The Shoshone Bannock Tribes

Fish and Wildlife Department

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Memorandum (200890400 ISRP FAN2 Response)                    October 29, 2009


**To:  Independent Scientific Review Panel**


**From:  The Shoshone Bannock Tribes:**  (EXP Salmon River Nutrient Enhancement)


**Subject:  The Shoshone Bannock Tribes response to ISRP review:**  EXP Salmon River
Basin Nutrient Enhancement Project:  (200890400 ISRP FAN2 Response)


Please see point by point response (blue font: SBT response (I-XII)) to ISRP review comments
(ISRP 2009-26) and associated revised project narrative (Filename_200890400 ISRP FAN2).

**Memorandum (ISRP 2009-26)**                    **June 30, 2009**

**To:**         Tony Grover, Fish and Wildlife Division Director, Northwest Power and
Conservation Council

**From:**      Eric Loudenslager, ISRP Chair

**Subject:**    Response Requested for Accord Proposal, Salmon River Basin Nutrient
Enhancement (2008-904-00)

**Background**

At the Council's June 12, 2009 request, the ISRP reviewed the Shoshone-Bannock Tribes'
Columbia River Fish Accord proposal titled Salmon River Basin Nutrient Enhancement (2008-
904-00[1]). 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.

**ISRP Recommendation**

*Response Requested*

The research proposed could be of significant benefit to the development of salmon restoration
plans for the Columbia Basin. The enhancement of nutrient availability and food web
productivity has been widely promoted as an effective restoration strategy, but our understanding
of ecosystem-level responses to nutrient addition is limited. This study will provide new
information on the utility of salmon carcass analogs as a potential enhancement tool.

A response is requested to address the following issues:

1. Nutrient and food limitation. Provide detailed methodology on the assessment of nitrogen
   or phosphorus limitation and food limitation in stream fishes.

   How will researchers determine if nitrogen or phosphorus is the key limiting nutrient?
   And (inserted from review section below) …… study site selection will be critical to the
   experimental outcome. Results of nutrient additions will be expressed differently in

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[1] www.nwcouncil.org/fw/projectselection/accord/200890400.pdf

streams with varying background nutrient concentrations (and nutrient ratios). Locations should be carefully picked to match baseline nutrient concentrations as closely as possible.

SBT response (I):

## 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

To directly test whether streams are nutrient limited, we will conduct a series of experiments to measure algal response to amendments of nitrogen, phosphorus, and a combination of nitrogen and phosphorus. We propose to measure the growth of stream biofilms 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 ($\pm$2) days. Samples will be analyzed for chlorophyll $a$ and AFDM using analysis of variance models (ANOVA).

Nutrient diffusing substrata experiments directly assess the degree of N, P, or co-limitation in periphyton communities. Results from NDS experiments will help to characterize the type and extent of nutrient limitation in potential study streams in the upper Salmon River subbasin. Nutrient limitation studies will be of value to managers considering nutrient additions as a tool to increase freshwater productivity for ESA listed fishes and will help the present study to: 1) appropriately select study streams- i.e., if our data suggests a particular stream is NOT nutrient limited, it makes little sense to include it as a treatment stream receiving supplemental nutrients; 2) evaluate stream specific response to nutrient additions from SCA treatments- i.e., results will help to explain differential response to SCA additions across study streams.

Nutrient diffusing substrata are incubated *in situ* for 20-30 days and provide a better picture of nutrient limitation and associated autotrophic response relative to water chemistry samples. Studies that compare nutrient limitation results from water chemistry ratios and those derived from *in-situ* experiments indicate that nutrient ratios have mixed success in predicting nutrient limitation of algal biomass in streams and that when nutrient concentrations are low, N:P ratios may be less useful indicators of nutrient limitation (Sanderson et al. 2009). In addition, NDS

results will help to explore the heterotrophic nature of study streams by providing an autotrophic index measure. These types of data will be extremely valuable when evaluating potentially variable responses to nutrient additions across study streams. And as mentioned by ISRP reviewers, NDS results could also be used to specifically formulate inorganic nutrient (N:P) ratios. This information would be helpful to managers attempting to increase freshwater productivity via inorganic nutrient additions.

We propose to use SCA as a primary nutrient addition tool, and will not attempt, or have the ability to, manipulate nutrient ratios on a stream by stream basis; however, NDS and water chemistry data will be useful in the selection of study streams that have similar background nutrient concentrations, exhibit similar nutrient limiting characteristics, and presumably similar autotrophic responses to supplemental nutrient additions. We feel strongly that NDS experiments are a valuable component of our study design.

## 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. To the extent possible, we will select study streams with similar background nutrient concentrations and similar background nutrient (N:P) ratios, as suggested.

