FY 2008-2009 F&W Program Accords (MOA) Proposal Review

Narrative

Project ID:

Title: Salmon River Basin Nutrient Enhancement

Table 1. Proposal Metadata

Project Number	2008-904-00
Proposer	The Shoshone-Bannock Tribes (SBT)
Short Description	The proposed project seeks to partially mitigate for the dramatic decline of anadromous salmonids (and the associated reduction of available marine-derived nutrients to freshwater spawning and rearing habitat) by experimentally enriching nutrient limited upper Salmon River subbasin streams with carbon, nitrogen, and phosphorus using salmon carcass analogs.
Province(s)	Mountain Snake
Subbasin(s)	Salmon River
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Information transfer:

A. Abstract

Pacific salmon and steelhead once contributed large amounts of marine-derived carbon, nitrogen, and phosphorus to freshwater ecosystems in the Pacific Northwest of the United States of America (California, Oregon, Washington, and Idaho). Declines in historically abundant anadromous salmonid populations represent a significant loss of returning nutrients across a large spatial scale. A paucity of marine derived nutrients in the Salmon River subbasin has been identified as a limiting factor to freshwater productivity and the growth and survival of resident and anadromous fishes (including four species listed as threatened or endangered under the Endangered Species Act). We propose to mitigate diminished marine-derived nutrient inputs with experimental treatments using pathogen-free salmon carcass analogs and/or inorganic nutrients (silver bullets). We will employ a randomized-treatment experimental design, similar to previously completed work by the Shoshone Bannock Tribes and other Columbia Basin cooperators, to assess the effectiveness of nutrient enrichment treatments in upper Salmon River subbasin streams. Specific project objectives include: quantification of streamwater nutrient concentrations; stream nutrient limitation; stream nutrient cycling and retention; periphyton standing stock; macroinvertebrate density, biomass, and community composition; leaf litter decay rates, aquatic food web connections, and the bioenergetics, growth, and survival of resident and anadromous salmonids in treatment streams receiving nutrient additions and

control streams that do not receive nutrient additions. Additional objectives will be to address significant data gaps related to treatment spatial and temporal scales and nutrient enrichment levels. Nutrient enrichment response variables will be measured using common data collection protocols to facilitate application between cooperators, projects, and managers. Project results will be published in annual reports and submitted to peer-reviewed journals. The overarching objective will be to assess the effectiveness of experimental nutrient enrichment strategies at mitigating the adverse effects to fish and wildlife caused by the development of the hydropower system.

B. Technical and/or scientific background

Abundant populations of anadromous salmonids (*Oncorhynchus* spp.) historically contributed large amounts of marine-derived carbon (C), nitrogen (N), and phosphorus (P) to aquatic and terrestrial ecosystems in the Pacific Northwest (PNW) of the United States of America (California, Oregon, Washington, and Idaho) (Kline et al. 1990; Larkin & Slaney 1997; Cederholm et al. 1999; Gresh et al. 2000; Bilby et al. 2003). In the Columbia River Basin an estimated 10-16 million anadromous fishes returned annually (NPPC 2000). Nutrients and carbon sequestered in the marine environment, where approximately 95% of the body mass of Pacific salmon accumulates, are subsequently delivered to inland watersheds via upstream migrations (Groot & Margolis 1991). These migrations represent a major energy vector from the marine environment to freshwater and terrestrial ecosystems (Cederholm et al. 1999).

After reaching natal spawning habitat, Pacific salmon complete their life cycle and in turn deliver ecologically significant amounts of marine-derived nutrients (MDN) to inland habitats (Thomas et al. 2003). Anadromous fishes deliver MDN to freshwater ecosystems through excretion, gametes, and their own nutrient rich carcasses. Three primary nutrient pathways from salmon carcasses to stream biota include: 1) uptake of mineralized inorganic nutrients by primary producers and subsequent food web transfer; 2) uptake of dissolved organic matter by microfauna in the streambed and subsequent food web transfer; and 3) direct consumption of eggs and carcass materials by secondary producers and fishes (Cederholm et al. 1999). This energy source also benefits a myriad of wildlife species and acts to sustain the ecological integrity and proper functioning condition of whole ecosystems. In the PNW, Cederholm et al. (1989) documented 22 species of mammals and birds that were observed or known to directly consume salmon carcasses. And Bilby et al. (1996) estimated that riparian area vegetation along a salmon bearing stream contained an 18% allocation of MDN.

Spawning salmon contribute an estimated 5 to 95% of the P and N loading in salmon-bearing watersheds (Gresh et al. 2000), and even small input of nutrients and carbon may be important to the maintenance of trophic productivity (Larkin & Slaney 1997). This process has been described as a positive feedback loop functioning to enhance freshwater productivity for future generations of anadromous and resident stream biota (Wipfli et al. 1998; Hicks et al. 2005). The presence and availability of MDN has been shown to increase the growth rate, lipid level, and condition factor of juvenile fishes (Bilby et al. 1996; Wipfli et al. 2004); and higher growth rates appear to increase freshwater and marine survival (Beckman et al. 1999; Bilton et al. 1982; Ward and Slaney 1988). It is now clear that spawning salmon serve numerous ecological functions and should be an important component of ecosystem recovery plans (Cederholm et al. 1999).

Following periods of intense commercial harvest, hydrosystem development, hatchery production, and habitat loss, significant declines in Pacific salmon abundance have occurred throughout the region (Lichatowich 1999). Returning anadromous adults in the Columbia River Basin, once estimated at 10-16 million fish annually, now return at an average of 1 million fish per year (NPPC 2000). Healthy populations of salmon that once provided annual nutrient subsidies to otherwise nutrient impoverished environments remain depressed or have been extirpated (Levy 1997). Currently, Pacific salmon occupy approximately 40% of their historic range (Nehlsen et al. 1991) and contribute just 6-7% of the MDN historically delivered to PNW rivers and streams (Gresh et al. 2000). Consequently, many forested streams of the region are now characterized as ultra-oligotrophic (Welsh et al. 1998), a condition of low nutrient concentrations suggested to result from a combination of parent geology and low numbers of returning salmon (Ambrose et al. 2004).

In the upper Salmon River basin of central Idaho, the paucity of returning adult salmon and watershed scale nutrient deficits may constrain freshwater productivity and effectively limit efforts to recover salmon and steelhead populations. Thomas et al. (2003) estimated that 25-50% of Idaho streams are nutrient limited and Achord et al. (2003) found evidence of density-dependent mortality at population sizes well below historical levels, suggesting nutrient deficits as a limiting factor capable of reducing stream rearing carrying capacities. In a recent analysis, Scheuerell et al. (2005) examined phosphorus-transport dynamics by spring/summer Chinook salmon (*Oncoryhnchus tshawytscha*) in the Snake River basin and estimated that over the past 40 years <2% of historical marine-derived phosphorus reached natal streams. Moreover, observations of variable density-dependent mortality at low spawning densities could lead to a net nutrient export from freshwater ecosystems, as more nutrients leave as smolts than are returned as adults (Moore & Schindler 2004). Given contemporary anadromous production, hydrosystem conditions, low smolt to adult returns (SAR), and ocean productivity trends, conservation efforts could be stymied by a lack of available nutrients to freshwater rearing habitat in the Salmon River basin (Achord et al. 2003; Thomas et al. 2003).

Numerous studies have investigated freshwater food web responses to nutrient enrichment from inorganic fertilizers and salmon carcasses (Stockner & Shortreed 1978; Ashley & Slaney 1997; Chaloner et al. 2004; Lang et al. 2006); however, very few have examined the efficacy and response of stream food web variables to a manufactured, pasteurized, salmon carcass analog treatment (Wipfli et al. 2004, Kohler et al. 2008). Salmon carcass analog(s) (SCA) developed by Pearsons et al. (2007) contain similar complements of nutrients and carbon-based compounds (rare earth elements) as naturally returning salmon; therefore, their effect on stream food webs is hypothesized to mimic natural enrichment pathways. Salmon carcass analogs are pasteurized to create a pathogen free product that slowly releases nutrients and particulates similar to naturally decomposing salmon and are easy to store, transport, and distribute. Benefits include direct consumption by juvenile salmonids (Pearsons 2007, personal communication; Kohler et al. 2009, in preparation). Other advantages include the ability to produce large amounts of SCA for dispersal into areas where hatchery carcass placement is unwarranted due to access (i.e. roadless areas), availability (lack of hatchery returns), or potential pathogen and contaminant issues (fish pathogens).

Kohler et al. (2008) compared four streams in the upper Salmon River subbasin: two control and two treatment streams using SCA as an experimental treatment. Response variables measured included: surface streamwater chemistry; nutrient limitation status; carbon and nitrogen stable isotopes; periphyton chlorophyll *a* and ash-free dry mass (AFDM); macroinvertebrate density and biomass; and leaf litter decomposition rates. The study demonstrated that a single experimental addition of SCA in two central Idaho streams significantly stimulated periphyton and macroinvertebrate food web variables, with no apparent response in dissolved nutrient concentrations, no changes in nutrient limitation status, and no obvious shifts in macroinvertebrate community composition in one kilometer treatment reaches. Periphyton chlorophyll *a* and AFDM and macroinvertebrate biomass were significantly higher in stream reaches treated with SCA. Enriched stable isotope ($\delta^{15}N$) signatures were observed in periphyton and macroinvertebrate samples collected from treatment reaches in both treatment streams, indicating trophic transfer from SCA to consumers. Densities of ephemerellidae, elmidae, and brachycentridae were significantly higher in treatment reaches. Macroinvertebrate community composition and structure, as measured by taxonomic richness and diversity, did not appear to respond significantly to salmon carcass analog treatment. Leaf breakdown rates were variable among treatment streams: significantly higher in one stream treatment reach but not the other.

In a separate analysis, Kohler and Taki (2009) analyzed macroinvertebrate assemblages in four central Idaho, U.S.A. streams using multivariate ordination to explore the relative influence of salmon carcass analogue (SCA) nutrient enrichment. Nonparametric spatial ordination of macroinvertebrate communities illustrated relationships to measured stream food web and environmental variables; joint plots correlating variables to ordination scores described this relationship. An evaluation of stream macroinvertebrate assemblages showed significant between stream differences ($P = <0.001$) and a clear reach level SCA treatment response ($P = <0.030$) within treatment streams; no reach level differences were found in control streams ($P = >0.458$) or in treatment streams before SCA applications ($P = >0.130$). Biological variables significantly and positively correlated to NMDS ordination scores and suggesting a SCA treatment response included: the presence of SCA, elevated periphyton and macroinvertebrate $\delta^{15}N$, increased periphyton ash free dry mass, and increased percent composition of dipterans, collectors, and Chironomidae. A weaker autotrophic response in one treatment stream relative to the other appears to be partially explained by differences in canopy shading and is supported by periphyton autotrophic index values; increased shading may have decreased periphyton accrual and increased the heterotrophic nature of the periphyton community. In a study of macroinvertebrate communities found on leaf packs Sylvestre and Bailey (2005) found distinct communities in ‘high’ and ‘low’ nutrient streams.

