the long-term genetic effects of supplementation will remain.

Management Recommendations

The cooperating agencies that conducted ISS have some common management goals with respect to anadromous salmonids. These are:

1. Restoration of natural-origin populations to levels that seed available habitat,
2. Mitigation for loss of anadromous fish due to hydrosystem development,
3. Sustainable harvest of both natural-origin and hatchery fish.

The first level of recovery is population viability warranting delisting and removal from ESA protection. The next level allows for sustainable harvest and other management options (broad-sense recovery). The Nez Perce Tribe Department of Fishery Resources Management Plan and Shoshone-Bannock Tribes Snake River Policy take these goals a step further by listing ecosystem recovery as the ultimate goal of restoration efforts. In other words, restoration is achieved when salmon abundances provide not only for harvest, but also for delivery of marine nutrients to both aquatic and terrestrial habitats in support of “ridge-top to ridge-top” habitat structure and function. Supplementation is intended to be one of the tools by which managers might achieve those goals, and will continue to be implemented in the Columbia River basin (e.g., Kline and Flagg 2014; Fast et al. 2015). As implemented by ISS, supplementation failed to achieve even the lowest of the recovery goals. Supplementation alone cannot overcome problems that have driven population declines. However, we have shown some positive results, indicating that supplementation can be useful given specific objectives and with sufficient guidance.

For supplementation to be a useful management tool, its proper uses must be defined and its implementation must be improved based on the findings of this project. Supplementation needs to be part of an integrated life-cycle strategy that includes improvements in hydrosystem and habitat management, especially to allow sustainable harvest. Given what we have learned, there are at least three goals appropriate for supplementation programs: 1) to maintain smolt at LGR production during low escapements, 2) to seed unoccupied or restored habitats, and 3) to buffer the target population from harvest impacts in mixed stock fisheries. Below we make recommendations for program management to allow efficient and effective use of supplementation.

There are several general guidelines that emerge from the ISS experience, and these are generally consistent with HSRG’s (2009, 2014) recommendations. Supplementation programs need to be customized to the intended target populations. This follows from the definition used at the outset of the ISS project (“Supplementation is the attempt to use artificial propagation to maintain or increase natural production while maintaining the long-term fitness of the population, and while keeping the ecological and genetic impacts on non-target populations within specified biological limits” [RASP 1992]). Within the scope of this definition, there is a continuum of supplementation strategies available based on degree of genetic and demographic risk. These range from population rescue (Kline and Flagg 2014) through captive rearing (Stark et al. In press) to augmentation with an integrated broodstock (HSRG 2009, 2014). The supplementation strategy employed should be guided by population status and management goals. The ultimate goal is population recovery and the cessation of supplementation. However, through judicious integration, hatchery and natural-origin production could be managed to maximize overall abundance allowing harvest on both components (e.g., HSRG 2009).

Supplementation programs need to be adaptively managed. There are many sources of uncertainty regarding performance of salmon populations: a high degree of natural variability in important processes (e.g., life stage survival), logistical difficulties in making relevant measurements, and imperfect understanding of influential factors. Therefore, monitoring is vital and learning should be an explicit management goal. These are general guidelines; below are more specific recommendations. Implementation of a supplementation program is a policy decision, but in the following recommendations we assume that this decision has already been made.

Specific Recommendations:

1. **Key Finding:** When supplementation females were added to the stream, there was an increase in the number of redds, emigrants at RST, and smolts at LGR 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.

2. **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.

3. **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.

4. **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.

5. **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.

6. **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.

7. **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.

8. **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.

9. **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.

REPORT SUMMARY

Lessons learned from ISS provide guidance for future supplementation programs. The landscape approach to study design maintained its power to detect supplementation effects, even when management changes occur in individual watersheds. The variability among study populations demonstrates the idiosyncratic nature of these programs and hence the need for strategic monitoring programs and adaptive management. Lastly, the body of data accumulated provides the opportunity for more analyses than appropriate for this completion report.

The Idaho Supplementation Studies have significantly advanced our understanding of Chinook Salmon population dynamics in Idaho and paved the way for future conservation and management of these populations. Further, because of its powerful design, these results are useful across the Columbia River basin and beyond. Study results show that supplementation is useful as part of an integrated management approach to maintain population abundance in the face of low survival conditions. Post supplementation results show that temporary benefits can be achieved while keeping ecological costs low (i.e., the supplemented populations were still resilient after supplementation ceased). The decision to intervene is a policy decision, not a management action. As such, policy makers need to consider the substantial resources and strategic collaboration across programs (harvest, hatchery, hydropower, and habitat) needed to ensure supplementation programs maximize benefit and minimize risk. However, supplementation alone is not a panacea because it does not correct fundamental limiting factors; these limiting factors must be addressed to achieve population levels capable of sustaining ecological function and management opportunities such as harvest.

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APPENDICES

Appendix A. Definition and derivation of model metrics not defined in the text.

Appendix A. Metrics used in calculation of variables used in the ISS analyses.

Metric	**Description**
Adult Age	Assigning brood years to returning adults was necessary and to do this we used a variety of methods. Coded wire tags and fin clips provided known ages for supplementation fish, while data from dorsal fin rays (Copeland 2007) aged by the IDFG Aging Lab provided the best estimate for naturally produced fish. Based on fin ray data (Copeland 2006) age-3 and age-6 female returns were negligible and therefore were not included in our analyses. Ages from fin rays were applied to un-aged fish with a known sex and length using R version 3.1.2 (2014-10-31) with Finite Mixture Distribution Models version 0.5-4 (Macdonald 2011), which outputs an age proportion based on mean length at age and the distribution around it. When there was little variation in length at age among years and adjacent streams in the known age sample, we pooled those ages across years and in some cases streams in order to alleviate sample size bias in years or streams with low carcass recovery. The known age samples were processed with each year of un-aged fish separately to estimate the age composition for a given year on a given stream. In years where fin ray data were not available, age composition was estimated by applying known length at age data to the lengths of carcasses collected on the spawning ground or to adults passed over weirs using the R scripts. In streams and years when no carcasses were recovered the average age-composition for that stream was used. Age-3 males were included because they make up a substantial portion of returns. Male and female age proportions were multiplied by the total natural-origin return to determine natural-origin adult progeny by parental brood year, $$NReturnBY = (Adults * Age3pBY + 3) + (Adults * Age4pBY + 4) + (Adults * Age5pBY + 5)$$ where p = proportion, and BY = brood year.

Appendix A. Continued.

Metric	Description
Adult Escapement	Adult abundance (escapement) was estimated for streams with weirs because weirs were not 100% efficient. Numbers of fish passed above weirs along with carcass recoveries were used to estimate escapement of natural-origin and supplementation adults. In most years, adults passed over weirs received an opercular punch or other identifying mark and total escapement was estimated using the modified Peterson estimator (Ricker 1975, equation 3.7). In years when carcasses were not collected or fish were not marked at the weir, abundance was estimated by dividing the number passed above the weir (marked) by the average weir efficiency. We estimated escapement above weirs for natural-origin, supplementation, and non-treatment hatchery Chinook. Hatchery proportions on streams without weirs were taken directly from carcass collections. We produced escapement estimates for non-treatment hatchery fish above weirs by using the carcass collection efficiency. Carcass collection efficiency is the number of natural-origin carcasses found divided by their escapement estimate, $$CCeff = \frac{NATc}{NATesc}$$ which is then used to estimate the number of non-treatment hatchery fish above weirs, $$NTHFesc = \frac{NTHFc}{CCeff}$$ where, CCeff = carcass collection efficiency, NATc = number of natural-origin carcasses found, NATesc = natural-origin escapement, NTHFc = non-treatment hatchery carcasses found, and NTHFesc is the escapement estimate for non-treatment hatchery fish. Non-treatment hatchery proportion (PNTHF) is the NTHF escapement divided by the total escapement. When carcasses were not collected or fish were not marked at weirs we used the stream average proportion.

Appendix A. Continued.