What methods are proposed to determine if food is limiting smolt yield or growth rate?

SBT response (II):

As we discuss in the proposal, our study provides an innovative opportunity to use a bioenergetic model to assess food limitation for stream-dwelling salmonids in the upper Salmon River subbasin. We plan to adapt past applications of the model (e.g. Hayes et al. 2000) to assess changes in habitat quality for salmonid populations based on changes in food availability from nutrient enhancement efforts.

In our study, we plan to measure invertebrate drift abundance in treated sections of representative streams, both before and after nutrient additions are applied to study streams. Because stream-dwelling salmonids are primarily drift-feeding predators, we will directly measure changes in food availability with corresponding treatment effects. Measures of drift abundance can then be included in bioenergetic modeling exercises to determine if any increase in invertebrate drift provides a net increase in energy intake. Because salmonids react to, capture, and ingest prey one-at-a-time from the stream current, handling time may limit the upper consumption rate for drift-feeding salmonids. The bioenergetic model we will adapt for this study calculates maximum consumption rates for fishes and will determine if increases in invertebrate drift provide increased net energy intake rates for individual fishes foraging in streams receiving SCA treatments.

In addition, benthic invertebrate samples will be collected to determine abundance and biomass estimates, thereby providing an additional measure of potential food availability. These measures, coupled with juvenile salmonid abundance, growth rate, life stage specific morphological characteristics, survival, and production estimates will help determine if food is limiting smolt yield and/or growth rates.

2. Eyed egg boxes may provide inconsistent and variable results and may not ensure the stream is at juvenile carrying capacity. How will the evaluation deal with variable juvenile density in the analysis? And (inserted from review section below) …… fish production results may be seriously confounded by the presence, and likely variable abundance, caused by eyed egg boxes. Studies of this nature should ideally be conducted when the system is at carrying capacity for juvenile abundance, to provide comparisons that are not confounded by density effects. Presence of the eyed egg boxes will likely cause juvenile abundance to be highly variable.

SBT response (III):

Project sponsors agree that the presence of eyed egg boxes could potentially result in highly variable juvenile densities within and between study streams. Therefore, we will not conduct nutrient enhancement treatments in areas directly influenced by eyed egg box production.

Natural juvenile densities in selected study streams will undoubtedly be variable; however, we are planning to measure juvenile densities within study stream reaches and will be able to use juvenile densities as a covariate in the statistical analysis of stream food web response to SCA additions, if appropriate.

We also agree that, ideally, studies of this nature should be conducted in stream systems that are at carrying capacity for juvenile abundance; however, ideal situations are difficult to achieve using this criterion, especially in the upper Salmon River basin. Salmon River juvenile salmonid populations may experience density dependence at low population levels, especially those utilizing nutrient-impoverished streams as spawning and rearing areas. Achord et al. (2003), in a study conducted in central Idaho, suggest that juvenile salmon may experience density-dependent mortality at population sizes far below historical levels. And Scheuerell et al. (2005) speculate that a loss of marine derived subsidies has caused a state shift in the productivity of freshwater systems within the Snake River basin, such that strong density-dependent survival is occurring in juvenile salmon populations.

We will attempt to select study streams with the above information and objectives in mind.

3. The key response variable to address effectiveness of salmon carcass analog addition should be wild smolt recruitment as a function of spawner density. This measure will require an estimate of wild smolt production from the study sites. How will this be accomplished?  And (inserted from review section below) …… There is no indication that smolt production from the study sites will be measured (except for the detection of tagged individuals at Lower Granite Dam). The primary objective of enhancing trophic production in salmon streams with salmon carcass analogs or nutrients is to increase growth and survival of juvenile fish (egg – smolt survival). This key response variable cannot be quantified unless the smolts produced by the treated and control reaches in this study are enumerated. The response should address whether or not smolts can be sampled at the study sites, and if not, what alternatives might be available to address this deficiency. Smolt sampling should include weights in order to address the question of whether nutrient additions contribute to growth.

SBT response (IV):

We agree that wild smolt recruitment as a function of spawner density is an important response variable to consider in nutrient enrichment studies that attempt to increase freshwater productivity and the growth and survival of salmonid fishes.  Under ideal situations, study streams in the upper Salmon River basin would have adult and juvenile trapping/counting facilities that enable precise and accurate measurements of adult escapement and subsequent brood year smolt production.