Knowing how macroinvertebrate community structure changes following SCA nutrient enrichment will help managers predict the effects on higher trophic levels, such as endangered anadromous fishes. Increased autotrophic production, and the absence of major shifts in the macroinvertebrate community composition and structure in treatment streams, appears to support previous studies that suggest SCA as a viable nutrient enrichment strategy. This study improves our understanding of how macroinvertebrate communities and associated stream food web and environmental variables respond to novel nutrient enrichment strategies like Salmon carcass analogues. This information should be valuable for understanding how macroinvertebrate communities respond to SCA nutrient enrichment and the relationships between macroinvertebrate assemblages and SCA treatment response variables at the reach level spatial scale. The study results can be used to infer how SCA treatments will affect stream dwelling salmonid food resources.

Preliminary meta-analysis results (in preparation for submittal to a peer-reviewed journal) that include data from upper Salmon River tributaries (Kohler et al. 2008), Yakima River tributaries (Pearsons et al. 2003), Klickitat River tributaries (Zendt & Sharp 2006), and Wind River tributaries (Mesa et al. 2007) suggest that SCA treatments significantly increased primary (periphyton) and secondary (macroinvertebrate) producer biomass and the stomach fullness and specific growth rates (length and weight) of stream resident salmonids. Trophic transfer, characterized by stable isotope signatures, was evident in periphyton and macroinvertebrate samples and less evident in fish samples. No significant changes in streamwater nutrient chemistry were detected (Kohler et al. 2009, in preparation).

Pearsons et al. (2007) suggest that SCA could be produced using unused fish parts recycled from commercial fisheries. Large scale production costs of SCA are not available at this time; however, the development and production details have been published and the benefits over alternative nutrient enhancement methods outlined. Readers are referred to Pearsons et al. (2007) for a detailed discussion of the development, production, and benefits of SCA.

Our results strongly indicate that supplemental nutrient additions are required to increase freshwater productivity in nutrient limited streams of the Columbia River basin and the upper Salmon River subbasin in particular (Kohler et al. 2008; Kohler et al. 2009, in preparation); however, although nutrient enhancement using SCA appears effective and ecologically innocuous at the scale of recent studies, analogs should not be viewed as a substitute for naturally spawning salmon. Moore, Schindler, & Scheuerell (2004) identified spawning salmon as important habitat modifiers in aquatic systems used by sockeye salmon. This bioturbation was shown to affect the structure and function of aquatic ecosystems and may play important roles not obvious to stream ecologists and natural resource managers. Managers adopting enrichment strategies that attempt to stimulate diminished stream productivity using SCA and/or inorganic nutrients “silver bullets” should understand the benefits and limitations of such an approach.

Until naturally spawning populations of salmon and steelhead are recovered, the use of an interim nutrient enhancement program to increase freshwater productivity in nutrient limited streams of the upper Salmon River subbasin appears warranted. Nutrient enrichment treatments at variable levels (high, medium, and low nutrient loading rates) and larger spatial (> 1km treatment stream reaches) and temporal (multiple years of treatment) scales should be evaluated using a rigorous experimental design; response variables should be collected using common data collection protocols and results should be peer-reviewed and available to researchers and managers throughout the Columbia River basin.

C. Rationale and significance to regional programs

In addition to the technical, scientific, and biological rationale provided in section B above, there are numerous relationships between the proposed project and: 1) the objectives in the Columbia River Basin Accords; 2) the goals and objectives of the Northwest Power and Conservation Council (NPCC) Columbia River Basin Fish and Wildlife Program; 3) and the objectives identified in the Salmon River Subbasin Plan. The proposed project will further goals identified in the Federal Columbia River Power System (FCRPS) Biological Opinion and in focal species Salmon Recovery Plans.

Columbia Basin Fish Accords

Columbia Basin
Fish
Accords
2008 - 2018

The Columbia Basin Fish Accords are designed to supplement National Oceanic and Atmospheric Administration (NOAA) Fisheries Biological Opinions and NPCC's Fish and Wildlife Program, providing firm commitments to hydro, habitat, and hatchery actions and greater clarity about biological benefits and secure funding for a ten year period. The agreements are designed to foster working partnerships ("on the ground") to provide tangible survival benefits for ESA listed salmon and steelhead populations in the Snake River Basin and associated fish and wildlife mitigation in blocked areas. Salmon River nutrient enhancement is specifically identified in the Shoshone-Bannock Tribes Columbia Basin Fish Accord as a mitigation measure to improve habitat conditions and the growth and survival of resident and ESA listed salmonids. Additional benefits include enhanced energy and nutrient connections between aquatic and terrestrial ecosystems.

Northwest Power and Conservation Council Columbia River Basin Fish and Wildlife Program

The Northwest Power and Conservation Council Columbia River Basin Fish and Wildlife Program (Fish and Wildlife Program) is intended to integrate Endangered Species Act (ESA) requirements, Northwest Power Act requirements, and the policies of the states and Indian Tribes of the Columbia River Basin into a comprehensive program grounded in a solid scientific foundation.

The NPCC recognizes that the Shoshone-Bannock Tribes have vital interests directly affected by activities covered in the Fish and Wildlife Program and that the United States has a trust obligation to preserve and protect the natural resources reserved by or protected in treaties, executive orders, and federal statutes. The NPCC also recognizes that significant interaction and cooperation with the Tribes as co-managers of affected fish and wildlife resources will be necessary to fully implement the Fish and Wildlife Program and its goals, objectives, and strategies.

The Fish and Wildlife Program identifies the Northwest Power Act directive to protect, mitigate, and enhance fish and wildlife (and associated habitat) of the Columbia River and its tributaries. In the executive summary the Program identifies dramatic declines (from an estimated 10-16 million annual adult return to a contemporary return of approximately 1 million) of salmon and steelhead populations in the Columbia River and its tributaries as a result of degraded habitat, intensive harvest, and variable ocean conditions. In addition, the Program estimates that the “proportion of the decline attributable to the construction and operation of hydroelectric dams in the Columbia River Basin is, on average, 5 million to about 11 million adult fish.” A specific objective outlined in the executive summary is to mitigate across basins for the adverse effects caused by the development and operation of the Columbia and Snake River hydrosystem. The above mentioned declines in anadromous returns and the Northwest Power Act directive to mitigate adverse effects of the hydrosystem provide significant rationale and support for the proposed project.

The Fish and Wildlife Program acknowledges that successful protection, mitigation, and recovery efforts will need to involve a myriad of strategies for habitat protection and improvement. Experimental nutrient enrichment in nutrient limited streams of the upper Salmon River subbasin may be an important component of this approach. The project’s design and approach will attempt to follow the Fish and Wildlife Program’s policy judgment that actions should be taken in an adaptive, experimental manner, including the use of experimental designs and techniques that integrate appropriate monitoring and evaluation to assess whether measurable, quantifiable biological objectives are being met.

Furthermore, the proposed project rationale, objectives, and goals support specific scientific principles as outlined in the Fish and Wildlife Program. Specifically, the project attempts to address the ecological integrity of critical habitat for a number of ESA listed focal species through experimental nutrient enrichment. Principle 1) states that the abundance, productivity, and diversity of organisms are integrally linked to the characteristics of their ecosystems; principle 4) states that habitats develop through and are maintained by physical and biological processes; principle 5) states that species play key roles in developing and maintaining ecological conditions; principle 7) states that ecological management is adaptive and experimental; and principle 8) states that ecosystem function, habitat structure, and biological performance are affected by human actions. This project attempts to increase the freshwater productivity (principle 1 and 4) of Salmon River subbasin streams that are nutrient limited (principle 5) due to diminished returns (principle 8) of anadromous salmon and steelhead. The project will employ an experimental design and approach that supports principle 7.

In **appendix D (provisional statement of biological objectives for environmental characteristics at the basin level)** of the Fish and Wildlife Program a stated objective is to: protect and enhance habitats and ecological function; protect and increase the ecological connectivity between aquatic areas and riparian zones, floodplains, and uplands; and increase energy and nutrient connections within the system to increase productivity and expand biological communities. The numerous ecological functions of spawning salmon should be an integral component of any recovery plan; however, until naturally spawning populations of anadromous salmonids are recovered, experimental nutrient enrichment may be warranted as an interim strategy to increase freshwater productivity in nutrient limited streams of the upper Salmon River subbasin.

Salmon River Subbasin Plan

Salmon subbasin assessment

The Salmon Subbasin Assessment identifies factors limiting fish, wildlife, and habitats. **Section 1.2.2 (1-4)** lists biological objectives including: a Columbia River ecosystem that sustains an abundant, productive, and diverse community of fish and wildlife; the mitigation across basins for the adverse effects to fish and wildlife caused by the development of the hydropower system; sufficient populations of fish and wildlife that afford abundant opportunities for tribal trust and treaty right harvest; and the recovery of ESA listed species. Considering the decline of wild salmon and steelhead populations throughout the Columbia River Basin, a lack of available C, N, and P may limit the recovery of ESA listed stocks in the Salmon River subbasin. As stated in the project abstract, our overarching objective is to assess the effectiveness of experimental nutrient enrichment strategies aimed at mitigating the adverse effects to fish and wildlife caused by the development of the hydropower system- i.e. reduced availability of marine-derived nutrients as a result of diminished anadromous fish returns. Measurable objectives will assess freshwater productivity and the growth and survival of resident and anadromous fishes, including ESA listed focal species, in streams receiving experimental nutrients and control streams that do not receive nutrient additions. Previous results from the project sponsors and cooperators demonstrate that nutrient enrichment is effective at increasing freshwater productivity and the growth rates of fishes in nutrient limited streams. Hypothetically, nutrient enrichment will help to restore abundant populations of fish and wildlife by improving the habitat and ecological conditions in natal spawning and rearing areas of the upper Salmon River subbasin.

In **section 1.3.1 (Importance to the Region)** the Salmon Subbasin Assessment declares that anadromous fish were historically significant sources of nutrients for other fish species and wildlife; and **section 1.7.4 (Disturbance)** recognizes that the decline of anadromous fish returns to the Salmon subbasin impacts both aquatic and terrestrial food webs associated with the loss of marine-derived nutrients and associated organic materials. Declining anadromous returns are stated to impair the ecological integrity and biodiversity of riparian-associated wildlife at the watershed scale. **Table 2-1** describes the focal aquatic species (4 ESA listed fish: 1) Spring/summer Chinook salmon; 2) Steelhead trout; 3) Snake River sockeye salmon; and 4) bull trout) key roles in maintaining ecological conditions in terms of contributions of carbon, nitrogen, and phosphorus from decaying adult carcasses (species 1-3) and nutrient cycling (species 4).

Section 2.1.1.1 (Key Ecological Functions and Environmental Correlates) identifies anadromous salmon as "keystone" species important to the ecological integrity of aquatic and terrestrial habitats and the organisms therein (Gross et al. 1998; Schmidt et al. 1998; Cederholm et al. 1999; Gresh et al. 2000). The presence of salmon carcasses was noted to increase aquatic macroinvertebrate biomass and taxonomic richness (Piorkowski 1995; Minakawa 1997) with subsequent indirect benefits to riparian obligate and insectivorous wildlife. And increased growth rates of juvenile resident and anadromous fishes are noted to benefit avian and mammalian predators. **Table 2-3** identifies 87 wildlife species associated with anadromous salmonids in the Salmon River subbasin. **Section 2.2.1.1.3 (Population Trends and Distribution)** outlines declining adult returns to the Salmon River as a result of the construction of dams on the mainstem Snake and Columbia rivers (Irving & Bjornn 1981). In summary, **section 2.1.1.1** clearly identifies that key roles played by anadromous salmon are functionally missing in the Salmon River subbasin with resulting impacts to the distribution and abundance of terrestrial and avian species (Ben-David et al. 1998).