Metric	Description
Adult Origin	The origin of most fish was identifiable by the marks and tags observed in carcass collections and from adults returning to weirs. Mass marking of hatchery fish was not implemented until midway through Phase 1, so it was necessary to estimate contributions of hatchery and wild fish to the spawning populations in these treatment streams. In the Clearwater drainage, inefficient or nonexistent weirs and lack of marked subgroups forced us to use average origin proportions from carcasses or rack returns (post 1996). In the Salmon basin, most of the hatchery releases had representative groups of marked fish, with coded wire tags and ventral fin clips. In order to estimate the number of unmarked production fish returning in 1992, 1993, and 1994 we divided the number of marked adult fish collected at hatchery weirs by the ratio of marked to unmarked juveniles released by brood year, $$UGPReturn = \frac{MReturn}{Mjuv/Ujuv}$$ UGP = unmarked general production (i.e., non-treatment hatchery fish), U = unmarked, M = marked. Dividing the number of unmarked general production fish by the total number of unmarked fish that returned produced the proportion of unmarked hatchery fish in the population (PNTHF), $$PNTHF = \frac{UGPReturn}{UReturn}$$ The natural-origin proportion is then, $$1 - PNTHF$$ and the number of natural-origin adults returning is, $$NReturn = UReturn - UGPReturn$$ We multiplied the natural-origin female proportion by the escapement estimate (described below) to estimate the number of natural-origin females above weirs on the spawning grounds.

Appendix A. Continued.

Metric	**Description**
Juveniles Released	Hatchery origin juveniles released into the stream for supplementation. In brood years 1993, 1996-2002 the South Fork Salmon River brood years and brood year 1991 the Upper Salmon River received presmolt treatments that were standardized to a prescribed smolt release. To standardize the subyearling release we estimated the number of smolts that would have needed to be released in the headwaters to achieve the same number reaching LGR using the equation, $$Smolt_{EQ,REL} = \frac{Sub_{rel} * Sub_{SURV}}{Smolt_{SURV}}$$ where $Smolt_{EQ,REL}$ is the smolt equivalent release, Sub_{REL} is the number of subyearlings released, Sub_{SURV} is the survival of the subyearlings to LGR, and $Smolt_{SURV}$ is the survival of the smolts to LGR in that same year. When smolt survival from the supplementation release was not available, the natural-origin smolt survival estimate was used.
$Migrants_{RST}$	Estimated brood year abundance at rotary screw traps. Juvenile abundance is estimated at the screw traps as they are migrating downstream and the methods used are explained in the Idaho Supplementation Studies annual reports. Young-of-the-year fry were not included in the index because they are not taggable size (60 mm) and were marked too inconsistently to be comparable across years and streams. Summer parr were not included in the index because screw traps were not operated during the summer migration period from 1992 to 1997 thus eliminating any comparisons between Phase 1 and the other phases. We also did not include precocials in the abundance estimates because we could not estimate trapping efficiency for this group, which differed from other PIT-tagged migrants, as precocials generally remain resident. Therefore, presmolt and smolt estimates were summed to produce an index of juvenile abundance from each brood year.
$Progeny_{redds,BY}$	Redds constructed from adult returns of the brood year of interest, summed over two return years, $$Progeny_{Age4,BY} + Progeny_{Age5,BY}$$

Appendix A. Continued.

Metric	Description
Progeny$_{redds,BY}$ / *Parent*$_{redds,BY}$	Spawner to spawner productivity is evaluated by the number of redds produced by natural-origin female adult progeny. The proportion of natural-origin females (PNF) on the spawning ground in a given return year, $PNF_{ry} = \#NF \;/\; (\#NF \;+\; \#SF \;+\; \#GPF)$ was multiplied by the total redds and the age proportions to estimate the number of redds constructed by natural-origin female adult progeny, $Progeny_{redds,BY} = \left(PNF_{ry} \;*\; PAge4_{BY} * REDDS_{ry}\right) + (PNF_{ry} \;*PAge5_{BY} * REDDS_{ry+1})$ where P = proportion, BY = brood year, ry = return year, ry + 1 = the following return year, F = female, N = natural-origin, S = supplementation, GP = non-treatment hatchery fish, and REDDS = total redds. This leads to the response, $Progeny_{redds.BY} \;/\; Parent_{redds,BY}$ where progeny redds are natural-origin only but parent redds include all origin types on the spawning ground. 2013 and 2014 redd counts on Crooked Fork Creek and Colt Killed Creek were estimated by regression analysis of the index counts and census counts from 1992 to 2012, because those streams were reduced to index counts in those years.
Smolts$_{LGR,BY}$	The number of smolts at Lower Granite Dam is a product of juvenile abundance at the screw trap and survival to LGR, $Smolts_{LGR,By} = Migrants\;_{BY} \;*\; Survival_{BY}$
Survival$_{BY}$	We estimated the survival of PIT-tagged juveniles to LGR using PIT tag interrogations at dams on the Snake and Columbia rivers and the Survival Under Proportional Hazards (SURPH) model (Lady 2010).

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Appendix B. Basin-level analyses of abundance and productivity model output.

This appendix contains a series of three tables of model output for each basin and life-stage response variable. The first table contains model ranking information. The second table provides model-averaged parameter estimates, and the third provides information on the importance of random terms in explaining variance in the data.

CLEARWATER BASIN
Abundance

Appendix B. Table 1. Clearwater River model selection table for redd abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	9	-234.238	487.609	0	0.598	0.118	0.805
1	10	-233.660	488.713	1.104	0.344	0.122	0.804
3	8	-238.010	492.920	5.311	0.042	0.102	0.807
5	8	-239.497	495.894	8.285	0.009	0.063	0.819
4	9	-239.222	497.577	9.968	0.004	0.064	0.818
6	7	-242.111	498.917	11.308	0.002	0.058	0.819

Appendix B. Table 2. Clearwater River parameter estimates from model averaging for redd abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	2.33	0.55	1.25	3.42
p1	-0.63	0.28	-1.18	-0.09
T	0.17	0.08	0.02	0.33
p3	0.58	0.45	-0.30	1.45
S	0.60	0.20	0.20	1.00
p3t	-0.12	0.26	-0.62	0.38

Appendix B. Table 3. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for redd abundance.

Group	N	Variance	SD
year	21	0.545	0.738
stream:group	10	1.533	1.238
group	4	0.275	0.524
Residual	169	0.598	0.773

Appendix B. Table 4. Clearwater River model selection table for emigrant abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal *R^2*	Conditional *R^2*
2	9	-129.450	279.178	0	0.320	0.044	0.662
5	8	-131.200	280.199	1.021	0.192	0.030	0.656
6	7	-132.568	280.519	1.340	0.164	0.011	0.642
3	8	-131.423	280.646	1.468	0.154	0.033	0.659
1	10	-129.323	281.466	2.288	0.102	0.044	0.660
4	9	-130.997	282.272	3.093	0.068	0.028	0.651

Appendix B. Table 5. Clearwater River parameter estimates from model averaging for emigrant abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	8.89	0.49	7.94	9.84
p1	0.12	0.54	-0.93	1.18
p3	0.39	0.59	-0.76	1.55
T	0.11	0.11	-0.10	0.32
S	0.35	0.40	-0.44	1.13
p3t	-0.04	0.20	-0.43	0.36

Appendix B. Table 6. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for emigrant abundance.

Group	N	Variance	SD
year	21	0.984	0.992
stream:juv group	6	0.292	0.541
juv group	2	0.0002	0.015
Residual	89	0.631	0.794

Appendix B. Table 7. Clearwater River model selection table for smolts at Lower Granite Dam.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
5	8	-108.797	235.567	0	0.361	0.035	0.671
6	7	-110.525	236.564	0.997	0.219	0.005	0.668
2	9	-108.218	236.937	1.369	0.182	0.032	0.670
4	9	-108.790	238.079	2.512	0.103	0.036	0.673
3	8	-110.245	238.462	2.895	0.085	0.010	0.677
1	10	-108.197	239.493	3.926	0.051	0.033	0.672

Appendix B. Table 8. Clearwater River parameter estimates from model averaging for smolts at Lower Granite Dam.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	8.00	0.44	7.14	8.86
p1	0.30	0.47	-0.63	1.22
p3	0.26	0.51	-0.73	1.26
T	0.10	0.09	-0.08	0.28
S	0.11	0.25	-0.37	0.59
p3t	0.01	0.16	-0.30	0.32

Appendix B. Table 9. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for smolts at Lower Granite Dam.