The present study will use the Yankee Fork Salmon River (YFSR) to evaluate the effects of natural and volitional releases of spawning adult Chinook salmon on stream food web response variables.  Importantly, the SBT operates a temporary adult Chinook salmon weir and a juvenile rotary screw trap in the YFSR.  These monitoring and evaluation facilities are fully funded under the Lower Snake River Compensation Plan and operated by the SBT Yankee Fork Salmon River Supplementation Program.  The project sponsors will take advantage of these facilities to derive recruit/spawner estimates as suggested.  This will be accomplished using: reach level juvenile salmonid adundance estimates; mark-recapture data from study reaches and subsequent rotary screw trap recaptures; Length, weight, and age composition data from study reaches and the rotary screw trap; and adult Chinook salmon escapement and redd count data in the YFSR.

In addition to the infrastructure, funding, and operational considerations associated with adult and juvenile trapping operations, the subsequent ability to investigate wild smolt yield as a function of spawners is further confounded by the life history characteristics of juvenile Chinook salmon in the upper Salmon River basin.  A significant amount of data across the Salmon River basin indicates that large proportions (the majority) of brood year migrants emigrate from Salmon River basin streams as summer and fall parr.  Below are a few examples from the Idaho Supplementation Studies that display the number of juvenile Chinook salmon migrants over time (rotary screw trap sampling efforts):

**Marsh Creek**



**Upper Salmon River**



**Lake Creek**



**Secesh River**
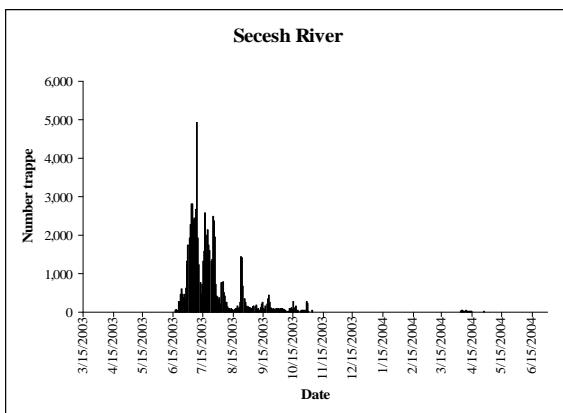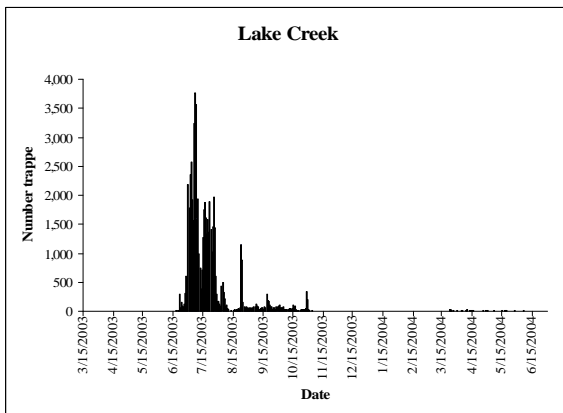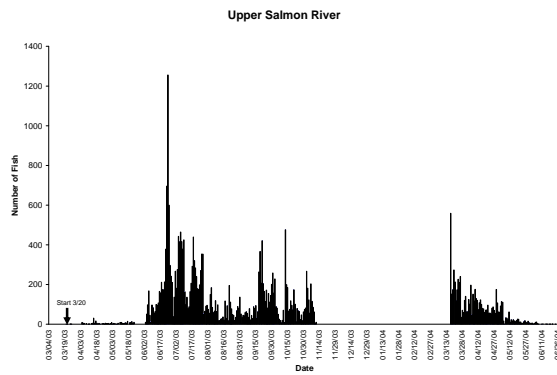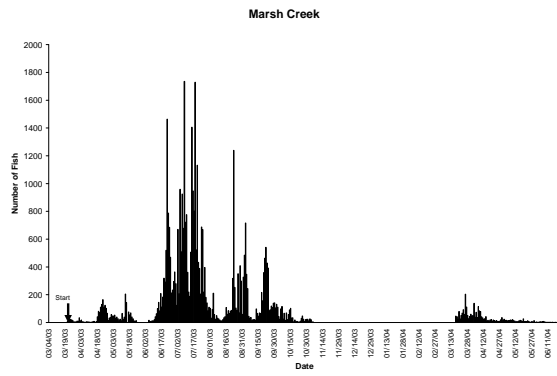
As these graphs illustrate, the majority of brood year migrants are emigrating as parr, with a minority overwintering and smolting within natal spawning streams. These fish are considered to be stream-type Chinook salmon and often migrate from natal streams in late summer and fall to overwinter in larger, downstream riverine habitats (Healey 1991), initiating seaward migrations during the following spring as age 1+ smolts (Folmar and Dickhoff 1980). The presumption has been that downstream habitats offer more productive rearing conditions. Therefore, in order to gain insight into juvenile smolt length, weight, and condition associated with nutrient additions in selected study streams, we propose to use automated diversion gates in the juvenile fish bypass system at the lower Snake River dams to separate fish based on PIT tag codes. These fish, PIT tagged as parr in study streams, will be interrogated as smolts, diverted, sampled for length and weight data, and released below the dam (Achord et al. 2003). Associated survival estimates from PIT tagging efforts will be used to estimate smolt production in study streams (i.e., using the estimated number of smolts passing lower Granite Dam). This technique will allow for smolt characteristics and production estimates to be made in study streams without juvenile trapping facilities such as rotary screw traps. In streams without adult trapping/counting facilities, estimates of adult spawners will be based on redd counts.