Section 3.2.2.1 (Nutrient Cycling) supports the concept that anadromous returns represent an important nutrient source for a myriad of aquatic and terrestrial species and promote nutrient cycling, an important component to the maintenance of ecosystem health (Gresh et al. 2000). This section goes on to identify significant consequences to focal habitats and ecosystems in the Salmon River subbasin; the assessment cites data collected by the Shoshone-Bannock Tribes that identified nutrient limitation (nitrogen and phosphorus) in Salmon River subbasin stream experiments and acknowledges the work of Achord et al. (2003) that suggest a decrease in available marine-derived nutrients may be increasing density-dependent mortality. The "keystone" role of spawning anadromous fishes is again stressed as an ecologically significant link between aquatic and terrestrial ecosystems. The assessment points out that anadromous fish were once found in 60% of Idaho waters (IDFG 1992) and that wild anadromous fish abundance is approximately 1% of estimated predevelopment levels (NRC 1996). Moreover, 80% of the contemporary returns are of hatchery origin (ISG 1999) and primarily return to hatcheries, effectively limiting the distribution of carcasses and associated nutrients. **Section 3.2.2.1** concludes with a sober observation that a dramatic reduction of nutrients may be an indication of ecosystem failure contributing to a downward spiral of salmonid abundance and diversity with associated impacts to terrestrial focal species and habitats dependent on nutrient resources (Gresh et al. 2000).

The Salmon subbasin assessment's working hypotheses (**section 4.2.5**) includes:

H_A: Low numbers of naturally spawning salmon and steelhead limit nutrient cycling and productivity of aquatic and terrestrial habitats and species in the salmon subbasin.

The proposed project will directly address nutrient limitation, nutrient cycling, and freshwater productivity in treatment streams receiving nutrient additions and control streams that do not receive supplemental nutrients.

Salmon subbasin management plan

The Salmon Subbasin Management Plan (SSMP) outlines biological goals and sets forth strategies to restore and protect aquatic and terrestrial species and respective habitats. The plan includes research, monitoring, and evaluation components to determine the effectiveness of strategies outlined to address limiting factors, uncertainties, and data gaps.

Section 3.2.1 (Biological Components) addresses problem statements, objectives, and strategies impacting aquatic and terrestrial species. The proposed project addresses **problem 3 (data gaps preclude effective management of aquatic focal species in the Salmon River subbasin)**, **objectives 3A (address data gaps necessary to measure freshwater survival and productivity)** and **3B (compare freshwater conditions among populations to more accurately define habitat rehabilitation needs)** by measuring nutrient limitation and aquatic productivity variables in upper Salmon River subbasin tributaries.

Section 3.2.2 (Environmental Components) addresses problem statements, objectives, and strategies impacting fish and wildlife habitat. The proposed project addresses **problem 62 (the loss or dramatic reduction in anadromous fish runs throughout the subbasin has reduced nutrient inputs and reduced habitat suitability for salmon-dependent wildlife)** and **objective 62A (restore natural nutrient input cycles and mitigate for damages to aquatic and terrestrial populations due to the loss of these nutrients)** by experimentally evaluating nutrient enrichment strategies aimed at increasing freshwater productivity in Salmon River subbasin tributaries.

Section 3.2.2.1 (Subbasin-Level Problem Statement, Objectives, and Strategies) outlines objectives and strategies with the underlying goal of improving freshwater survival-productivity. In this section, the SSMP highlights a paucity of research addressing the effect of habitat rehabilitation and associated biological response. As detailed in our experimental design, we will measure a wide range of stream food web response variables (see Table 2 in §G. Monitoring and Evaluation), helping to address uncertainties and data gaps in the Salmon River subbasin. The proposed design includes direct measurement of nutrient limitation (nutrient diffusing substrata) and nutrient cycling and retention (uptake lengths) in study streams. The collection of these data will directly address SSMP **strategy 62A1 (assess nutrient inputs and cycling in the Salmon River subbasin)**. Furthermore, the proposed design includes fish population measurements that will help to address SSMP **strategy 62A7 (monitor focal fish and wildlife to assess population response to changes in nutrients)**. Data collection and analyses under the proposed project will help to quantify "the impact of reduced nutrient inputs into the subbasin" and allow for "a more in-depth understanding of ecosystem processes and more effective management of subbasin resources".

Section 4.2 (Research Needs) addresses aquatic research needs developed from the objectives and strategies section of the SSMP. The proposed project addresses **strategy 7A1 (determine the effects of reductions in marine-derived nutrients on aquatic and terrestrial food webs)** and the associated null hypothesis (H_o: Aquatic and terrestrial trophic levels are not influenced by reductions in salmon carcasses) by incorporating concepts identified in **strategy 62A4 (research innovative methods to restore nutrients)**. Experimental nutrient enrichment of study streams in the upper Salmon River subbasin will build on existing knowledge (Kohler et al. 2008). And expanding the spatial and temporal scale of experimental nutrient enrichment will address key uncertainties and data gaps associated with nutrient limitation, nutrient cycling, and freshwater productivity.

Clearly, reduced inputs of marine-derived nutrients are considered limiting factors to the maintenance of ecologically functioning habitats and the recovery of aquatic and terrestrial populations those habitats support. The proposed project will assess the effectiveness of experimentally enriching Salmon River subbasin streams with carbon, nitrogen, and phosphorus and is a logical component to the overall conceptual framework of the Columbia River Accords, the NPCC Columbia River Basin Fish and Wildlife Plan, the Salmon River subbasin Plan, and ESA recovery planning. The proposed project will likely provide mitigation benefits to focal fish, wildlife, and habitat in the upper Salmon River subbasin.

D. Relationship to other projects

The proposed project is directly related to, and builds upon, a number of completed and one on-going BPA funded project(s). In addition, the study will compliment and benefit from two other non-BPA funded projects:

2001-055-00 Nutrient Enhancement Studies (completed)

- The Shoshone Bannock Tribes (contract #7848)
- Bio-Oregon (contract #7695)
- Yakama Indian Nation (contract #7534)
- Washington Department of Fish and Wildlife (contract #5636)
- NOAA Fisheries (contract #7621)

and

2007-332-00 Mitigation of Marine-Derived N (on-going)

- Washington State University
- Idaho Department of Fish and Game (IDFG)
- Idaho State University

Project 2001-055-00 encompassed a collaborative effort to evaluate stream nutrient enhancement using salmon carcass analogs developed by Bio-Oregon and the Washington Department of Fish and Wildlife. The project was funded during the innovative solicitation process conducted by the NPCC.

The Shoshone Bannock Tribes and NOAA Fisheries collected data in the Salmon River subbasin; the Yakama Indian Nation collected data in the Klickitat River subbasin; and the Washington Department of Fish and Wildlife collected data in the Yakima River subbasin. Data sharing and collaboration was further coordinated with researchers at the United States Geological Survey where data was collected in the Wind River subbasin.

Experimental nutrient enrichment using salmon carcass analogs was conducted at the 1 kilometer reach scale in the above mentioned subbasins. As mentioned in section B, a great deal of data and knowledge was gained and disseminated by these initial experiments.

Project 2007-332-00 intends to mitigate marine-derived nutrient loss resulting from extirpated anadromous fish returns in the Boise/Payette/Weiser subbasin. Pasteurized salmon and salmon carcass analog treatments will occur in 0.5 kilometer stream reaches over 3 years. Subsequent to nutrient treatments a suite of aquatic, vegetative, and terrestrial food web response variables will be collected and analyzed.

The proposed project seeks to utilize the knowledge base from **project 2001-055-00**, as well as information from on-going **project 2007-332-00**, as a strong foundation and reference.

Shoshone Bannock Tribes Steelhead Egg Box Program

The Shoshone Bannock Tribes utilize funding under the Lower Snake River Compensation Plan (USFWS) to supplement upper Salmon River subbasin streams with steelhead eyed egg boxes. Steelhead trout fry and parr productivity is monitored annually. The proposed project seeks to include study streams where steelhead egg box production presently occurs (Basin Creek) or is planned to occur (Panther Creek tributaries). The presence of supplementation steelhead trout in nutrient enrichment treatment streams will enable the evaluation of supplemented fish response to nutrient enrichment. Data collected under the proposed project and the SBT egg box program will be mutually beneficial.

Lemhi River Intensively Monitored Watershed (IMW)

The proposed project seeks to include study streams within the Lemhi River subbasin (Hayden Creek and Big Timber Creek). Because these streams are within the Lemhi River IMW, the proposed study may benefit from a wealth of available baseline data.

Data collection and analyses from the above mentioned bodies of work will serve to guide the proposed project in terms of experimental design, sampling protocols, power analyses, and supporting evidence. By expanding the spatial and temporal scale of previous nutrient enrichment treatments, including additional measured response variables, and using variable treatment levels, we will address significant uncertainties and data gaps important to managers. We will also continue to communicate and collaborate with multiple agencies and entities including, but not limited to: the United States Forest Service (USFS), NOAA Fisheries, IDFG, Idaho State University (ISU), University of Idaho (UI), and the Idaho Department of Environmental Quality (IDEQ). Reporting of findings in peer-reviewed scientific journals will assist other scientists and managers in decisions regarding future habitat enhancement activities.

E. Project history (for ongoing projects)

N/A- this is a new project.

F. Proposal biological/physical objectives, work elements, methods, and metrics

Overarching Objective: Increase the freshwater productivity of upper Salmon River subbasin streams using nutrient enrichment methods.

H_o: Adding C, N, and P to nutrient limited streams in the upper Salmon River subbasin does not increase freshwater productivity.

H_a: Adding C, N, and P to nutrient limited streams in the upper Salmon River subbasin increases freshwater productivity.

Objective 1: Identify nutrient limited streams within the upper Salmon River subbasin

Freshwater productivity is often limited by the availability of carbon, nitrogen, and phosphorus. In the Pacific Northwest, many rivers and streams are considered to be oligotrophic, a condition characterized by extremely low concentrations of dissolved nutrients. Nutrient limitation may inhibit primary productivity and affect higher trophic levels.

Task 1.1 Conduct nutrient diffusing substrata experiments to determine the nutrient limiting status of upper Salmon River subbasin streams

We propose to measure whether the growth of stream biofilms are nutrient limited using nutrient diffusing substrata (NDS) in candidate streams in the upper Salmon River subbasin. Macro-nutrient limitation will be evaluated using NDS amended with N, P, a combination of N and P, and an un-amended control (Tank et al. (2006) (Nitrogen Limitation and Uptake chapter) in Hauer and Lamberti (2006) (Methods in Stream Ecology)). Nutrient diffusing substrata will be constructed using frames holding 30 ml polycon cups covered with fritted glass discs. Cups will be filled with 2% agar amended with: a 0.5M solution of $NaNO_3$ (N treatment); a 0.5M solution of KH_2PO_4 (P treatment); a combination of N and P; and a non-amended agar (control). Seven replicates of each treatment (control, N, P, and N+P in an upstream to downstream order) will be secured to frames and incubated in riffle habitat units for 21 (±2) days. Samples will be analyzed for chlorophyll *a* and AFDM using analysis of variance models (ANOVA). Results from NDS experiments will help to characterize and assess nutrient limitation in potential study streams in the upper Salmon River subbasin.