Group	N	Variance	SD
year	21	0.730	0.854
stream:juv group	6	0.260	0.510
juv group	2	0.039	0.198
Residual	82	0.466	0.682

Appendix B. Table10. Clearwater River model selection table for adult progeny.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	9	-140.305	300.342	0	0.600	0.042	0.832
1	10	-139.534	301.203	0.861	0.390	0.058	0.826
6	7	-147.553	310.163	9.822	0.004	0.009	0.803
3	8	-146.736	310.844	10.503	0.003	0.022	0.794
5	8	-147.299	311.969	11.627	0.002	0.012	0.804
2	9	-146.394	312.518	12.176	0.001	0.027	0.795

Appendix B. Table 11. Clearwater River parameter estimates from model averaging for adult progeny.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	2.55	0.56	1.45	3.64
p1	-0.43	0.26	-0.94	0.08
T	-0.11	0.08	-0.26	0.04
p3	0.75	0.60	-0.44	1.93
p3t	-1.80	0.51	-2.81	-0.79
S	0.09	0.17	-0.23	0.41

Appendix B. Table 12. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for adult progeny.

Group	N	Variance	SD
year	18	0.423	0.651
stream:group	9	1.375	1.172
group	3	0.290	0.538
Residual	114	0.393	0.627

Productivity

Appendix B. Table 13. Clearwater River model selection table for emigrants at RST/redd.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
3	8	-91.262	200.847	0	0.493	0.169	0.169
6	7	-93.684	203.145	2.298	0.156	0.103	0.124
2	9	-91.139	203.230	2.383	0.150	0.172	0.172
5	8	-92.615	203.553	2.706	0.127	0.136	0.136
1	10	-91.137	205.940	5.093	0.039	0.172	0.172
4	9	-92.584	206.118	5.271	0.035	0.137	0.137

Appendix B. Table 14. Clearwater River parameter estimates from model averaging for emigrants at RST/redd.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	6.00	0.33	5.36	6.64
p1	0.80	0.41	-0.01	1.61
p3	-0.13	0.27	-0.66	0.40
S	-0.43	0.37	-1.16	0.30
T	0.02	0.06	-0.10	0.15
p3t	0.01	0.11	-0.22	0.23

Appendix B. Table 15. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for emigrants at RST/redd.

Group	N	Variance	SD
year	21	0	0
stream:juv group	6	0	0
juv group	2	0	0
Residual	71	0.811	0.901

Appendix B. Table 16. Clearwater River model selection table for smolt/redd.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
3	8	-81.959	182.444	0	0.645	0.327	0.327
2	9	-81.763	184.740	2.296	0.205	0.331	0.331
1	10	-81.241	186.481	4.037	0.086	0.342	0.342
6	7	-86.283	188.497	6.053	0.031	0.126	0.287
5	8	-85.480	189.486	7.042	0.019	0.208	0.253
4	9	-84.439	190.092	7.648	0.014	0.236	0.282

Appendix B. Table 17. Clearwater River parameter estimates from model averaging for smolt/redd.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	5.09	0.31	4.48	5.71
p1	1.14	0.40	0.35	1.94
p3	-0.11	0.27	-0.63	0.41
S	-0.92	0.38	-1.67	-0.18
T	0.02	0.06	-0.09	0.13
p3t	0.04	0.18	-0.31	0.39

Appendix B. Table 18. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for smolt/redd.

Group	N	Variance	SD
year	21	0	0
stream:juv group	6	0	0
juv group	2	0	0
Residual	66	0.747	0.864

Appendix B. Table 19. Clearwater River model selection table for adult progeny/redd.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
5	8	-70.409	158.436	0	0.317	0.072	0.584
6	7	-71.873	158.990	0.554	0.240	0.056	0.583
4	9	-69.605	159.255	0.819	0.210	0.082	0.594
2	9	-70.382	160.810	2.373	0.097	0.072	0.586
3	8	-71.867	161.351	2.915	0.074	0.056	0.584
1	10	-69.592	161.712	3.276	0.062	0.082	0.595

Appendix B. Table 20. Clearwater River parameter estimates from model averaging for adult progeny/redd.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	0.61	0.16	0.29	0.93
p1	0.16	0.18	-0.19	0.51
T	-0.06	0.05	-0.16	0.05
p3	-0.32	0.41	-1.12	0.48
p3t	-0.10	0.23	-0.56	0.35
S	0.01	0.07	-0.13	0.14

Appendix B. Table 21. Restricted maximum likelihood estimates of random effects for the optimal Clearwater River hypothesis for adult progeny/redd.

Group	N	Variance	SD
year	18	0.216	0.465
stream:group	8	0.016	0.128
group	3	0	0
Residual	98	0.167	0.409

SALMON BASIN

Appendix B. Table 22. Salmon River model selection table for redd abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	9	-338.538	695.721	0	0.693	0.104	0.837
1	10	-338.442	697.675	1.954	0.261	0.109	0.837
5	8	-342.654	701.822	6.101	0.033	0.089	0.826
4	9	-342.556	703.758	8.037	0.012	0.086	0.827
3	8	-347.123	710.760	15.039	0	0.072	0.838
6	7	-349.783	713.965	18.244	0	0.067	0.832

Appendix B. Table 23. Salmon River parameter estimates from model averaging for redd abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	3.03	0.55	1.95	4.11
p1	0.31	0.26	-0.20	0.83
T	0.17	0.04	0.09	0.26
p3	1.17	0.46	0.26	2.08
S	0.66	0.28	0.12	1.20
p3t	0.03	0.15	-0.26	0.31

Appendix B. Table 24. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for redd abundance.

Group	N	Variance	SD
year	21	0.767	0.876
stream:group	14	0.291	0.539
group	5	1.093	1.046
Residual	289	0.416	0.645

Appendix B. Table 25. Salmon River model selection table for emigrant abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	9	-173.789	366.893	0	0.428	0.119	0.645
5	8	-175.369	367.781	0.889	0.274	0.084	0.613
1	10	-173.612	368.842	1.949	0.161	0.136	0.647
4	9	-175.360	370.034	3.141	0.089	0.086	0.612
6	7	-178.930	372.666	5.773	0.024	0.048	0.620
3	8	-177.812	372.668	5.775	0.024	0.063	0.634

Appendix B. Table 26. Salmon River parameter estimates from model averaging for emigrant abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	9.26	0.30	8.68	9.85
p1	0.42	0.34	-0.24	1.08
p3	0.79	0.37	0.07	1.52
T	0.13	0.06	0.02	0.25
S	0.41	0.42	-0.43	1.24
p3t	0.03	0.16	-0.29	0.35

Appendix B. Table 27. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for emigrant abundance.

Group	N	Variance	SD
year	21	0.428	0.654
stream:juv group	9	0.283	0.532
juv group	3	0	0
Residual	147	0.418	0.647

Appendix B. Table 28. Salmon River model selection table for smolt abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	9	-149.014	317.424	0	0.367	0.127	0.531
5	8	-150.373	317.854	0.431	0.296	0.076	0.522
1	10	-148.578	318.874	1.450	0.178	0.152	0.552
2	9	-150.199	319.793	2.369	0.112	0.085	0.528
6	7	-153.623	322.101	4.677	0.035	0.034	0.520
3	8	-153.571	324.249	6.825	0.012	0.035	0.519

Appendix B. Table 29. Salmon River parameter estimates from model averaging for smolt abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	8.21	0.24	7.74	8.68
p1	0.31	0.29	-0.26	0.88
p3	0.51	0.29	-0.05	1.07
T	0.14	0.06	0.01	0.26
p3t	0.25	0.31	-0.35	0.85
S	0.08	0.23	-0.37	0.54

Appendix B. Table 30. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for smolt abundance.