4. Some project elements do not seem to support the overarching objective of the study (effect of salmon carcass analogs on food web dynamics). The response should clearly explain how the nutrient diffusing substrata, nutrient spiraling, and course particulate organic matter transport elements of the study will provide information relevant to the interpretation of the effects of the salmon carcass analogs on stream trophic dynamics and specifically on smolt production.

SBT response (V):

Nutrient diffusing substrata elements: Please refer to SBT response (Section I) for justification.

Nutrient spiraling elements:

We proposed to measure transient storage and nutrient uptake parameters using nonconservative nutrient and conservative solute releases in study streams. We believe that measures of this kind would provide valuable information; however, method collection, analysis, and reporting is time consuming and somewhat expensive (as mentioned in the review). It is this type of proposed measure that may have lead reviewers to note that the project is "ambituous (perhaps overly ambitious?)". Furthermore, we agree with reviewer comments that suggested additional measures (e.g., primary productivity) to compliment periphyton sampling. Therefore, we are willing to drop the nutrient spiraling elements (Task 3.2) and will revise our proposal to include whole-stream metabolism measures that generate estimates of gross primary productivity and community respiration.

CPOM transport elements:

Allochthonous CPOM is a major energy source for stream ecosystems (Vannote et al. 1980) and may provide a large proportion of fixed carbon to study streams in the upper Salmon River basin. We propose to conduct reach-scale evaluations to gain insight into the CPOM retentive capacity of study streams. Organic matter retention is likely variable between reaches within and among study streams and may help to explain observed stream food web response to SCA additions.

CPOM sampling (as proposed) does not require expensive equipment and analyses (i.e., it is cheap and relatively easy to do). We agree that the transport and retention of CPOM using proxy materials (e.g., paper strips, leaves, etc.) does not directly reflect the transport and retention of SCA material; however, understanding CPOM parameters will help us better understand the hydrologic, substrate-related, and riparian features that affect the transport and retention of organic materials. These data will also be valuable when coupled with measurements of organic (i.e., leaf) matter breakdown. And as suggested by Young et al. (2008), these measures represent important functional indicators for assessing river ecosystem health. Habitat complexity and functional attribute measures of this kind will contribute to our knowledge of stream ecosystem response to nutrient additions. The project sponsors feel strongly that CPOM retention measures should be included in our study design.

5. Provide some additional detail on the rationale for the variable treatment intensities over the three years of the study. How will potential cumulative impacts of repeated nutrient supplementation be assessed with this design?

SBT response (VI):

6. Discuss how the information gathered from these investigations will be used to design larger scale pilot or full implementation of salmon carcass analog applications as a salmon/stream restoration strategy.

SBT response (VII):

By comparing responses in replicate experimental streams distributed across the upper Salmon River basin, our study will attempt to capture and document the range of expected responses to nutrient enhancement across a large geographic area designated as critical habitat for Pacific salmon and steelhead ESU's. Based on these data, a larger scale assessment of historic spawning streams in Idaho could then use these baseline data to determine the likely response to nutrient additions in other streams. Results gathered from these investigations will provide the foundation for an adaptive management approach to the design of larger scale pilot or full implementation projects using SCA applications as an interim management tool to increase the freshwater productivity of upper Salmon River streams.

Using results from this study, and associated work conducted throughout the Columbia River basin and elsewhere, we will attempt to design larger scale (e.g., whole-stream) pilot projects

that address remaining uncertainties.  At that time, if stream food web response at the stream segment scale using SCA additions appears to increase freshwater productivity and the growth and survival of salmonid fishes, without damaging the ecological integrity of stream ecosystems, then large-scale, whole-stream nutrient additions will most likely be proposed.  Streams will be selected where evaluation of natural smolt yield as a function of spawner density (i.e., smolts/spawner/km as a function of the number of spawners) can be determined, as suggested and reported in Ward et al. (2006).

Using this type of adaptive management approach will offer the needed flexibility to address uncertainties and ensure that project activities best support the recovery of ESA listed species within the Salmon River basin.