Task 1.2 Select potential study streams in the upper Salmon River subbasin based on nutrient limitation results.

We will select potential study streams based on nutrient limitation assessments from NDS experiments and streamwater chemistry (Redfield ratio) results. Nutrient limited streams will be considered for SCA nutrient enrichment treatments.

Objective 2: Increase freshwater productivity by adding supplemental nutrients (SCA) to selected streams in the upper Salmon River subbasin.

From our previous and on-going work in the upper Salmon River subbasin we have identified a number of appropriate study streams including, but not limited to: Smiley Creek, Cape Horn Creek, Elk Creek (trib. of Valley Creek), Basin Creek, West Fork Yankee Fork Salmon River, Yankee Fork Salmon River, Slate Creek, Thompson Creek, Squaw Creek (near Thompson Creek), Morgan Creek, Hayden Creek, Big Timber Creek, Carmen Creek, Indian Creek, Squaw Creek (near Indian Creek), and Panther Creek (tribs. only). From these prospective streams we will select 9 study streams: 3 control and 6 treatment streams. Treatment streams will be randomly selected and applied to 3 km stream reaches. The West Fork Yankee Fork Salmon River and the Yankee Fork Salmon River will not receive SCA treatments; instead, these streams will be evaluated for adult Chinook salmon outplants as described in objective 4 (page 23).

In Kohler et al. (2008) we stocked SCA at densities of 30g analog material m^{-2} of bankfull channel width. Stocking densities were based on target carcass levels developed from Wipfli et al. (2003). Current recommendations indicate that a maximum stocking density of 0.50 kg m^{-2} of salmon carcass analog material should not be exceeded. As suggested by Mesa et al. (2007), we propose to test 3 treatment levels: a (low) stocking density of 0.03 kg m^{-2}; a (medium) stocking density of 0.15 kg m^{-2}; and a (high) stocking density of 0.27 kg m^{-2}. The low stocking density will allow comparisons to earlier treatment levels from studies conducted in the upper Salmon, Yakima, and Klickitat rivers; the medium stocking density will allow comparisons to levels described in Bilby et al. (2001) and the high stocking density will allow comparisons to work conducted by Wipfli et al. (2003) and Mesa et al. (2007).

Task 2.1 Apply salmon carcass analogs to treatment streams in the upper Salmon River subbasin.

Salmon carcass analog(s) (SCA) developed by Pearsons et al. (2007) contain similar complements of nutrients and carbon-based compounds (rare earth elements) as naturally returning salmon; therefore, their effect on stream food webs is hypothesized to mimic natural enrichment pathways. Salmon carcass analogs are pasteurized to create a pathogen free product that slowly releases nutrients and particulates similar to naturally decomposing salmon and are easy to store, transport, and distribute. Benefits include direct consumption by juvenile salmonids (Kohler et al. 2009, in preparation). Other advantages include the ability to produce large amounts of SCA for dispersal into areas where hatchery carcass placement or inorganic nutrient application is unwarranted due to access (i.e. roadless areas), availability (lack of hatchery returns), or potential pathogen and contaminant issues (fish pathogens and heavy metals). Pearsons et al. (2007) suggest that SCA could be produced using unused fish parts recycled from commercial fisheries. Large-scale production costs of SCA are not available at this time; however, the development and production details have been published and the benefits over alternative nutrient enhancement methods outlined. Readers are referred to Pearsons et al. (2007) for a detailed discussion of the development, production, and benefits of SCA.

Prior to application of SCA to treatment streams, we propose to send a subsample of SCA to an independent laboratory for analysis of contaminant levels.

We propose to apply SCA to randomly selected treatment streams in August-September following the proposed Table 1. schedule adopted from Mesa et al. (2007).

Table 1. Variable treatment schedule for upper Salmon River study streams, 2010-2012.

Stream	**2010**	**2011**	**2012**
Treatment stream 1	High	Low	Medium
Treatment stream 2	High	Low	Medium
Treatment stream 3	Low	Medium	High
Treatment stream 4	Low	Medium	High
Treatment stream 5	Medium	High	Low
Treatment stream 6	Medium	High	Low

In 2013 we will cease treatments and collect 1 year of post treatment data. Analyses and interpretation of results from these treatments will help to direct future treatments and management options (2014-2018). Alternatives for the 2014-2018 periods include the continuation of the current study design utilizing different aquatic food web response variables, investigation of alternative nutrient enrichment strategies, or whole stream nutrient enrichment SCA applications.

Objective 3: Document chemical, physical, and biological conditions in study streams.

Task 3.1 Collect, analyze, and report dissolved nutrient concentration variables including: nitrate (NO_3); nitrite (NO_2); ammonium (NH_4^+); soluble reactive phosphorus (SRP; PO_4); total nitrogen (TN); and total phosphorus (TP).

Dissolved nutrients and organic matter are intrinsically linked with biological processes in freshwater ecosystems (Allan 1995). Water chemistry and associated variables will be monitored in all study streams. Water will be sampled from the thalweg and inorganic nutrient subsamples filtered in the field as necessary. All samples will be kept in coolers (on ice) and sent to an analytical laboratory certified in conducting low-level water chemistry analyses within 48 hours. Samples that cannot be shipped within 48 hours will be frozen and sent at the earliest possible date. Samples will be collected and analyzed using standard methods (APHA 2005).

Task 3.2 Collect, analyze, and report nutrient cycling variables.

Nutrient cycling is an important ecosystem process in stream environments. We propose to investigate nutrient spiraling characteristics by measuring nutrient uptake lengths and transient storage using nutrient (nonconservative) and/or solute (conservative) release experiments in study streams. One method described by Webster and Valett (2006) (Solute Dynamics chapter in Hauer and Lamberti (2006) Methods in Stream Ecology) involves the release of a conservative solute and subsequent downstream measurements over time. Chloride can be used as a conservative solute and specific conductance as a conservative measure. Discharge measurements are used to derive the necessary solute release rate to measurably raise the stream chloride concentration above background levels (~10*u*s). At the bottom of a 100 meter reach (starting at the solute release site), conductivity measurements are taken every 1-5 minutes from release until the pulse arrives, and subsequently every 15-30 seconds as chloride concentrations increase rapidly. During the plateau, additional measurements will be taken at 10 meter intervals from the downstream end of the reach to the release site. At this point the solute release is shut off and measurements are continued at the downstream site until conductivity returns to near background levels. A graph of the conservative solute concentrations versus time (at the downstream end of the reach) is used to evaluate transient storage in experimental reaches. An alternative method described by Tank et al. (2006) (Nitrogen Limitation and Uptake chapter in Hauer and Lamberti (2006) Methods in Stream Ecology) uses a short-term nitrogen addition (with a conservative tracer) to measure N uptake length. A computer model called OTIS (One-dimensional Transport with Inflow and Storage) can be used to calculate transient storage parameters (Runkel 1998). Results from nonconservative nutrient and conservative solute releases will provide a useful method for comparing nutrient uptake and transient storage across study streams and/or under variable experimental conditions.

Task 3.3 Collect, analyze, and report physical habitat and associated variables including: stream channel slope; discharge; velocity; dominant substrate composition and embeddedness; riparian vegetation cover; course particulate organic matter (CPOM) transport and retention; temperature; dissolved oxygen; pH; and conductivity.

Physical habitat measures help to characterize and assess stream ecosystem habitats. All physical habitat and associated variables will be collected using common aquatic habitat methods described in Bain and Stevenson (1999), except CPOM transport and retention described in Lamberti and Gregory (2006) (CPOM Transport, Retention, and Measurement chapter in Hauer and Lamberti (2006) Methods in Stream Ecology). Stream channel slope will be measured using survey equipment; percent slope will be calculated using the equation rise/run x 100. Discharge and velocity will be measured using a calibrated flowmeter and cross sectional channel measurements; a rating curve will be established using discharge and stage measurements. Dominant substrate will be characterized using the modified Wentworth classification of substrate types by size and Wolman pebble counts. A course visual assessment using embeddedness ratings from stream channel materials (Platts et al. 1983) will be conducted to characterize embeddedness. Riparian vegetative cover (% shading) will be measured using a spherical densitometer. Course particulate organic matter transport and retention will be measured using a CPOM proxy release of 1000 pieces of colored paper; retention of release materials will be measured within a 500 m stream reach and retention structures (rock, wood, bank,etc.) will be recorded. Temperature will be recorded using long-term temperature loggers and DO, pH, and conductivity will be measured using calibrated sondes.

Task 3.4 Collect, analyze, and report biological variables including: periphyton chlorophyll *a* and ash-free dry mass (AFDM); macroinvertebrate benthic and drift density and biomass; macroinvertebrate benthic and drift community composition and structure; salmonid population abundance, growth rates, bioenergetics modeling, and survival; salmonid, periphyton, and macroinvertebrate nitrogen and carbon stable isotopes; and leaf litter decomposition rates.

Periphyton Chlorophyll a, AFDM, and C and N stable isotope analysis

Stream autotrophic production is dominated by photosynthetic algae, representing an important trophic level in freshwater food webs. We propose to measure periphyton standing stock (chlorophyll *a* (mg m^{-2}) and AFDM (g m^{-2})) and C and N stable isotopes from unglazed ceramic tiles (incubated in-stream for 30 ± 2 days) or natural substrata in all study streams. Known areas will be sampled using a tubular sampler with a basal neoprene seal. Sample area periphyton will be removed with a hard bristle brush. The brush will be rinsed and the resulting sample slurry will be filtered onto glass fiber filters

(0.45 *u*m). Filters will be placed in dark coolers on ice and frozen as soon as possible. Samples will be analyzed for chlorophyll *a* and AFDM using standard laboratory methods (APHA 1995) and for C and N stable isotopes as mentioned above. The trophic nature of stream periphyton communities will be evaluated using the autotrophic index calculated using the following equation: AI = (AFDM (mg m^{-2}) / Chlorophyll *a* (mg m^{-2})) (Steinman & Lamberti 1996). Stable isotope samples (periphyton, macroinvertebrate, and fish) will be analyzed at the Idaho State University or the University of Idaho Stable Isotope Facility using an elemental analyzer and a mass spectrometer. Sample values will be calculated using the following formula:

$$\delta\, {}^{15}N/{}^{13}C = [(R_{sample} - R_{standard}) / R_{standard}] \times 1000$$

where R_{sample} = the stable isotope ratio in the sample and $R_{standard}$ = the stable isotope ratio in the standard. Isotope analyses will be conducted following protocols described in Kline et al. (1990) and Bilby et al. (1996). Samples will be dried, ground, and prepared in the laboratory. Stable isotope analyses will help to verify transfer of marine-derived nutrients to autotrophic algae.