Group	N	Variance	SD
year	21	0.182	0.426
stream:juv group	9	0.191	0.437
juv group	3	0	0
Residual	139	0.368	0.607

Appendix B. Table 31. Salmon River model selection table for adult progeny abundance.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
5	8	-268.157	552.924	0	0.430	0.046	0.796
2	9	-267.709	554.184	1.260	0.229	0.051	0.800
4	9	-267.745	554.256	1.332	0.221	0.042	0.798
1	10	-267.480	555.901	2.977	0.097	0.046	0.801
6	7	-272.448	559.369	6.445	0.017	0.029	0.797
3	8	-272.432	561.474	8.550	0.006	0.029	0.798

Appendix B. Table 32. Salmon River parameter estimates from model averaging for adult progeny abundance.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	3.67	0.49	2.71	4.62
p1	-0.39	0.25	-0.87	0.10
T	0.12	0.05	0.03	0.21
p3	0.34	0.50	-0.65	1.32
S	0.08	0.19	-0.30	0.46
p3t	-0.09	0.22	-0.52	0.35

Appendix B. Table 33. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for adult progeny abundance.

Group	N	Variance	SD
year	18	0.402	0.634
stream:group	14	0.300	0.548
group	5	0.853	0.924
Residual	245	0.359	0.599

Productivity

Appendix B. Table 34. Salmon River model selection table for emigrants at RST/redd.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
6	7	-136.262	287.331	0	0.412	0.020	0.550
5	8	-135.796	288.636	1.305	0.214	0.024	0.536
3	8	-136.152	289.347	2.016	0.150	0.021	0.546
4	9	-135.412	290.138	2.808	0.101	0.033	0.534
2	9	-135.649	290.611	3.281	0.080	0.027	0.533
1	10	-135.119	291.856	4.525	0.043	0.046	0.534

Appendix B. Table 35. Salmon River parameter estimates from model averaging for emigrants at RST/redd.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	5.62	0.33	4.97	6.26
p1	0.28	0.21	-0.13	0.69
p3	-0.04	0.20	-0.42	0.35
T	-0.02	0.03	-0.08	0.05
S	-0.04	0.16	-0.35	0.27
p3t	-0.03	0.11	-0.25	0.20

Appendix B. Table 36 Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for emigrants at RST/redd.

Group	N	Variance	SD
year	21	0.090	0.300
stream:juv group	9	0.086	0.293
juv group	3	0.257	0.507
Residual	147	0.281	0.530

Appendix B. Table 37. Salmon River model selection table for smolts at LGR/redd.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
5	8	-137.794	292.696	0	0.339	0.028	0.659
6	7	-139.201	293.256	0.560	0.256	0.018	0.668
2	9	-137.497	294.390	1.694	0.145	0.035	0.654
4	9	-137.767	294.930	2.234	0.111	0.031	0.658
3	8	-139.035	295.177	2.481	0.098	0.019	0.661
1	10	-137.399	296.518	3.822	0.050	0.045	0.653

Appendix B. Table 38. Salmon River parameter estimates from model averaging for smolts at LGR/redd.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	4.53	0.37	3.80	5.26
p1	0.19	0.27	-0.34	0.72
p3	-0.18	0.27	-0.72	0.35
T	-0.05	0.05	-0.14	0.05
S	-0.06	0.19	-0.44	0.32
p3t	-0.01	0.11	-0.22	0.20

Appendix B. Table 39. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for smolts at LGR/redd.

Group	N	Variance	SD
year	21	0.190	0.436
stream:juv group	9	0.214	0.463
juv group	3	0.243	0.493
Residual	139	0.287	0.535

Appendix B. Table 40. Salmon River model selection table for adult progeny.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	9	-163.644	346.095	0	0.517	0.098	0.611
1	10	-162.864	346.718	0.623	0.379	0.104	0.614
5	8	-167.215	351.073	4.977	0.043	0.069	0.602
3	8	-167.628	351.899	5.804	0.028	0.066	0.621
4	9	-166.586	351.979	5.884	0.027	0.076	0.601
6	7	-170.241	354.981	8.885	0.006	0.045	0.623

Appendix B. Table 41. Salmon River parameter estimates from model averaging for adult progeny.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	1.21	0.15	0.93	1.50
p1	-0.29	0.16	-0.60	0.03
T	-0.07	0.03	-0.12	-0.02
p3	-0.47	0.41	-1.28	0.33
S	-0.37	0.18	-0.72	-0.02
p3t	-0.10	0.18	-0.46	0.25

Appendix B. Table 42. Restricted maximum likelihood estimates of random effects for the optimal Salmon River hypothesis for adult progeny.

Group	N	Variance	SD
year	18	0.277	0.527
stream:group	14	0.007	0.086
group	5	0	0
Residual	233	0.188	0.434

Appendix C. Intensive studies of supplemented streams with weirs model output.

RETURN FROM SUBYEARLING AND SMOLT RELEASES

Appendix C. Table1. Model selection table for releasing juveniles to increase supplementation brood year returns.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
1	6	-116.077	245.487	0	0.517	0.192	0.663
2	5	-117.353	245.643	0.157	0.478	0.127	0.661
4	4	-123.312	255.240	9.753	0.004	0	0.545
3	5	-122.863	256.663	11.176	0.002	0.038	0.550

Appendix C. Table2. Restricted maximum likelihood estimates of variance for each random effect in the basin-level model for supplementation brood year return.

Group	N	Variance	SD
year	16	0.996	0.998
stream	8	0.582	0.763
Residual	70	0.980	0.990

CLEARWATER BASIN

Redds

Appendix C. Table 3. Model selection table for releasing adult females onto the spawning grounds to increase redds in the Clearwater basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	6	-33.659	83.136	0	0.625	0.676	0.820
4	5	-36.542	85.692	2.556	0.174	0.616	0.800
1	7	-33.560	86.454	3.318	0.119	0.682	0.805
3	6	-35.697	87.212	4.076	0.081	0.643	0.744

Appendix C. Table 4. Parameter estimates from model averaging using females released above the weir to predict redds in the Clearwater basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	-0.01	0.63	-1.24	1.21
Natural	0.86	0.13	0.60	1.11
T-Ratio	0.58	0.45	-0.31	1.47
Non ISS-Ratio	0.03	0.15	-0.26	0.33

Appendix C. Table 5. Restricted maximum likelihood estimates of random effects for the intensive Clearwater River hypothesis for total redds using adults released as a treatment variable.

Group	N	Variance	SD
year	10	0.704	0.839
stream	3	0	0
Residual	19	0.304	0.551

Emigrants at RST

Appendix C. Table 6. Model selection table for releasing adult females onto the spawning grounds to increase emigrants at RST in the Clearwater basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	5	-25.174	64.963	0	0.693	0.586	0.760
3	6	-24.263	67.526	2.563	0.192	0.503	0.843
2	6	-25.010	69.020	4.057	0.091	0.585	0.767
1	7	-23.748	71.678	6.716	0.024	0.500	0.849

Appendix C. Table 7. Parameter estimates from model averaging using females released above the weir to predict emigrants at RST in the Clearwater basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	6.37	0.81	4.79	7.95
Natural	0.77	0.19	0.40	1.15
Non ISS-Ratio	-0.12	0.28	-0.67	0.43
T-Ratio	0.04	0.21	-0.38	0.45

Appendix C. Table 8. Restricted maximum likelihood estimates of random effects for the intensive Clearwater River hypothesis for emigrants at RST using adults released as a treatment variable

Group	N	Variance	SD
year	10	0.704	0.839
stream	3	0	0
Residual	19	0.304	0.551

Smolt Abundance

Appendix C. Table 9. Model selection table for releasing adult females onto the spawning grounds to increase smolts at LGR in the Clearwater basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	5	-14.283	45.232	0	0.878	0.688	0.881
3	6	-13.897	50.294	5.062	0.070	0.716	0.877
2	6	-14.225	50.950	5.718	0.050	0.692	0.876
1	7	-13.846	57.692	12.459	0.002	0.721	0.880

Appendix C. Table 10. Parameter estimates from model averaging using females released above the weir to predict smolts at LGR in the Clearwater basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	4.97	0.67	3.66	6.29
Natural	0.87	0.15	0.57	1.17
Non ISS-Ratio	0.02	0.16	-0.29	0.34
T-Ratio	0.01	0.11	-0.21	0.22

Appendix C. Table 11. Restricted maximum likelihood estimates of random effects for the intensive Clearwater River hypothesis for smolts at LGR using adults released as a treatment variable.