## ISRP Comments

1. Technical Justification, Program Significance and Consistency, and Project Relationships (sections B-D)

Technical justification for the proposed nutrient addition using salmon carcass analogs was supported by the scientific literature and linked effectively to the Fish and Wildlife Program. Enhancement of trophic productivity has become a popular restoration method in the Columbia Basin, but its effects are not fully understood. This proposal details what is known about food web enhancement of salmon streams and identifies several knowledge gaps that this study will attempt to address. There appears to be good communication between this project and similar studies occurring on other locations in the basin.

2. Objectives, Work Elements, and Methods (section F)

The overarching objective of this project, to evaluate food web responses to the addition of salmon carcass analogs, is an important issue for salmon restoration in the Columbia River Basin. The project proponents are to be commended on the comprehensive approach they are proposing to evaluate system responses to nutrient enhancement. The study proposed is comprehensive and ambitious (perhaps overly ambitious?) encompassing all trophic levels and with generally appropriate analytical techniques, in the field, the laboratory, and statistically. The study would include the involvement of numerous graduate students and will be led by competent researchers who are leaders in this field of study. If accomplished as planned, this study would significantly improve our understanding of stream ecosystem response to salmon carcass analog additions. However, there were places where some additional thought or clarification is required.

There are several potential complications that may arise from comparing fish production and yield that should be addressed in the response. First, the fish production results may be seriously confounded by the presence, and likely variable abundance, caused by eyed egg boxes. Studies of this nature should ideally be conducted when the system is at carrying capacity for juvenile abundance, to provide comparisons that are not confounded by density effects. Presence of the eyed egg boxes will likely cause juvenile abundance to be highly variable.

A more robust approach for assessing fish response to salmon carcass analog treatments would be the evaluation of (wild) smolt yield as a function of spawner density (i.e., smolts/spawner/km as a function of the number of spawners) in treatment and control study sites. This approach could be combined with a staircase treatment design to address environmental variation as well. Further, if the sites are not at carrying capacity, it is possible that there are sufficient food resources for the limited number of fish present in the study reach, thus no need for food enhancement via salmon carcass analogs. Examination and comparison of wild smolt abundance, size at age, and recruitment trends will be necessary, as in Ward et al. (2008[2]), to assess the key response variable.

There is no indication that smolt production from the study sites will be measured (except for the detection of tagged individuals at Lower Granite Dam). The primary objective of enhancing trophic production in salmon streams with salmon carcass analogs or nutrients is to increase growth and survival of juvenile fish (egg – smolt survival). This key response variable cannot be quantified unless the smolts produced by the treated and control reaches in this study are enumerated. The response should address whether or not smolts can be sampled at the study sites, and if not, what alternatives might be available to address this deficiency. Smolt sampling should include weights in order to address the question of whether nutrient additions contribute to growth.

The proposal treats salmon carcass analog additions as simply a nutrient enhancement and focuses all evaluations on capturing bottom-up effects on food web dynamics. Salmon carcass analogs, or actual salmon carcasses, can enrich aquatic food webs in two ways; bottom-up by increasing availability of nutrients limiting primary production or by providing a direct food subsidy to secondary consumers (invertebrates and fishes). The assessment approach proposed does a very thorough job of examining the bottom-up response to salmon carcass analog additions. It does not explicitly present an approach for assessing the effect of the direct food subsidy. The stable isotope analysis and sampling of fish stomachs can be useful in assessing this potential enrichment pathway. Samples would need to be collected at the appropriate time (soon after salmon carcass analog placement) in order to evaluate direct consumption of the salmon carcass analog and distinguish the response from this pathway from bottom-up enrichment of the food web. The methods that will be used to assess the direct consumption of salmon carcass analogs should be included in the response.

SBT response (VIII):

We propose to evaluate direct consumption of SCA material in study streams by capturing juvenile salmonids ~1-2 weeks after SCA additions.  In a study conducted by Pearsons et al. (2003) using SCA treatments, juvenile salmonid diet analysis revealed considerable amounts of

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[2] Ward, B.R, Slaney P.A and D.J.F. McCubbing. 2008. Whole-river ecosystem restoration to reconcile fisheries and habitat impacts in coastal British Columbia, Pp. 587-602, In [J. Neilsen, ed.] Proceedings of the Fourth World Fisheries Congress, 4 to 7 May, 2004, Vancouver, B. C., Canada. American Fisheries Society Symposium.

Study site selection will be critical to the experimental outcome. Results of nutrient additions will be expressed differently in streams with varying background nutrient concentrations (and nutrient ratios). Locations should be carefully picked to match baseline nutrient concentrations as closely as possible.