Macroinvertebrate (benthic and drift) density, biomass, community composition and structure, and C and N stable isotope analysis

Aquatic macroinvertebrates represent a fundamental link in the food web between organic matter resources and fishes (Hauer and Resh (2006) Macroinvertebrates chapter in Hauer and Lamberti (2006) Methods in Stream Ecology). Benthic macroinvertebrates will be sampled from riffle habitat units using a modified Hess or surber sampler (363 *u*m net). Substrate within the sampler will be disturbed for three minutes to a depth of approximately 10 cm to standardize sampling effort. Drifting macroinvertebrates will be sampled during diurnal periods using drift nets (363 um net) placed across the stream channel (n = 3 per transect). Drift nets will be placed 2-3 cm above the stream bottom and as recommended by Smock (Macroinvertebrate Dispersal chapter in Hauer and Lamberti (2006) Methods in Stream Ecology). Drift density will be expressed as the number of invertebrates drifting per 100 m^3 of water using the following formula:

Drift density = [(N)(100)]/[(t)(W)(H)(V)(3600 s/h)]

where N represents the number of invertebrates in a sample; t represents the time the net was in the stream; W represents the net width (m); H represents the mean height of the water column in the net mouth (m); and V represents the mean water velocity at the net mouth (m/s).

Benthic and drift macroinvertebrates will be rinsed and stored in 70% ethanol. Preserved samples will be sorted, identified to the lowest feasible taxonomic level (usually genus), dried at 50°C for 48 hours, and weighed to estimate whole sample biomass. Macroinvertebrate samples collected for SIA will be held in freshwater for 24 hrs to allow for gut evacuation, frozen, and subsequently analyzed for C and N stable isotopes.

Stable isotope analyses will help to verify direct and trophic transfer from salmon carcass analogs and autotrophic algae to macroinvertebrate consumers.

Salmonid population, growth rate, bioenergetics modeling, and survival estimates

Population abundance and growth rate estimates

A primary response variable for evaluating the efficacy of nutrient enrichment strategies will be the growth of resident and anadromous juvenile salmonids and any potential changes in population abundance following SCA treatments. We will conduct multiple removal/depletion studies to estimate population abundance and single pass electrofishing efforts to capture and mark (PIT tag) as many individual fish as possible for growth rate estimates. Juvenile Chinook salmon, steelhead trout, and resident cutthroat and rainbow trout will be PIT tagged (>60mm if using 12mm tags and >45mm if using 8mm tags) to evaluate growth and survival. Electrofishing methods will follow detailed guidelines presented in the Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations (Johnson et al. 2007). Prior to electrofishing, a snorkeler will survey the study reach to establish the presence/absence of adult Chinook salmon. If adult Chinook salmon are observed within the study reach, electrofishing efforts will avoid the area of occupation. Subsequent sampling efforts will allow the recapture of marked fish to generate specific growth rates.

Specific growth rates are used to express growth relative to an interval of time and are commonly expressed as a percentage. We will calculate instantaneous growth rates using the following formula from Lang et al. (2006):

Growth rate (Gr) = {[(Wt+1 – Wt)Wt-1]D-1} x 100

where Gr is the relative growth rate expressed as the percent weight gained per day over the time period from capture at time (t) to recapture at time (t+1): Wt is the weight of an individual at time (t); Wt+1 is the weight of an individual at time (t+1); and D is the number of days occurring between time (t) and time (t+1).

Fish production estimates

Because fish population abundance and biomass measures are static measures of a population's status, we propose to integrate static and dynamic population measures over time to estimate annual fish production rates. Production is an important indicator of ecological success and is responsive to environmental change (Mann and Penczak 1986). Production measures synthesize biomass, recruitment, growth, and mortality to estimate the rate of tissue elaboration over time (Waters 1977) and are expressed in units of quantity/space/time (Hayes et al. (2007) Abundance, Biomass, and Production chapter in Guy and Brown (2007) Analysis and interpretation of Freshwater Fisheries Data). We propose to estimate annual fish production using available computer software (Pop/Pro (Kwak 1992)).

Bioenergetics modeling

Past nutrient supplementation studies have often found dramatic increases in primary and secondary production with increased levels of limiting nutrients (Grant et al. 1998). A fundamental inference of such results is that 'bottom-up' increases in primary and secondary production will increase fish production. In addition to assessing differences in growth and abundance of salmonids, our study will provide a bioenergetics assessment of changes in habitat quality before and after nutrient supplementation and between control and treatment streams. Such an evaluation is important because stream-dwelling salmonids are visual predators that encounter and capture drifting invertebrates as prey sources for energy acquisition.

Salmonid fish acquire energy by successfully capturing invertebrates drifting in the water column and they expend energy to maintain a position in the stream and to meet metabolic demands. Based on these assumptions, only habitats that yield some minimum net energy gain may be suitable for fish growth (Nislow et al. 1999; Guensch et al. 2001). Bioenergetic models estimate net energy intake rates (NEI) and offer an approach to estimate the profitability of stream habitat by calculating the energetic costs and benefits of foraging locations. Unlike habitat assessment procedures based on static physical habitat variables, bioenergetic models can be used to estimate the energetic profitability of fish habitat as flow conditions vary across seasons (Rosenfeld 2003).

Understanding factors that influence habitat quality are particularly important because habitat alteration and fragmentation represent some of the most significant threats to fish populations (Malmqvist and Rundle 2002). Bioenergetic models offer a means of assessing how broad scale changes in habitat quality may drastically alter the range of suitable habitat for fishes. For example, nutrient supplementation studies attempt to improve fish habitat by increasing the availability of limiting nutrients in oligotrophic streams. Increases in primary production then increase biomass production at higher trophic levels that are limited food sources for salmonids (Grant et al. 1998). While nutrient supplementation are predicted to have significant influences on salmonid abundance (Ficke et al. 2007), their impact on a given population may be smaller or larger, depending on how close the available habitat is to optimum (Ries and Perry 1995). Bioenergetic models offer the opportunity to assess potentially complex interactions by comparing current conditions with different scenarios under changing levels of productivity.

Net Energy Intake model

We plan to estimate energy availability to juvenile salmonid fishes in stream reaches receiving SCA treatments and upstream control reaches that do not receive SCA applications by combining aspects of salmonid foraging ecology with energetic requirements of fish at specific temperatures. Salmonid fish in streams often occupy positions near the substrate, where they maintain holding positions and defend feeding territories. From these positions, fish face into the current and feed on drifting invertebrates that are suspended in the water column and enter their field of view. In the most basic terms, the rate of net energy intake (NEI) is equal to the energy gain minus the energy costs associated with maintaining a position in the stream and metabolic activity. Energy gain, or gross energy intake (GEI), is the total energy from invertebrates that fish are able to intercept. GEI is calculated by estimating the size of the capture window for a given size of fish, also known as the Maximum Capture Area (MCA), multiplied by the rate of drift passing through this window. If food abundance (number $\cdot$ m^{-3}) is constant across a habitat, then GEI increases with current velocity, until current speeds are reached that make it impossible for fish to detect and intercept prey before they are swept downstream. From GEI, costs are then subtracted and include: energetic losses from swimming, costs of intercepting prey in the stream current, costs of digesting prey, basic metabolic costs, and energy lost through waste excretion. The cost of swimming against the current and the cost of capturing prey increase with increasing current velocities. Generally, low NEI values are the result of limited food availability, very high current velocities, or low water temperatures that decrease the metabolic scope of the fish.

Bioenergetics models stem from general optimal foraging theory (e.g. Werner and Hall 1974), such that individuals seek to maximize the energy they obtain from the environment in an attempt to increase their fitness through improved growth, survival, and reproductive rates. For stream-dwelling salmonid fishes, the widespread application of this theory is largely attributable to Fausch (1984) and Hughes and Dill (1990). Hughes and Dill (1990) used published functional relationships describing fish responses to temperature and physical habitat features to derive a position choice model that has become the foundation for bioenergetics modeling of salmonid fishes.

Many variations of the Hughes and Dill (1990) model have been developed. In the proposed study, we will construct a model to include estimates of fish energy requirements (Elliott 1975, 1976), minimum prey size that fish ingest (Keeley and Grant 1997), and estimates of the distance that fish can detect prey (Hayes et al. 2000) from other published studies. To account for potential satiation of fish, we will use the maximum food ration (Elliott 1976) and resulting energy (C_{max}) that fish could ingest in a day as the upper limit for gross energy intake (GEI). Estimates of NEI will be computed as follows:

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If GEI **Error! Objects cannot be created from editing field codes.** C_{max}, then: NEI = $C_{max} \cdot E_i - SC$

which includes for each prey size class i: the maximum capture area (MCA_i), average velocity at a fish focal point (V_{ave}), the drift density (DD_i), the energy acquired from a food item (E_i), the cost of capturing the prey item (CC_i), the swimming costs associated with a holding position (SC) and the time spent handling a prey item (t_{fi}). In our study we will use 20 size classes of prey, ranging in length from 0.5 to 10 mm in length.

The maximum capture area (MCA_i) refers to the area of the half circle positioned perpendicular to the stream flow within which a fish can intercept prey items that are detected upstream. The MCA_i is calculated using the maximum capture distance (MCD_i) as the radius of the half circle. The MCD_i is computed using the specific reaction distance for prey size class i (RD_i), the current velocity experienced by the fish, and the maximum swimming speed of the fish used to capture the prey item (V_{max}). The reaction distance (RD_i) refers to the distance that a fish can visually detect a prey item in the drift and is positively related to the size of the prey and fish size. The maximum velocity that a fish can maintain for 60 minutes (V_{max}) is dependent on fish size and water temperature. Estimates of MCD increase with increasing fish and prey sizes and are negatively related to current velocity. In the event that the stream depth is less than the potential MCD_i for a given prey size class, the MCA_i will be truncated to reflect the stream depth.

Based on monthly estimates of invertebrate drift abundance in study streams, we will estimate the amount of food available to fish in the stream using site and month-specific densities (DD_i; number $\cdot$ m^{-3}) for each size class of prey. We will estimate the energy provided by prey items (PE_i) of each size class i (from Smock 1980) and subtract the cost of digesting prey (14%, Brett and Groves 1979) and the estimated energy lost through waste excretion (28%, Elliott 1976).

Survival

Juvenile salmonids captured during electrofishing efforts will be held in buckets and transferred to in-stream live wells. Salmonids will then be anesthetized for measuring and weighing using a stock solution of 15 grams of MS222 and 30 grams of sodium bicarbonate per liter of water. Dissolved oxygen, temperature, and pH levels will be monitored, and adjusted accordingly, throughout the sampling effort. All anesthetized fish will be weighed to the nearest 0.1 grams and fork length will be measured to the nearest millimeter. A subsample of fishes will be selected to determine diet composition using the gastric lavage method (citation needed). Individual fish (>60mm if using 12mm tags and >45mm if using 8mm tags) will be implanted with Passive Integrated Transponder (PIT) tags following guidelines outlined in the PIT Tag Marking Procedures Manual (Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee version 2.0 1999). Passive integrated transponder data will be entered in the PITAGIS database maintained by the Pacific States Marine Fisheries Commission. For PIT tagged salmonids that adopt an anadromous life history, we will estimate survival probabilities to Lower Granite Dam using a 'SURvival under Proportional Hazards' model (SURPH) developed by the University of Washington, School of Aquatic and Fisheries Sciences (Lady et al. 2001). SURPH is an analytical tool used to estimate survival probabilities. Release and recapture data are used as a function of environmental effects. We will use the Cormack-Jolly-Seber (CJS) method to estimate survival probabilities and associated standard errors (Cormack, R.M. 1964; Jolly, G.M. 1965; and Seber, G.A.F. 1965).