Group	N	Variance	SD
year	9	0.250	0.500
stream	3	0	0
Residual	15	0.188	0.434

Natural-origin Adult progeny

Appendix C. Table 12. Model selection table for releasing adult females onto the spawning grounds to increase natural-origin adult progeny returns in the Clearwater basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	5	-32.852	78.313	0	0.612	0.001	0.896
3	6	-32.388	80.595	2.282	0.196	0.007	0.910
2	6	-32.617	81.052	2.739	0.156	0.009	0.875
1	7	-32.306	83.945	5.632	0.037	0.012	0.899

Appendix C. Table 13. Parameter estimates from model averaging using females released above the weir to predict natural-origin adult progeny returns in the Clearwater.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	4.47	0.72	3.07	5.88
Natural	0.02	0.14	-0.26	0.29
NonISS-Ratio	0.04	0.12	-0.19	0.27
T-Ratio	0.04	0.17	-0.29	0.37

Appendix C. Table 14. Restricted maximum likelihood estimates of random effects for the intensive Clearwater River hypothesis for adult progeny using adults released as a treatment variable.

Group	N	Variance	SD
year	11	0.842	0.917
stream	4	0.431	0.657
Residual	29	0.144	0.380

SALMON BASIN

Redds

Appendix C. Table 15. Model selection table for releasing adult females onto the spawning grounds to increase redds in the Salmon basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
1	7	-14.710	46.447	0	0.623	0.904	0.944
2	6	-16.623	47.457	1.011	0.376	0.869	0.941
3	6	-22.850	59.910	13.463	0.001	0.866	0.921
4	5	-24.509	60.556	14.109	0.001	0.828	0.917

Appendix C. Table 16. Parameter estimates from model averaging using females released above the weir to predict redds in the Salmon basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	-0.07	0.28	-0.62	0.49
Natural	1.02	0.05	0.93	1.10
T-Ratio	0.72	0.18	0.37	1.07
Non ISS-Ratio	0.24	0.25	-0.25	0.73

Appendix C. Table 17. Restricted maximum likelihood estimates of random effects for the intensive Salmon River hypothesis for total redds using adults released as a treatment variable.

Group	N	Variance	SD
year	13	0	0
stream	4	0.066	0.257
Residual	45	0.093	0.305

Emigrants at RST

Appendix C. Table 18. Model selection table for releasing adult females onto the spawning grounds to increase emigrants at RST in the Salmon basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
1	7	-38.566	94.243	0	0.460	0.569	0.819
3	6	-40.442	95.155	0.912	0.292	0.577	0.781
2	6	-41.191	96.652	2.409	0.138	0.524	0.754
4	5	-42.768	97.114	2.871	0.110	0.532	0.721

Appendix C. Table 19. Parameter estimates from model averaging using females released above the weir to predict emigrants at RST in the Salmon basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	6.53	0.56	5.42	7.63
Natural	0.76	0.09	0.58	0.94
T-Ratio	0.35	0.37	-0.38	1.08
Non ISS-Ratio	0.62	0.47	-0.31	1.55

Appendix C. Table 20. Restricted maximum likelihood estimates of random effects for the intensive Salmon River hypothesis for emigrants at RST using adults released as a treatment variable.

Group	N	Variance	SD
year	13	0.024	0.155
stream	4	0.316	0.562
Residual	44	0.245	0.495

Smolt Abundance

Appendix C. Table 21. Model selection table for releasing adult females onto the spawning grounds to increase smolts at LGR in the Salmon basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
4	5	-37.858	87.295	0	0.358	0.428	0.715
2	6	-36.581	87.432	0.137	0.334	0.424	0.753
1	7	-35.934	88.979	1.684	0.154	0.433	0.787
3	6	-37.357	88.984	1.688	0.154	0.436	0.745

Appendix C. Table 22. Parameter estimates from model averaging using females released above the weir to predict smolts at LGR in the Salmon basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	6.27	0.52	5.25	7.28
Natural	0.57	0.09	0.40	0.74
T-Ratio	0.23	0.30	-0.37	0.82
Non ISS-Ratio	0.12	0.26	-0.39	0.62

Appendix C. Table 23. Restricted maximum likelihood estimates of random effects for the intensive Salmon River hypothesis for smolts at LGR using adults released as a treatment variable.

Group	N	Variance	SD
year	13	0.042	0.204
stream	4	0.292	0.541
Residual	44	0.202	0.449

Natural-origin Adult progeny

Appendix C. Table 24. Model selection table for releasing adult females onto the spawning grounds to increase natural-origin adult progeny returns in the Salmon basin.

Model	K	logLik	AICc	Delta AICc	Weight	Marginal R^2	Conditional R^2
2	6	-29.693	73.597	0	0.438	0.065	0.800
4	5	-31.516	74.571	0.975	0.269	0.038	0.759
1	7	-29.186	75.399	1.802	0.178	0.076	0.799
3	6	-31.032	76.275	2.679	0.115	0.049	0.755

Appendix C. Table 25. Parameter estimates from model averaging using females released above the weir to predict natural-origin adult progeny returns in the Salmon basin.

Parameter	Estimate	Unconditional SE	Lower 95%	Upper 95%
(Intercept)	5.31	0.44	4.44	6.17
Natural	0.11	0.09	-0.07	0.28
T-Ratio	0.23	0.24	-0.24	0.70
Non ISS-Ratio	0.07	0.18	-0.27	0.41

Appendix C. Table 26. Restricted maximum likelihood estimates of random effects for the intensive Salmon River hypothesis for adult progeny using adults released as a treatment variable

Group	N	Variance	SD
year	13	0.239	0.489
stream	4	0.094	0.306
Residual	45	0.093	0.304

Appendix D. Annotated bibliography of project publications.

Appendix D. Annotated Bibliography of publications produced by cooperating agencies participating in the Idaho Supplementation Studies (ISS), with notes on project years covered and content. Publications are organized first by type (routine progress reports, special technical reports, thesis and dissertations, and peer-reviewed publications), authors, and publication year.

Publication	Agency	Years	Content
Progress Reports			
Arnsberg, B.D. 1993. Salmon Supplementation Studies in Idaho Rivers, annual report 1992. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	1992 (Phase 1)	Progress report
Beasley, C., J. Lockhart, T. Tabor, and R. Kinzer. 2003. Salmon supplementation studies in Idaho rivers; 2000-2001 annual report. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	2000-2001 (Phase 2)	Progress report
Bretz, J., and J. Olson. 2003. Salmon supplementation studies in Idaho rivers. Annual progress report to Bonneville Power Administration, Project No. 198909801, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	USFWS	2002 (Phase 2)	Reported an increase in BY 2000 emigrants over BY1999. Some uncontrolled escapement of adults in Clear Creek reported.
Gass, C., and J. Olson. 2004. Salmon supplementation studies in Idaho rivers; field activities conducted on Clear and Pete King Creeks in 2001. Annual progress report to Bonneville Power Administration, Project No. 198909801, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	USFWS	2001 (Phase 2)	Reports that no juvenile supplementation release of BY1999 fish was made in Clear Creek. Weir breach allowed uncontrolled adult escapement into Clear Creek.

Appendix D. Continued.