Please refer to SBT response section (I).

It was unclear how some of the project elements fit into the overall research effort. In particular, the identification of limiting nutrients using nutrient diffusing substrates (NDS) and the evaluation of nutrient spiraling length appear to be only tangentially related to the primary objectives of this study. The proposal did indicate that the NDS work would be one factor used in identifying study sites. But it is not clear how this information would be used. Will sites with the greatest response to nutrient addition be selected?

Please refer to SBT response section (I).

The connection between the identification of limiting nutrients and the proposed treatment is also not entirely clear. If addition of inorganic nutrients were being proposed, the relationship between the NDS results and the subsequent nutrient addition would be obvious; use the NDS work to formulate the nutrient soup to be added to the stream. But the salmon carcass analog composition cannot be altered to address any identified nutrient limitation. The NDS results might help in the interpretation of a food web response at a site; the change in food web dynamics could be attributed to an increase in the concentration of the element that the NDS work identified as limiting. But the ability to make this connection seems to add little to the value of the study and the value of the NDS work is questionable.

Please refer to SBT response section (I).

The evaluation of nutrient spiraling length also is not clearly associated with project objectives, and in any case is often very difficult to determine. No objective is provided for this component of the study. How does the spiraling length assessment relate to the salmon carcass analog treatments?  Is the hypothesis that the spiral length will in some way provide an index of how effective the nutrients from salmon carcass analog treatments are likely to be?  Some discussion of how the NDS and nutrient spiraling elements of the study will contribute to better understanding the food web responses to salmon carcass analog additions or salmon releases should be included in the response or these components of the study should be eliminated.

Please refer to SBT response section (V): Nutrient spiraling elements.

The relationship between the salmon carcass analog additions and the CPOM transport assessment also is not clear. The release of plastic strips or colored paper has been used to evaluate the transport of leaf litter. But the CPOM released by the degradation of the salmon carcass analogs is unlikely to resemble leaves. Assessment of the distance traveled by salmon

carcass analog fragments would be a useful, although not critical, addition to this study. It might be possible to do so using a biochemical marker, but this has yet to be demonstrated in the field. But the determination of short-term leaf transport distances appears to be unrelated to the objectives of the study. As with the NDS and nutrient spiraling work, the response should clearly indicate the relationship of this work to the salmon carcass analog additions or omit it from the study.

Please refer to SBT response section (V): CPOM transport elements.

Relying on changes in AFDW and Chl a on tiles or natural substrate to evaluate the effects of salmon carcass analog addition on primary production can be complicated by differential grazing pressure between treated and reference reaches and among study streams. If invertebrate grazing pressure is high, Chl. a or AFDW may not be a good reflection of primary production. Whole-stream metabolism measures using highly-accurate DO sensors has been used to measure primary production in streams with good success for the last decade or so. You might consider augmenting the AFDW and Chl. a responses with some whole-stream metabolism measures. Information on this technique may be found in the following two publications:

*Bott, T.L. 2007. Primary productivity and community respiration. Pages 663-690 in F.R. Hauer and G.A. Lamberti, editors. Methods in Stream Ecology. Academic Press, San Diego, CA*

*Young, R.G., and A. D. Huryn. 1999. Effects of land use on stream metabolism and organic matter turnover. Ecological Applications 9:1359-1376.*

Another method (although not as accurate) of estimating primary production is to measure Chl a accrual on artificial substrates that have previously been "conditioned" to the ambient stream setting. This can be done by allowing artificial substrates (e.g., unglazed porcelain tiles) to incubate in the streams for a couple of weeks, then brushing the periphyton off to "reset" them, and sequentially sampling the rate of accumulation of Chl a on the substrates over about 10 days. The rate of chlorophyll accrual is an approximation of primary production if there are few grazing invertebrates on the substrates over the first 10 days.

SBT response (IX):

We agree that the addition of stream reach metabolism measures will compliment our periphyton sampling.  River metabolism (gross primary productivity and ecosystem respiration) measures identify carbon production rates and use within stream ecosystems and provide a direct estimate of the riverine food base (Young et al. 2008).  As suggested by Young et al. (2008) we propose to employ open-system methods described in:

*Bott, T.L. 2007. Primary productivity and community respiration. Pages 663-690 in F.R. Hauer and G.A. Lamberti, editors. Methods in Stream Ecology. Academic Press, San Diego, CA.*

The salmon carcass analog treatment schedule is not fully explained. The amount of salmon carcass analogs added to the study sites will vary among years so that each site will receive a high, medium, and low treatment level by the end of the study. The reason for this design is not provided in the proposal. The ISRP assumes the rationale for this approach is to ascertain the relative effect of each treatment level on each study reach. However, this design does not

account for the possibility of effects of a treatment carrying into the following year. For example, if a site receives a high level of salmon carcass analogs in year 1 and a low level in year 2, it might be possible that the some of the nutrients associated with the year 1 addition would still be present at the study site and the response in year 2 could represent a cumulative salmon carcass analog addition over two years rather than a response strictly associated with the addition of a low level of salmon carcass analogs. The authors should provide a clearer explanation of the study design as it pertains to the salmon carcass analog treatment schedule and provide some indication of how the results will be interpreted in light of the possibility of cumulative effects.