Salmonid C and N Stable Isotope Analysis

Analysis of C and N stable isotope values provides an opportunity to evaluate trophic transfer of marine-derived nutrients through freshwater food webs. A sub sample of individual fish will be used for N and C Stable Isotope Analysis (SIA). Sanderson et al. 2008 demonstrated that non-lethal sampling of fish caudal fins yields valuable stable isotope data for threatened and endangered fishes; the relationship between fin and muscle tissue was consistent across years and streams. We propose to use non-lethal tissue sampling and to verify the SIA relationship between fin and muscle tissue with non-listed resident fishes. Stable isotope analyses will help to verify direct and trophic transfer from salmon carcass analogs and macroinvertebrates to salmonid consumers.

Leaf litter decomposition

In many stream ecosystems a significant energy pathway is represented by allochthonous organic materials entering the stream channel in the form of autumnal leaves. Studies have found increased decomposition rates with the addition of in-stream nutrients (Robinson & Gessner 2000; Grattan & Suberkropp 2001), but relatively few have addressed how marine-derived nutrients affect in-stream leaf decay rates (Kohler et al. 2008; Ito 2003). Leaf litter decomposition rates (k) will be estimated in study streams using riparian vegetation collected on-site. Collection, deployment, processing, and analytic techniques will follow methods described in Benfield (2006) (Decomposition of Leaf Material chapter) in Hauer and Lamberti (2006) (Methods in Stream Ecology). Leaf decomposition k values will be computed using an exponential decay model that assumes the rate of loss from leaf packs as a constant proportion over time.

Objective 4: Evaluate the stream food web response to ongoing volitional releases of spring Chinook salmon in the upper Yankee Fork Salmon River

Task 4.1 Collect, analyze, and report chemical, physical, and biological variables before and after volitional spawning of spring Chinook salmon in the upper Yankee Fork Salmon River

Although nutrient enhancement using SCA appears effective and ecologically innocuous at the scale of recent studies, analogues should not be viewed as a substitute for naturally spawning salmon. Moore et al. (2004) identified spawning salmon as important habitat modifiers in aquatic systems used by sockeye salmon. This bioturbation was shown to affect the structure and function of aquatic ecosystems and may play important roles not obvious to stream ecologists and natural resource managers. Managers adopting enrichment strategies that attempt to stimulate diminished stream productivity using SCA should understand the benefits and limitations of such an approach. In 2009, 2010, and 2011 the Shoshone Bannock Tribes expect to outplant ~1,200 spring Chinook salmon adults from the Sawtooth Hatchery for volitional spawning above a temporary weir near Five Mile Creek. We propose to evaluate the stream food web response to volitionally spawning spring Chinook salmon in the upper Yankee Fork Salmon River; the West Fork Yankee Fork Salmon River will serve as a control. This unique opportunity will allow comparison of SCA treatment streams, streams with naturally spawning salmon, and control streams in the upper Salmon River subbasin.

Objective 5: Disseminate Salmon River subbasin nutrient enrichment results

Task 5.1 Prepare reports and submit manuscripts to peer-reviewed scientific journals summarizing results from stated objectives.

We will prepare quarterly and annual reports for submission to the Bonneville Power Administration and manuscripts for submission to peer-reviewed scientific journals. The dissemination of project results will help researchers and managers make informed decisions about the future use of nutrient enrichment strategies.

Factors that may limit the success of the proposed project

If uncontrolled variation in measured response variables is so great that the design is not adequate to answer study questions, project objectives will be difficult to assess; however, the proposed project builds upon previously published and on-going nutrient enrichment work, includes a detailed study design using common data collection protocols, and incorporates a robust statistical framework designed to measure stream food web response to nutrient enrichment. Moreover, the project will utilize previously collected data and contemporary baseline data collections to complete a sample size/power analysis prior to experimental treatments.

Another factor potentially limiting the study design is the production cost of SCA. Large-scale production costs of SCA are not available at this time. If SCA costs exceed the proposed project's budget, then smaller treatment reaches (2 km) or fewer treatment streams (n=4) will be employed.

Novel methods offered by the proposed project

Previous nutrient enrichment studies using SCA in the Columbia River basin have applied experimental treatments at the 0.5-1km treatment reach level scale. Our study proposes to apply SCA treatments to 3 kilometer treatment reaches, a scale that more closely resembles natural spawning distributions within the upper Salmon River subbasin. Our study also includes variable treatment levels (low, medium, and high) and a three year treatment period followed by an adaptive management phase. This is a novel approach addressing larger spatial and temporal scales that more closely mimic natural variation. In addition, our study will be the first nutrient enrichment study to provide a bioenergetics modeling assessment of changes in habitat quality based on potential changes in food availability. The fish (abundance, growth, production, and survival), stable isotope analyses, and bioenergetics modeling will combine to specifically evaluate the effects of SCA nutrient enrichment on stream dwelling salmonids with a resolution novel to previously conducted studies. Another important component of the proposed study will be the evaluation of nutrient enrichment in the form of volitionally spawning spring Chinook salmon in the upper Yankee Fork Salmon River. As mentioned above, ~1,200 adult spring Chinook salmon from the Sawtooth Fish Hatchery will be outplanted each year for at least 3 or 4 years. This provides a unique opportunity to evaluate the stream food web response to a naturally spawning population within the upper Salmon River subbasin.

G. Monitoring and Evaluation

Table 2. Annual chemical, physical, and biological variables to be measured during the proposed study including sampling periods and locations for upper Salmon River study streams.

Variable	**Pre-treatment**	**Post-treatment**	**Sample location**[1]
Discharge/Stage	Numerous	Numerous	A
Velocity	Numerous	Numerous	B, C, D
Depth	Once	Once	B, C, D
Channel slope	Once		A
Substrate type	Once		B, C, D
Embeddedness	Once		B, C, D
Percent shading	Once	Once	B, C, D
CPOM retention	Once		A
Temperature	Continuous	Continuous	B,C,D
Dissolved oxygen	Numerous	Numerous	B, C, D
pH	Numerous	Numerous	B, C, D
Conductivity	Numerous	Numerous	B, C, D
Dissolved nutrients	Once	Bi-weekly[2,3,4]	B, C, D
Nutrient limitation (NDS)	Once	Once	A,B,C
Nutrient cycling		Once	A
Leaf decomposition		Once	B,C
Periphyton variables	Once	Once[3,4]	B, C, D
Macroinvertebrate variables	Once	Once[3,4]	B, C, D
Fish variables	Once	Once[3,4]	B, C

[1] Sample location code: A = study stream reach (upstream and/or downstream); B = upstream control reach; C = downstream treatment reach; D = one kilometer below downstream end of treatment reach

[2] Dissolved nutrients sampled immediately before, 2, and 4 weeks after SCA additions

[3] Samples collected ~30 days after SCA treatment

[4] Samples collected ~1yr after SCA treatment

Experimental design

Upstream-downstream, before-after comparisons and experimental introduction of SCA will be used to investigate the response in stream food web variables to nutrient enrichment. Six treatment and 3 control streams in the upper Salmon River subbasin will be selected. Salmon carcass analog treatments will be randomly allocated to 6 of 9 study streams. Study sites within streams will be divided into 3km upstream (control) and 3km downstream (treatment) reaches. Stream reaches will be stratified into upper, middle, and lower stratum for sampling. Within each stratum, riffle sample sites will be randomly chosen for sampling. Before SCA treatments occur, we will conduct a sample size/power analysis to ensure that a sufficient number of sites will be sampled to have a high probability of detecting biologically meaningful treatment differences. Sample collection periods will be immediately before SCA additions, during SCA treatment in August-September, and 1 year after SCA treatments. In 2010 (before treatments) sampling events will represent pre-treatment baseline conditions; in 2010-2012, SCA treatments will occur in treatment streams; and in 2013, sampling will continue in the absence of SCA treatments. Project periods from 2014-2018 will use information gathered from 2009-2013 to direct treatment and management options using an adaptive management approach. As stated above, alternatives for the 2014-2018 periods include the continuation of the current study design investigating different aquatic food web response variables, utilizing alternative nutrient enrichment strategies, or whole stream nutrient enrichment SCA applications.

Statistical analysis

Samples collected within riffles will be considered subsamples and used to calculate mean values for each stream reach. Before Mean reach values for streamwater nutrient concentrations, periphyton biomass, macroinvertebrate measures, fish variables, leaf litter decomposition, and stable isotope values will be analyzed using a multilevel model (MIXED) analysis of variance (ANOVA) to facilitate comparisons between treatment and control streams (Proc mixed; SAS Institute Inc.; 2003). This approach will allow for correct estimation of standard errors and result in improved estimation of fixed and random effects (Wagner et al. 2006). Any natural escapement of Chinook salmon into study stream reaches will be enumerated and treated as a covariate. Streams will be considered replicates and a treatment by reach interaction effect will be analyzed for statistically significant differences using a probability of alpha 0.10.

The effect of nutrient amendments on chlorophyll *a* values from nutrient diffusing substrata will be determined using one-way ANOVA to test for differences among treatment groups.

The community composition of macroinvertebrate assemblages will be investigated using multivariate ordination techniques (PC-ORD; McCune and Mefford 1999).

H. Facilities and equipment

The Shoshone Bannock Tribes Fish and Wildlife Department has office and laboratory space available in Fort Hall, Idaho. The office space includes computers, faxes, copy machines, limited storage space, and basic field equipment available to meet many project objectives. Specialized equipment available for the study includes a Turner model 10-AU fluorometer. Dr. Keeley's laboratory at Idaho State University is approximately 450 square feet and has desk space for graduate students to enter and analyze data. A microscope with a digitizing system is also available to sort, measure, and enumerate invertebrate drift samples. Dr. Keeley's laboratory currently has two Celeron computers equipped with internet access and Microsoft Office for data analysis and report writing. The University has a site license for SAS statistical software that is leased on an annual basis. The ISU Department of Biological Sciences clerical office maintains two photocopy machines and a FAX machine that are available for faculty, staff, and students to use. The University maintains a fleet of four-wheel drive vehicles that can be rented on a monthly basis for travel to field sites. Dr. Keeley's laboratory currently has electroshocking equipment that can be used for fish sampling at study sites.

I. References

Achord S., Levin P.S., & Zabel R.W. (2003) Density-dependent mortality in Pacific salmon: the ghost of impacts past? *Ecology Letters*, **6**, 335-342.

Allan D.J. (1995) *Stream Ecology Structure and function of running waters*. Chapman and Hall, London, England.

Ambrose H.E., Wilzbach M.A., & Cummins K.W. (2004) Periphyton response to increased light and salmon carcass introduction in northern California streams. *The North American Benthological Society*, **23**(4), 701-712.

APHA (2005) *Standard Methods for the Examination of Water and Wastewater*, 21st edition, American Public Health Association, Washington, D.C., U.S.A.

Ashley K.I. & Slaney P.A. (1997) Accelerating recovery of stream and pond productivity by low-level nutrient enrichment. In: *Fish Habitat Rehabilitation Procedures* (Eds P.A. Slaney & D. Zaldokas), pp. 239-262. Catchment Restoration Tech. Circ. No. 9. British Columbia Ministry of Environment, Lands and Parks and Ministry of Forests, Vancouver, BC.