Publication	Agency	Years	Content
Hesse J.A., and B.D. Arnsberg. 1994. Salmon supplementation studies in Idaho rivers; Idaho supplementation studies, 1993 annual report. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	1993 (Phase 1)	Progress report
Hesse, J., P. Cleary, and B. Arnsberg. Salmon Supplementation Studies in Idaho Rivers, 1994 annual report. 1995. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	1994 (Phase 1)	Progress report
Keith, R.M., M. Rowe, E. Honena, and T. Trahant. 1995. Salmon supplementation studies in Idaho rivers; progress report, period covered: July 1, 1992 to December 31, 1994. Annual progress report to Bonneville Power Administration, Project No. 198909803, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	SBT	1992-1994 (Phase 1)	Report on activities in East Fork Salmon, South Fork Salmon and West Fork Yankee Fork Salmon rivers; and Bear Valley, Herd, and Valley creeks for first three years of study.
Keith, R.M., M. Rowe, C.A. Reighn, E. Honena, and T. Trahant. 1996. Salmon supplementation studies in Idaho rivers; progress report, period covered: January 1, 1995 to December 3 1, 1995. Annual progress report to Bonneville Power Administration, Project No. 198909803, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	SBT	1995 (Phase 1)	Report on activities in East Fork Salmon, South Fork Salmon and West Fork Yankee Fork Salmon rivers; and Bear Valley, Herd, and Valley creeks. Reported low juvenile abundances observed during snorkel surveys, and much lower redd numbers than in 1994. Zero redds were observed in East Fork Salmon and West Fork Yankee Fork Salmon rivers; and in Herd and Valley creeks.

Appendix D. Continued.

Publication	Agency	Years	Content
Kinzer, R., W. Keller, and T. Covel. 2010. Salmon supplementation studies in Idaho rivers, 2008-2009 annual report (brood year 2007). Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2007 (end Phase 2)	Progress report
Kinzer, R., W. Keller, T. Covel, and R. Santo. 2011. Salmon supplementation studies in Idaho rivers, 2009-2010 annual report (brood year 2008). Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2008 (Phase 3)	Progress report
Kohler, A., D. Taki, and A. Teton. 2001. Salmon supplementation studies in Idaho rivers; progress report, period covered: January 1, 1999 to December 31, 2000. Annual progress report to Bonneville Power Administration, Project No. 198909803, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	SBT	1992-2000 (Phases 1 and Phase 2)	Report on activities in East Fork Salmon, South Fork Salmon and West Fork Yankee Fork Salmon rivers; and Bear Valley, Herd, and Valley creeks. Provides tables of summary data collected for all years of project, with discussion of general findings since start of project.
Leitzinger E.J., K. Plaster, and E. Bowles. 1993. Idaho supplementation studies, annual report 1991-1992. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res-Leitzinger1992%20Idaho%20Supplementation%20Studies.pdf.	IDFG	1991-1992 (Phase 1)	Reported low summer juvenile abundances and low redd counts in most study streams
Leitzinger, E.J., K. Plaster, P. Hassemer, and P. Sankovich. 1996. Idaho supplementation studies, annual progress report, period covered: January 1, 1993 to December 31, 1993. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res96-26Leitzinger1993%20Idaho%20Supplementation%20Studies.pdf.	IDFG	1993 (Phase 1)	Provided detailed methods for trying to improve summer parr instream abundance estimates; reported low redd counts throughout study area; difficulty reaching spring smolt tagging goals

Appendix D. Continued.

Publication	Agency	Years	Content
Lockhart, J., W. Keller, R. Kinzer, and T. Covel. 2006. Salmon supplementation studies in Idaho rivers; 2004-2005 annual report (Brood Year 2003), 2004 through 2005. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2003 (Phase 2)	Progress report
Lockhart, J., W. Keller, R. Kinzer, and T. Covel. 2006. Salmon supplementation studies in Idaho rivers; 2005-2006 annual report (Brood Year 2004), April 2005 through June 2006. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2004 (Phase 2)	Progress report
Lockhart, J., W. Keller, R. Kinzer, T. Covel, and J. Helmich. 2008. Salmon supplementation studies in Idaho rivers, 2006-2007 annual report (brood year 2005) April 2006 through June 2007. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2005 (Phase 2)	Progress report
Lockhart J., W. Keller, R. Kinzer, T. Covel, J. Helmich. 2009. Salmon supplementation studies in Idaho rivers, 2007-2008 Annual Report (Brood Year 2006). Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2006 (Phase 2)	Progress report
Lockhart, J., and R. Kinzer. 2006. Salmon supplementation studies in Idaho rivers; 2001 annual report (Brood Year 2000) April 2001 through June 2002. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate	NPT	2001-2002 (Phase 2)	Progress report

Appendix D. Continued.

Publication	Agency	Years	Content
Lockhart, J., and R. Kinzer. 2006. Salmon supplementation studies in Idaho rivers; (brood year 2002), 2003 through2004 annual report. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	Brood year 2002 (Phase 2)	Progress report
Lockhart, J., R. Kinzer, and T. Covel. 2006. Salmon supplementation studies in Idaho rivers; 2002 annual report (Brood Year 2001), April 2002 through June 2003. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	2002-2003 (Phase 2)	Progress report
Lockhart, J., and T.T. Tabor. 2006. Salmon supplementation studies in Idaho rivers; 1998 annual report (Brood Year 1997), April 1998 through June 1999. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	1998-1999 (Phase 2)	Progress report
Lockhart, J., and T.T. Tabor. 2006. Salmon supplementation studies in Idaho rivers; 1999 Annual Report (Brood Year 1998) April 1999 through June 2000. Annual progress report to Bonneville Power Administration, Project No. 198909802, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	NPT	1999-2000 (Phase 2)	Progress report
Lutch, J., B. Leth, K. Apperson, A. Brimmer, N. Brindza. 2003. Idaho Supplementation Studies, Project Progress Report 1997-2001. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res03-37Lutch1997-2004%20Idaho%20Supplementation%20Studies.pdf	IDFG	1997-2001 (Phase 2)	Reported the initial construction of a weir on Crooked Fork Creek. Redd locations were documented by gps starting in 2000. Describes new method to estimate juvenile emigrant abundances, applied in this and all future reports. Discusses changes in treatments prescribed in original study design

Appendix D. Continued.

Publication	Agency	Years	Content
Nemeth, D., K. Plaster, K. Apperson, J. Brostrom, T. Curet, and E. Brown. 1996. Idaho Supplementation Studies, Annual Report 1994, Report to Bonneville Power Administration, Contract No. 1989BP01466, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res96-20Nemeth1994%20Idaho%20Supplementation%20Studies.pdf.	IDFG	1994 (Phase 1)	Discusses low adult escapement throughout study area; wide variance with instream summer parr abundance estimates.
Olson, J.M., and J.K. Bretz. 2001. Idaho Supplementation Studies. Clear Creek and Pete King Creek 1997 progress report. Progress report to Bonneville Power Administration, Project No. 198909801, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate	USFWS	1997 (Phase 2)	
Olson, J.M., and J.K. Bretz. 2001. Idaho Supplementation Studies. Clear Creek and Pete King Creek progress report for field activities conducted in 1998, 1999, 2000. Progress report to Bonneville Power Administration, Project No. 198909801, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate	USFWS	1998 – 2000 (Phase 2)	
Reighn, C.A., B. Lewis, D. Taki, A. Teton, and E. Galloway. 1999. Salmon supplementation studies in Idaho rivers; progress report period covered: January 1, 1996 to December 31, 1998. Annual progress report to Bonneville Power Administration, Project No. 198909803, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.	SBT	1992-1998 (Phase 1 and Phase 2)	Report on activities in East Fork Salmon, South Fork Salmon and West Fork Yankee Fork Salmon rivers; and Bear Valley, Herd, and Valley creeks. Provides tables of summary data collected for all years of project, with discussion of general findings since start of project.
Rockhold, E.A., R.B. Roseberg, and J.M. Olson. 1994. Idaho supplementation studies – Pete King Creek and Clear Creek progress report. Period covered: January 1, 1991 to December 31, 1993. Progress report to Bonneville Power Administration, Project No. 198909801, Portland, Oregon. Available at: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate	USFWS	1991 – 1993 (Phase 1)	

Appendix D. Continued.