SBT response (X):

The rationale behind a randomized, variable treatment level whereby each stream receives a high, medium, and low treatment by the end of the study was to represent interannual variability in adult spawner abundance and to investigate a range of nutrient enhancement levels and associated stream food web response.

We agree that cumulative effects from nutrient enhancement are likely to occur.  We also agree that a high treatment, followed by a low treatment (likely to occur under the previous design) would potentially confound interpretation of the low treatment level.  For this reason, we will revise our variable treatment schedule to preserve the high, medium, and low treatment levels such that all randomly assigned levels are maintained within a specific stream for the duration of the treatment period (i.e., 3 years) (e.g., Revised Table 1.).

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

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

A few minor points for clarification:

- Task 3.3 includes the measurement of discharge and the creation of a stage rating curve. A stage curve is only useful if stage height is being recorded but there is no indication in the proposal that stage height recorders will be installed at the study sites. If not, flow measurements at the time when flow-sensitive samples are being collected should suffice.

SBT response (XI):

Yes, the development of a discharge rating curve depends upon consistent measurements of stage and discharge across a range of flow conditions.  We are planning to use staff gauges, stage height measurements, and discharge measurements to develop rating curves.  As stated in our narrative: "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."

What will happen if the salmon carcass analogs are found to contain contaminants?

SBT response (XII):

Salmon carcass analog material will be tested for potential pathogens and contaminants.  If pathogens and/or contaminants are found, then manufacturers will be immediately notified and no treatments will occur until a safe product is available.

If SCA material does not meet strict criterion, then alternative nutrients will be investigated (i.e., inorganic nutrients such as silver bullet or liquid forms).


      3. M&E (section G, and F)

This proposal is for research. All comments above pertain to M&E.

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

## Narrative (<span style="color:blue">200890400 ISRP FAN2:</span> revised narrative proposal)

## Project ID:

**Title:**  EXP Salmon River Basin Nutrient Enhancement

## Table 1.  Proposal Metadata

| Project Number | |
|---|---|
| **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 |
| **Contact Name** | Andre E. Kohler |
| **Contact email** | akohler@shoshonebannocktribes.com |

## 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 growth; macroinvertebrate density, biomass, and community composition; leaf litter decay rates, aquatic food web connections, and the 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. In addition, 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*
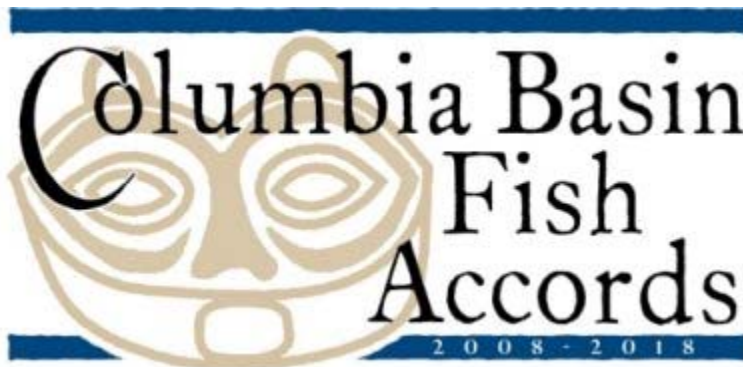


The Columbia Basin Fish Accords are designed to supplement National Oceanic and Atmospheric Administration (NOAA) Fisheries Biological Opinions and NPCC's Fish and Wildlife Program, providing firm commitments to hydro, habitat, and hatchery actions and greater clarity about biological benefits and secure 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 council 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 council 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 subbbasin may be an important component of this approach. The projects 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, it is logical to assume that aquatic and terrestrial ecosystems are limited by available C, N, and P 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 subbbasin.

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<sub>A</sub>: 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, 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):

**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. Data collection and analyses from this body 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 ($\pm$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 study streams in the upper Salmon River subbasin.  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: Yankee Fork Salmon River, Elk Creek (trib. of Valley Creek), Basin Creek, Cape Horn Creek, Slate Creek, Thompson Creek, Squaw Creek, Smiley Creek, Morgan Creek, Carmen Creek, Indian Creek, Squaw Creek, Hayden Creek (trib. of Pahsimeroi River), Big Timber Creek (trib. of Lemhi River), and Panther Creek.  From these prospective streams we will select 9 study streams: 3 control and 6 treatment streams.  Treatment streams will be randomly selected.