Bachman R. A. (1984) Foraging behavior of free-ranging wild and hatchery brown trout in a stream. *Trans. Am. Fish. Soc.,* **113**, 1-36.

Bain M.B. & Stevenson N.J. (1999) *Aquatic Habitat Assessment*, American Fisheries Society, Bethesda, Maryland, U.S.A.

Beckman B.R., Dickhoff W.W., Zaugg W.S., Sharpe C., Hirtzel S., Schrock R., Larsen D.A., Ewing D., Plamisano A., Schreck C.B., Mahnken C.V. (1999) Growth, smoltification, and smolt-to-adult return of spring chinook salmon (*Oncorhynchus tshawytshcha*) from hatcheries on the Deschutes River, Oregon. *Transactions of the American Fisheries Society*, 128:1125-1150.

Ben-David M., Hanley T.A., & Schell D.M. (1998). Fertilization of terrestrial vegetation by spawning Pacific salmon: the role of flooding and predator activity. *Oikos*, **83**, 47-55.

Benfield E.F. (2006) Decomposition of Leaf Material. Methods in Stream Ecology. Edited by Hauer R.F. & Lamberti G.A. Academic Press.

Bilby R.E., Fransen B.R. & Bisson P.A. (1996) Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. *Canadian Journal of Fisheries and Aquatic Sciences*, **53**, 164-173.

Bilby R.E., Fransen B.R., Walter J.K., Cederholm J. & Scarlett W.J. (2001) Preliminary evaluation of the use of nitrogen stable isotope ratios to establish escapement levels for Pacific salmon. *Fisheries*, **26**, 6-14.

Bilby R.E., Beach E.W., Fransen B.R., Walter J.K. & Bisson P.A. (2003) Transfer of nutrients from spawning salmon to riparian vegetation in western Washington. *Transactions of the American Fisheries Society*, **132**, 733-745.

Bilton H. T., Alderdice D. F., and Schnute J. T. (1982) Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. *Canadian Journal of Fisheries and Aquatic Sciences* **39**, 426–447.

Brett J. R. and N. R. Glass. (1973) Metabolic rates and critical swimming speeds of sockeye salmon (*Oncorhynchus nerka*) in relation to size and temperature. *J. Fish. Res. Board Can.,* **30**, 379-387.

Cederholm C.J., Houston D.B., Cole D.L., & Scarlett W.J. (1989) Fate of coho salmon (*Oncorhynchus kisutch*) carcasses in spawning streams. *Canadian Journal of Fisheries and Aquatic Sciences*, **46**, 1347-55.

Cederholm C.J., Kunze M.D., Murota T., & Sibatani A. (1999) Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. *Fisheries*, **24**, 6-15.

Chaloner D.T., Lamberti G.A., Merrit R.W., Mitchell N.L., Ostrom P.H., & Wipfli M.S. (2004) Variation in responses to spawning Pacific salmon among three south-eastern Alaska streams. *Freshwater Biology*, **49**, 587-599.

Cormack R.M. (1964) Estimates of survival from the sighting of marked animals. *Biometrika*, **51**, 429-438.

Elliott J. M. (1975) The growth of brown trout (*Salmo trutta* L.) fed on reduced rations. J. *Anim. Ecol*., **44**, 823-842.

Elliott J. M. (1976) The energetics of feeding, metabolism and growth of brown trout (*Salmo trutta* L.) in relation to body weight, water temperature and ration size. J. *Anim. Ecol*., **45**, 923-948.

Fausch K. D. (1984) Profitable stream positions for salmonids: relating specific growth rate to net energy gain. *Can. J. Zool*., **62**, 441-451.

Ficke A.D., Myrick, C.A., and Hansen, L.J. (2007) Potential impacts of global climate change on freshwater fisheries. *Rev. Fish. Biol. Fisheries*., **17**, 581-613.

Grant J.W.A., Steingrímsson S.Ó., Keeley E.R. and Cunjak R.A. (1998) Implications of territory size for the measurement and prediction of salmonid abundance in streams. *Can. J. Fish. Aquat. Sci*., **55(suppl. 1),** 181-190.

Grattan R.M. & Suberkropp K. (2001) Effects of nutrient enrichment on yellow poplar leaf decomposition and fungal activity in streams. *Journal of the North American Benthological Society*, **20**, 33-43.

Gresh T., Lichatowich J., & Schoonmaker P. (2000) An Estimation of Historic and Current Levels of Salmon Production in the Northeast Pacific Ecosystem: Evidence of a Nutrient Deficit in the Freshwater Systems of the Pacific Northwest. *Fisheries*, **25**, 15-21.

Groot C. & Margolis L. (Eds) (1991) *Pacific Salmon Life Histories*. University of British Columbia Press, Vancouver, BC.

Gross H.P., Wurtsbaugh W.A., & Luecke C. (1998) The role of anadromous sockeye salmon in the nutrient loading and productivity of Redfish Lake, Idaho. *Transactions of the American Fisheries Society*, **127**, 1-18.

Guensch G. R., Hardy T. B., and Addley R.C. (2001) Examining feeding strategies and position choice of drift-feeding salmonids using an individual-based, mechanistic foraging model. *Can. J. Fish.Aquat. Sci*., **58**, 446-457.

Guy C.S. & Brown M.L. (2007) Analysis and Interpretation of Freshwater Fisheries Data. American Fisheries Society, Bethesda, Maryland, U.S.A.

Hauer R.F. & Lamberti G.A. (2006) Methods in Stream Ecology. Academic Press.

Hauer R.F. & Resh V.H. (2006) Macroinvertebrates. Methods in Stream Ecology. Edited by Hauer R.F. & Lamberti G.A. Academic Press.

Hayes J. W., Stark J. D. and Shearer K.A. (2000) Development and test of a whole-lifetime foraging and bioenergetics growth model for drift-feeding brown trout. *Trans. Am. Fish. Soc.*, **129**, 315-332.

Hicks B.J., Wipfli M.S., Lang D.W., & Lang M.E. (2005) Marine-derived nitrogen and carbon in freshwater-riparian food webs of the Copper River Delta, southcentral Alaska. *Oecologia*, **144**, 558-569.

Hughes N.F. & Dill L.M. (1990) Position choice by drift-feeding salmonids: model and test for Arctic grayling (*Thymallus arcticus*) in subarctic mountain streams, interior Alaska. *Can. J. Fish. Aquat. Sci*., **47**, 2039-2048.

Idaho Department of Fish and Game (IDFG) (1992) Anadromous fish management plan 1992–1996. IDFG, Boise, ID.

Irving J.S. & Bjornn T.C. (1981) Status of Snake River fall Chinook salmon in relation to the Endangered Species Act. Unpublished Manuscript. Prepared for U.S. Fish and Wildlife Service. Available from Idaho Cooperative Fishery Research Unit, University of Idaho, Moscow, ID, 83843. 55 pp.

Independent Scientific Group (ISG) (1999) Scientific issues in the restoration of salmonid fishes in the Columbia River. American Fisheries Society 24(3):10–21.

Johnson D.H., Shrier B.M., O'neal J.S., Knutzen J.A., Augerot X., O'neal T.A. & Pearsons T.N. (2007) Salmonid Field Protocols Handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Jolly G.M. (1965) Explicit estimates from capture-recapture data with both death and immigrations--stochastic model. *Biometrika*, **52**, 225-47.

Keeley E. R. & Grant J.W.A. (1997) Allometry of diet selectivity in juvenile Atlantic salmon (*Salmo salar*). *Can. J. Fish. Aquat. Sci*., **54**, 1894-1902.

Kline T.C., Goering J.J., Mathisen O.A., Poe P.H., & Parker P.L. (1990) Recycling of elements transported upstream by runs of Pacific salmon: I. δ^{15}N and δ^{13}C evidence in Sashin Creek, southeastern Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 136-144.

Kohler A.E., Rugenski A., & Taki D. (2008) Stream food web response to a salmon carcass analogue addition in two central Idaho, U.S.A. streams. *Freshwater Biology,* **53**, 446-460.

Kohler A.E. & Taki D. (2009) Macroinvertebrate response to a salmon carcass analogue treatment in central Idaho, U.S.A. streams: exploring the relative influence of nutrient enrichment, stream food web, and environmental variables on macroinvertebrate assemblages. *Aquatic Ecology*, In review.

Kohler A.E., Pearsons T.N., Zendt J., Johnson C.L., & Mesa M. (2009) Nutrient enrichment using salmon carcass analogues in the Columbia River Basin: a stream food web study from Salmon River, Yakima River, Klickitat River, and Wind River tributaries. In preparation.

Kwak T.J. (1992) Modular microcomputer software to estimate fish population parameters, production rates and associated variance. *Ecology of Freshwater Fish*, **1**, 73-75.

Lady J., Westhagen P., & Skalski J.R. (2001) SURvival under Proportional Hazards, developed by the University of Washington, School of Aquatic and Fisheries Sciences.

Lamberti G.A. & Gregory S.V. (2006) CPOM Transport, Retention, and Measurement. Methods in Stream Ecology. Edited by Hauer F.R. & Lamberti G.A. Academic Press.

Lang D.W., Reeves G.H., Hall J.D., & Wipfli M.S. (2006) The influence of fall-spawning coho salmon (*Oncorhynchus kisutch*) on growth and production of juvenile coho salmon rearing in beaver ponds on the Copper River Delta, Alaska. *Canadian Journal of Fisheries and Aquatic Sciences*, **63**, 917-930.

Larkin G.A. & Slaney P.A. (1997) Implications of trends in marine-derived nutrient flux to south coastal British Columbia salmonid production. *Fisheries*, **22**, 16-24.

Levy S. (1997) Pacific salmon bring it all back home. *Bioscience*, **47**, 657-660.

Lichatowich J.A. (1999) *Salmon without rivers: a history of the Pacific salmon crisis*. Island Press, Washington, D.C.

Mann R.H.K. & Penczak T. (1986) Fish production in rivers: a review. *Polskie Archiwum Hydrobiologii*, **33**, 233-247.

Malmquist B., & Rundle S. (2002) Threats to the running water ecosystems of the world. Environ. *Cons.,* **29**, 134-153.

McCune B. & Grace J.B. (2002) Analysis of Ecological Communities, MjM Software Design, Oregon, U.S.A.

Mesa M.G., Magie C.D., Robinson T.C., Copeland E.S. & Connoly P.J. (2007) Nutrient assessment in the Wind River watershed: Report of phase III activities in 2006. U.S. Geological Survey, Western Fisheries Research Center, Columbia River Research Laboratory, Cook, WA.

Minikawa N. (1997) The dynamics of aquatic insect communities associated with salmon spawning. Ph.D. dissertation. University of Washington, Seattle.

Moore J.W. & Schindler D.E. (2004) Nutrient export from freshwater ecosystems by anadromous sockeye salmon (*Oncorhynchus nerka*). *Canadian Journal of Fisheries and Aquatic Sciences*, **61**, 1582-1589.

National Research Council (1996) Upstream: salmon and society in the Pacific Northwest. National Academy of Press. Washington D.C.

Nehlsen W., Williams J.E., & Lichatowich J.A. (1991) Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. *Fisheries*, **16**(3), 4-21.