Publication	Agency	Years	Content
Venditti, D.A., K.A. Apperson, A. Brimmer, N. Brindza, C. Gass, A. Kohler, and J. Lockhart. 2005. Idaho supplementation studies brood year 2002 cooperative report, August 1, 2002 – July 31, 2004. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res05-25Venditti2004%20Idaho%20Supplementation%20Studies.pdf.	IDFG NPT SBT USFWS	Brood year 2002 (Phase 2)	First cooperative progress report encompassing all activities for a specific brood year. Format and scope of this report is generally followed in all subsequent progress reports through broodyear 2012. Last brood year of culture of supplementation fish. Reports on implementation of increased carcass surveys to estimate spawner origin proportion and prevalence of prespawn mortality. First introduction of Bismarck Brown dye used to mark subtaggable juveniles for emigrant estimation, with discussion about assumptions and protocols. Summary of non-project release of adults in West Fork Yankee Fork Salmon River.
Venditti, D.A., K.A. Apperson, R. Kinzer, J. Flinders, A. Teton, C. Bretz, B. Bowersox, and B. Barnett. 2010. Idaho supplementation studies brood year 2007 cooperative report, August 1, 2007 – July 31, 2009. Annual progress report to Bonneville Power Administration. 198909800. Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res10-14Venditti2007%20ISS.pdf.	IDFG NPT SBT USFWS	Brood year 2007 (end of Phase 2)	Last year of adult supplementations. Last reporting on continuing supplementation activities in Johnson, Lolo, and Newsome creeks, as these streams will be omitted from the remaining years of ISS. Summarizes non-project releases of adults in West Fork Yankee Fork Salmon River and adults and eyed-eggs in the East Fork Salmon River.
Venditti, D.A., C. Bretz, B. Barnett, M.P. Corsi, K.A. Apperson, K. Tardy, R. Kinzer, and J. Messner. 2014. Idaho supplementation studies, brood year 2011 Synthesis Report August 1, 2011 – July 31, 2013. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res14-08VendittiISSBY2011%20Synthesis%20Report.pdf	IDFG NPT SBT USFWS	Brood year 2011 (Phase 3)	Discussion of attempts to improve juvenile emigrant trapping in Clear Creek; discussion of adjustments to redd count surveys in Pahsimeroi and Lemhi rivers following tributary reconnects and efforts to reduce aerial counts in preference for ground counts.

Appendix D. Continued.

Publication	Agency	Years	Content
Venditti D.A., J. Flinders, R. Kinzer, B. Bowersox, A. Teton, B. Barnett, C. Bretz, and K.A. Apperson. 2011. Idaho supplementation studies, brood year 2008 Synthesis Report August 1, 2008 – July 31, 2010. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res11-19VendittiBY2008ISS%20Synthesis%20Report.pdf.	IDFG NPT SBT USFWS	Brood year 2008 (Start of Phase 3)	Summarizes non-project releases of adults in West Fork Yankee Fork Salmon and East Fork Salmon rivers.
Venditti, D.A., J. Flinders, R. Kinzer, C. Bretz, M. Corsi, B. Barnett, K.A. Apperson, and A. Teton. 2012. Idaho supplementation studies, brood year 2009 Synthesis Report August 1, 2009 – July 31, 2011. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res12-13VendittiBY2009%20ISS%20Synthesis%20Report%20Final.pdf.	IDFG NPT SBT USFWS	Brood year 2009 (Phase 3)	Summarizes non-project releases of juveniles in South Fk Clearwater and adults in West Fork Yankee Fork Salmon and East Fork Salmon rivers. Summarizes SBT supplementation project and associated monitoring in West Fork Yankee Fork Salmon River. Notes unknown effects of adult releases of Coho salmon in Clearwater tributaries on Chinook salmon production and productivity.
Venditti, D.A., R. Kinzer, K.A. Apperson, J. Flinders, M. Corsi, C. Bretz, K. Tardy, and B. Barnett. 2013. Idaho supplementation studies, Brood Year 2010 Synthesis Report August 1, 2010 – July 31, 2012. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res13-09VendittiISSBY2010%20Synthesis%20Report.pdf.	IDFG NPT SBT USFWS	Brood year 2010 (Phase 3)	Reported on comparison of PIT tag injector types. Discussed poor juvenile emigrant trapping success in Clear Creek and replacement of screw trap with a fyke net. Discussed redd survey adjustments in response to tributary reconnects in Lemhi and Pahsimeroi rivers; and changing to ground redd survey of White Cap Creek. Discussed continued use of NOR males for broodstock prior to release upstream from weirs. Discussed ongoing adult releases by other projects.

Appendix D. Continued.

Publication	Agency	Years	Content
Venditti, D.A., R. Kinzer, B. Barnett, K.A. Apperson, K. Tardy, M.P. Corsi, M. Belnap, and C. Bretz. 2015. Idaho supplementation studies, Brood Year 2012 Synthesis Report August 1, 2012 – July 31, 2014. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res15-16VendittiISSBY2012%20Synthesis%20Report.pdf.	IDFG NPT SBT USFWS	Brood year 2012 (end Phase 3)	Final progress report. Discussion of ongoing challenge of estimating juvenile emigration in Clear Creek. Summary of coordination with other supplementation programs to maintain study integrity in final years.
Venditti, D.A., A. Kohler, K.A. Apperson, B. Barnett, A. Brimmer, and N. Brindza. 2006. Idaho supplementation studies, joint project progress report, 2002 interim report, January 1, 2002 — July 31, 2002. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res06-47Venditti2002%20Idaho%20Supplementation%20Studies.pdf.	IDFG SBT	2002 partial year (Phase 2)	Interim progress report to fill a gap in reporting activities since previous progress report and future “brood year specific” reports. Report is limited to juvenile hatchery releases, juvenile emigrant estimates and smolt survival for brood years 2000 and 2001.
Venditti, D.A., A. Kohler, K.A. Apperson, A. Brimmer, B. Bowersox, C. Bretz, and J. Lockhart. 2008. Idaho Supplementation Studies Brood Year 2005 Cooperative Report August 1, 2005 – July 31, 2007. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res08-07Venditti2007%20Idaho%20Supplementation%20Studies%20BY2005%20Cooperative%20Report.pdf.	IDFG NPT SBT USFWS	Brood year 2005 (Phase 2)	Evaluated factors that may influence screw trap efficiency estimates, specifically time of release during the day and distance of release upstream from traps. Discussed ongoing adult releases by other projects.
Venditti, D.A., A. Kohler, C. Bretz, N. Brindza, J. Lockhart, A. Brimmer, and K.A. Apperson. 2006. Idaho supplementation studies brood year 2003 Cooperative Report, August 1, 2003 – July 31, 2005. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res06-17Venditti2005%20Idaho%20Supplementation%20Studies.pdf.	IDFG NPT SBT USFWS	Brood year 2003 (Phase 2)	First reporting of smolt survival probabilities using SURPH. Introduced caudal clipping as alternative method to mark sub-taggable juveniles for emigrant estimation.

Appendix D. Continued.