Nislow K. H., Folt C.L., & D.L. Parrish. (1999) Favorable foraging locations for young Atlantic salmon: application to habitat and population restoration. *Ecol. App.*, **9**, 1085-1099.

Northwest Power Planning Council (NPPC) (2000) Columbia River Basin Fish and Wildlife Program, Council document 2000-19.

Pearsons T.N., Roley D.D., & Johnson C.L. (2007) Development of a carcass analog for nutrient restoration in streams. *Fisheries*, **32** (3), 114-124.

Pearsons T.N., Johnson C.L., Schmuck M., Webster T., Roley D., & Bilby R. (2003) Influences of stocking salmon carcass analogs on salmonids in Yakima River tributaries. 2001-2002 Technical report, Project No. 200105500, 44 electronic pages, BPA report DOE/BP-00005636-1.

Piorkowski R.J. (1995) Ecological effects of spawning salmon on several southeastern Alaskan streams. Ph.D. dissertation. University of Alaska, Fairbanks.

PIT Tag Marking Procedures Manual (1999) Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee, Version 2.0.

Platts W.S., Megahan W.F. & Minshall G.W. (1983) Methods for evaluating stream, riparian, and biotic conditions. U.S. Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-138, Ogden, Utah.

Tank J.L., Bernot M.L., & Rosi-Marshall E.J. (2006) Nitrogen Limitation and Uptake. Methods in Stream Ecology. Edited by Hauer F.R. & Lamberti G.A. Academic Press.

Thomas S.A., Royer T.V., Minshall G.W., Synder E. (2003) Assessing the historic contributions of marine-derived nutrients to Idaho streams. *Fisheries*, **34**, 41-55.

Ries R.D., and Perry, S.A. (1995) Potential effects of global climate warming on brook trout growth and prey consumption in central Appalachian streams, USA. *Clim. Res.*, **5**, 197-206.

Robinson C.T. & Gessner M.O. (2000) Nutrient addition accelerates leaf breakdown in an alpine springbrook. *Oecologia*, **122**(2), 258-263.

Rosenfeld J. S. (2003) Assessing the habitat requirements of stream fishes: an overview and evaluation of different approaches. *Trans. Am. Fish. Soc.*, **132**, 953-968.

Runkel R. (1998) One-dimensional transport with inflow and storage (OTIS): a solute transport model for streams and ricers. Water-Resources Investigations Report 98-4018, U.S. Geological Survey, Denver, CO.

Sanderson B., Coe H., Pelekis V., Vizza C., Haug E. & Radmer Z. (2008) Assessment of three alternative methods of nutrient enhancement (salmon carcass analogs, nutrient pellets, and carcasses) on biological communities in Columbia River tributaries. BPA report #P108490.

Scheuerell M.D., Levin P.S., Zabel R.W., Williams J.G., & Sanderson B.L. (2005) A new perspective of marine-derived nutrients to threatened stocks of Pacific salmon (*Oncorhynchus* spp.). *Canadian Journal of Fisheries and Aquatic Sciences*, **62**, 961-964.

Schmidt D.C, Carlson S.R., Kyle G.B., & Finney B.P. (1998) Influence of carcass-derived nutrients on sockeye salmon productivity in Karluk Lake, Alaska: importance in the assessment of an escapement goal. *North American Journal of Fisheries Management*, **18**, 743-763.

Seber G.A.F. (1965) A note on the multiple recapture census. *Biometrika*, **52**, 249-52.

Smock L.A. (2006) Macroinvertebrate Dispersal. Methods in Stream Ecology. Edited by Hauer R.F. & Lamberti G.A. Academic Press.

Smock. L. A. (1980) Relationships between body size and biomass of aquatic insects. *Freshwater Biol.*, **10**, 375-383.

Steinman A.D. & Lamberti G.A. (1996) Biomass and pigments of benthic algae. Methods in Stream Ecology. Edited by Hauer F.R. & Lamberti G.A. Academic Press.

Stockner J.G. & Shortreed K.R.S. (1978) Enhancement of autotrophic production by nutrient addition in a coastal rainforest stream on Vancouver Island. *Journal of the Fisheries Research Board of Canada*, **35**, 28-34.

Sylvestre S. & Bailey R.C. (2005) Ecology of leaf pack macroinvertebrate communities in streams of the Fraser River Basin, British Columbia. *Freshwater Biology*, **50**, 1094-1104.

Wagner T., Hayes D.B., & Bremigan M.T. (2006) Accounting for multilevel data structures in fisheries data using mixed models. *Fisheries*, **31**(4), 180-187.

Ward B.R. & Slaney P.A. (1988) Life history and smolt-to-adult survival of Keogh River steelhead trout (*Salmo gairdneri*) and the relationship to smolt size. *Canadian Journal of Fisheries and Aquatic Sciences*, **45**, 1110-1122.

Waters T.F. (1977) Secondary production in inland waters. *Advances in Ecological Research*, **10**, 91-164.

Webster J.R. & Valett M.H. (2006) Solute Dynamics. Methods in Stream Ecology. Edited by Hauer F.R. & Lamberti G.A. Academic Press.

Welsh E.B., Jacoby J.M., & May C.W. (1998) Stream quality. *River ecology and management: lessons from the Pacific Coastal Ecoregion*. Springer-Verlag, New York.

Werner E.E. & Hall D.J. (1974) Optimal foraging and the size selection of prey by the bluegill sunfish (*Lepomis macrochirus*). *Ecol.*, **55,** 1042-1052.

Wipfli M.S., Hudson J.P., & Caouette J.P. (1998) Influence of salmon carcasses on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 1600-1611.

Wipfli M.S., Hudson J.P., Caouette J.P. & Chaloner D.T. (2003) Marine subsidies in freshwater ecosystems: salmon carcasses increase the growth rates of stream-resident salmonids. *Transactions of the American Fisheries Society*, **132**, 371-381.

Wipfli M.S., Hudson J.P. & Caouette J.P. (2004) Restoring Productivity of Salmon-Based Food Webs: Contrasting Effects of Salmon Carcass and Salmon Carcass Analog Additions on Stream-Resident Salmonids. *Transactions of the American Fisheries Society*, **133**, 1440-1454.

Zendt J. & Sharp B. (2006) Influences of stocking salmon carcass analogs on salmonids in Klickitat River tributaries. 2001-2005 Completion report, Project No. 200105500, 25 electronic pages, BPA report DOE/BP-00007534-1.

J. Key personnel

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Area of specialization: aquatic ecology and conservation biology. Andre Kohler will be responsible for contract management and will serve as the principal investigator on behalf of the Shoshone Bannock Tribes. Andre Kohler has 13 years of experience working on water quality, stream food web ecology, habitat, and fisheries ecology issues.

Education:

B.Sc. - Lewis and Clark College, Portland, OR, U.S.A.
M.Sc. - Washington State University, Pullman, WA, U.S.A.

Professional Experience:

1998 - 2000	Contract Biologist, United States Geological Survey Biological Resources Division, Klamath Falls Field Office, Klamath Falls, OR.
2000 - 2001	Salmon Habitat Inventory and Assessment Program Biologist, Northwest Indian Fisheries Commission, Olympia, WA.
2001 - present	Aquatic Biologist, The Shoshone Bannock Tribes, Fort Hall, ID.

Selected Publications:

Kohler, A.E., Rugenski A., & Taki D. (2008) Stream food web response to a salmon carcass analogue addition in two central Idaho, U.S.A. streams. *Freshwater Biology*, **53,** 446-460.

Kohler, A.E. & Taki D. (2009) Macroinvertebrate response to a salmon carcass analogue treatment: exploring the relative influence of nutrient enrichment, stream food web, and environmental variables. **In review** at Journal of the North American Benthological Society.

Shively R.S., **Kohler A.E.**, Peck B.J., Coen M.A., & Hayes B.S. (2000) Water quality, benthic macroinvertebrate, and fish community monitoring in the Lost River sub-basin, Oregon and California, 1999. Report of sampling activities in the Lost River sub-basin conducted by the U.S. Geological Survey, Biological Resources Division, Klamath Falls Duty Station, 1999.

Kohler, A.E. (1998) A comparative bioassessment of Liberty Creek and Thompson, Creek, Washington, using benthic macroinvertebrate and salmonid communities. Masters thesis, Washington State University.

Ernest R. Keeley, Department of Biological Sciences, Idaho State University, Stop 8007, Pocatello, ID, 83209. tel: 208-282-3145, email: keelerne@isu.edu

Area of specialization: fisheries ecology and conservation biology. Dr. Keeley will be responsible for supervising a graduate student that will conduct field sampling for bioenergetic modeling exercises. Dr. Keeley has more than 17 years experience working on issues of salmonid fish ecology and conservation, including the application of bioenergetic modeling of habitat quality for Yellowstone cutthroat trout.

Education:

B.Sc. - Concordia University, 1990, Montréal, PQ., Canada.
M.Sc. - Concordia University, 1994, Montréal, PQ., Canada.
Ph.D. - The University of British Columbia, 1998, Vancouver, B.C., Canada.
Post Doctoral Fellow -The University of British Columbia, 1998-1999, Vancouver, B.C., Canada.

Professional Experience:

2004 - present	Associate Professor, Idaho State University, Department of Biological Sciences, Pocatello, Idaho, USA.
2008 - present	Vice-President, President-elect, Idaho Chapter of the American Fisheries Society
2006 - present	Associate Editor, North American Journal of Fisheries Management
1999 – 2004	Assistant Professor, Idaho State University, Department of Biological Sciences, Pocatello, Idaho, USA

Research Grants:

Dr. Keeley has had ten externally funded grants since arriving at ISU as PI or Co-PI; based on a diversity of funding sources, including the National Science Foundation, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game, and U.S. Department of Agriculture.

Teaching:

Dr. Keeley has taught seven classes since arriving at ISU, including: Biology 459: Fish Ecology; Biology 427: Ichthyology; Biology 491: Senior Seminar; Biology 337: Conservation of Natural Resources; Biology 192: Ecology Seminar; Biology 605: Biometry; Biology 100: Biology of Human Concerns (1999-2001).

Dr. Keeley has supervised 10 graduate students since arriving at ISU, eight M.S. students, one D.A. student and one Ph. D. student. Seven M.S. students, one D.A., and one Ph.D. students have successfully completed their degrees. All graduates are currently employed in a biology related career.

Selected Publications:

Seiler, S.M. & **Keeley, E.R.** (2009) Competition between native and introduced salmonid fishes: cutthroat trout have lower growth rate in the presence of cutthroat–rainbow trout hybrids. *Canadian Journal of Fisheries and Aquatic Sciences*, **66**, 133-141.

Seiler, M.B. & **Keeley, E.R.** (2009) Intraspecific taxonomy and ecology characterize morphological divergence among cutthroat trout (*Oncorhynchus clarkii* ssp. Richardson) populations. *Biological Journal of the Linnean Society*, **96,** 266-291

Imre, I, Grant, J.W.A., & **Keeley, E.R.** (2004) The effect of food abundance on territory size and population density of juvenile steelhead trout (*Oncorhynchus mykiss*). *Oecologia*, **138**, 371-378.

Keeley, E.R. (2001) Demographic responses to food and space competition by juvenile steelhead trout. *Ecology*, **82**, 1247-1259.