Publication	Agency	Years	Content
Venditti, D.A., J. Lockhart, A. Brimmer, A. Kohler, B. Bowersox, C. Bretz, and K.A. Apperson. 2009. Idaho supplementation studies, brood year 2006 Cooperative Report August 1, 2006 – July 31, 2008. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res09-07Venditti208%20Idaho%20Supplementation%20Studies%20BY2006%20Cooperative%20Report.pdf.	IDFG NPT SBT USFWS	Brood year 2006 (Phase 2)	Discussed ongoing adult releases by other projects.
Venditti, D.A., J. Lockhart, A. Kohler, A. Brimmer, K.A. Apperson, B. Bowersox, and C. Bretz. 2007. Idaho supplementation studies, brood year 2004 cooperative report August 1, 2004 – July 31, 2006. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res07-24Venditti2006%20Idaho%20Supplementation%20Studies.pdf.	IDFG NPT SBT USFWS	Brood year 2004 (Phase 2)	Reports on continued culture of juveniles for supplementation in Lolo, Newsome and Johnson creeks. Presents comparison of screw trap efficiencies using PIT tags and Bismarck Brown stain. Provides smolt survival estimates using SURPH for all years of study. Presents mark/recapture adult escapement estimates for all years available for streams with weirs.
Technical reports	**Agency**	**Years**	**Content**
Bowles, E., and E. Leitzinger. 1991. Salmon Supplementation Studies in Idaho Rivers; Idaho Supplementation Studies. Technical Report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res-Bowles1991%20Salmon%20Supplementation%20Studies%20in%20Idaho%20Rivers%20%20(Idaho%20Supplementation%20Studies)%20%20Experimental%20Design.pdf.	IDFG	NA	Original study design
Lutch, J., C. Beasley, and K. Steinhorst. 2003. Evaluation and statistical review of Idaho supplementation studies. Technical Report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res03-16Lutch2001%20Evaluation%20and%20Statistical%20Review%20of%20%20Idaho%20Supplementation%20Studies.pdf.	IDFG NPT U of I	1991-2001	Statistical review of first ten years of study. This report was a response to concerns raised by ISRP. A prototype analysis is presented with recommendations for the remainder of the study.

Appendix D. Continued.

Publication	Agency	Years	Content
Lutch, J, J. Lockhart, C. Beasley, K. Steinhorst, and D. Venditti. 2005. An Updated Study Design and Statistical Analysis of Idaho Supplementation Studies", Technical Report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res05-35Lutch2005%20Idaho%20Supplementation%20Studies%20Updated%20Study%20Design%20and%20Statistical%20Analysis.pdf.	IDFG NPT U of I	1992-2000	Updated study design following comments by ISRP to the mid-project statistical review.
Walters, J., J. Hansen, J. Lockhart, C. Reighn, R. Keith, and J. Olson. 1999. Idaho supplementation studies five year report 1992-1996. Annual progress report to Bonneville Power Administration, Project No. 198909800, Portland, Oregon. Available at: https://collaboration.idfg.idaho.gov/FisheriesTechnicalReports/Res99-14Walters1996%20Idaho%20Supplementation%20Studies.pdf.	IDFG, NPT SBT USFWS	1992-1996	Five year progress report. Summary of all activities accomplished relative to original design and refinements in methodologies. Explains changes in study streams and treatments. Several recommendations made that were followed through remainder of study, including: discontinuation of snorkel abundance estimates in study where emigrant estimates are produced, intensifying redd counts, organizing all data in central databases. Contributions to other projects and overall body of knowledge of populations discussed.
Thesis and Dissertation			
Leth, B.D. 2005. Reproductive success of hatchery and natural origin Chinook salmon (Oncorhynchus tshawytscha) in a stream with a history of supplementation management. Master's thesis, University of Idaho, Moscow, Idaho.	U of I IDFG	2002-2004	Microsatellite DNA markers, were used to determine the contribution of hatchery and natural origin Chinook salmon to juvenile offspring. Behavioral observations were conducted to determine if there were differences in spawn timing, distribution, and frequency of spawning behavior between hatchery-and natural origin adults. Hatchery and natural adults mixed, interacted and spawned in a random fashion with similar reproductive success.

Appendix D. Continued.

Publication	Agency	Years	Content
Peery C.A., and T.C. Bjornn. 1996. Small-scale investigations into Chinook salmon supplementation strategies and techniques 1992–1994. Ph.D. Dissertation, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho.	U of I	1992-1994	Studies on the types of interactions that can occur between hatchery and natural Chinook salmon juveniles and how these interactions change with different fish sizes and densities. The behavior of natural chinook salmon was significantly altered when hatchery fish were present. Predation by trout on hatchery Chinook salmon was size specific and the effect of predators on habitat used by hatchery fish was greatest when the hatchery fish were small. Hatchery Chinook salmon parr remained concentrated around release sites, and the distribution and growth of hatchery Chinook salmon was improved by spreading releases over multiple sites within a stream.
Peer reviewed publications			
Copeland, T., and D.A. Venditti. 2009. Contribution of three life history types to smolt production in a Chinook salmon (*Oncorhynchus tshawytscha*) population. Canadian Journal of Fisheries and Aquatic Sciences 66: 1658–1665.	IDFG	1992-2004	Survival of age-0 smolts, fall parr, and age-1 smolts to Lower Granite Dam. Relative abundances of each.
Copeland, T., D.A. Venditti, and B.R. Barnett. 2014. The importance of juvenile migration tactics to adult recruitment in stream-type Chinook Salmon populations. Transactions of the American Fisheries Society, 143:6, 1460-1475.	IDFG	1997-2007	Survival of subyearling versus yearling emigrants from natal reaches to Lower Granite Dam and from Lower Granite to Bonneville dam as adults. Expanded PIT tag detections to estimate adult production by emigrant type.
Kohler, A.E., P.C. Kusnierz, T. Copeland, D.A. Venditti, L. Denny, J. Gable, B.A. Lewis, R. Kinzer, B. Barnett, and M.S. Wipfli. 2013. Salmon-mediated nutrient flux in selected streams of the Columbia River basin, USA. Canadian Journal of Fisheries and Aquatic Sciences 70: 502–512.	SBT IDFG NPT	1998-2008	Modeled nutrient flow into and out of selected ISS streams via juvenile and adult Chinook Salmon.

Appendix D. Continued.

Publication	Agency	Years	Content
Peery, C.A., and T.C. Bjornn. 2000. Dispersal of hatchery-reared Chinook salmon parr following release into four Idaho streams. North American Journal of Fisheries Management 20:19–27.	U of I	1994	Snorkel surveys were used to observe dispersal of Chinook Salmon parr released at multiple sites within a stream versus a single release site.
Peery, C.A., and T.C. Bjornn. 2004. Interactions between natural and hatchery chinook salmon parr in a laboratory stream channel. Fisheries Research 66:311–324.	U of I	1993-1994	Documented changes in both aggressive behavior and habitat use by natural origin Chinook Salmon parr in the presence of hatchery origin conspecifics. They hypothesized that these changes could increase natural origin chinook salmon parr energy expenditures and exposure to predators.
Walters, A.W. T. Copeland, and D. A. Venditti. 2013. The density dilemma: limitations on juvenile production in threatened salmon populations. Ecology of Freshwater Fish 22: 508–519.	IDFG NWFSC	1991-2007	Density effects on smolt production at Lower Granite Dam as well as growth, survival, and movement timing.

Prepared by:

David A. Venditti
Senior Fisheries Research Biologist
Idaho Department of Fish and Game

Ryan N. Kinzer
Project Leader
Nez Perce Tribe

Kimberly A. Apperson
Regional Fisheries Biologist
Idaho Department of Fish and Game

Bruce Barnett
Senior Fisheries Technician
Idaho Department of Fish and Game

Matthew Belnap
Regional Fisheries Biologist
Idaho Department of Fish and Game

Timothy Copeland
Fisheries Program Coordinator
Idaho Department of Fish and Game

Matthew P. Corsi
Principal Fisheries Research Biologist
Idaho Department of Fish and Game

W. Tyler Gross
Senior Fisheries Technician
Idaho Department of Fish and Game

Laurie Janssen
Senior Fisheries Technician
Idaho Department of Fish and Game

Ryan Santo
Fisheries Technician
Nez Perce Tribe

Kurt Tardy
Anadromous Fish Biologist
Shoshone-Bannock Tribes

Angelo Teton
Fisheries Technician
Shoshone-Bannock Tribes

Approved by:

James P. Fredericks
Chief, Bureau of Fisheries
Idaho Department of Fish and Game

Peter F. Hassemer
Anadromous Fisheries Manager
Idaho Department of Fish and Game

David B. Johnson
Director, Fisheries Resources Management
Nez Perce Tribe

Chad Colter
Fish and Wildlife Director
Shoshone-Bannock Tribes

Christopher A. Peery
Fish Biologist
Idaho Fishery Resource Office
U.S. Fish and Wildlife Service