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.

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

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

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).

**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 primary productivity and community respiration measures.

River metabolism (gross primary productivity and ecosystem respiration) measures identify carbon production rates and use within stream ecosystems and provide a direct estimate of the riverine food base (Young et al. 2008). As suggested by Young et al. (2008) we propose to employ open-system methods described in:

*Bott T.L. (2006) Primary Productivity and Community Respiration. Methods in Stream Ecology. Edited by Hauer R.F. & Lamberti G.A. Academic Press, San Diego, CA, U.S.A.*

Measures of gross primary productivity and ecosystem respiration will be collected in upstream reference and downstream treatment reaches of all study streams (before SCA additions and ~4-6 weeks after SCA additions).

**Task 3.3** Collect, analyze, and report physical habitat and associated variables including: stream channel slope; mean channel width; mean channel depth; discharge; stage height; 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. Measures of stream channel characteristics (mean width and depth) will be collected in all study streams following methods described in Bain and Stevenson (1999).

**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, survival, and recruits per spawner; 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 $30 \pm 2$ 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, survival, and recruits per spawner 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 as many individual fish as possible for growth rate estimates. 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).

We propose to measure smolt length, weight, condition, age, and production in study streams that have rotary smolt traps (e.g., Yankee Fork Salmon River). In streams that do not have juvenile trapping facilities, PIT tagged fish will be monitored as smolts using automated diversion gates in the juvenile fish bypass system (lower Snake River dams) to separate fish based on PIT tag codes. These fish, PIT tagged as parr in study streams, will be interrogated as smolts, diverted, sampled for length and weight data, and released downstream (Achord et al. 2003).

### 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*

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.

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 bioenergetic assessment of changes in habitat quality pre-and post fertilization 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.

*Net Energy Intake model*

We plan to estimate energy availability to juvenile salmonid fishes 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 this 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, 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 estimates*

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). Juvenile abundance and survival estimates from electrofishing and PIT tagging efforts will be used to estimate smolt production in study streams that do not have juvenile trapping facilities.

*Recruits per spawner estimates*

Natural smolt recruitment as a function of spawner density is an important response variable to consider in nutrient enrichment studies that attempt to increase freshwater productivity and the growth and survival of salmonid fishes (Ward et al. 2006). Under ideal situations, study streams in the upper Salmon River basin would have adult and juvenile trapping/counting facilities that enable precise and accurate measurements of adult escapement and subsequent brood year smolt production. Moreover, these streams would also be at capacity production as suggested by Ward et al. (2006). These criterions are very difficult to meet in the upper Salmon River basin.

Salmon River juvenile salmonid populations may experience density dependence at low population levels, especially those utilizing nutrient-impoverished streams as spawning and rearing areas. Achord et al. (2003), in a study conducted in central Idaho, suggest that juvenile salmon may experience density-dependent mortality at population sizes far below historical levels. And Scheuerell et al. (2005) speculate that a loss of marine derived subsidies has caused a state shift in the productivity of freshwater systems within the Snake River basin, such that strong density-dependent survival is occurring in juvenile salmon populations.

The ability to investigate wild smolt yield as a function of spawners is further confounded by the life history characteristics of juvenile Chinook salmon in the upper Salmon River basin. These fish are considered to be stream-type Chinook salmon and often migrate from natal streams in late summer and fall to overwinter in larger, downstream riverine habitats (Healey 1991), initiating seaward migrations during the following spring as age 1+ smolts (Folmar and Dickhoff 1980). The presumption has been that downstream habitats offer more productive rearing conditions. A significant amount of data across the Salmon River basin indicates that large proportions (the majority) of brood year migrants emigrate from Salmon River basin streams as summer and fall parr. Therefore, it is important to measure both parr and smolt characteristics in study streams in the upper Salmon River subbasin.

The present study will use the Yankee Fork Salmon River (YFSR) to evaluate the effects of natural and volitional releases of spawning adult Chinook salmon on stream food web

response variables.  Importantly, the SBT operates a temporary adult Chinook salmon weir and a juvenile rotary screw trap in the YFSR.  These monitoring and evaluation facilities are fully funded under the Lower Snake River Compensation Plan and operated by the SBT Yankee Fork Salmon River Supplementation Program.  The project sponsors will take advantage of these facilities to derive recruit/spawner estimates as suggested.

In study streams without adult trapping facilities, adult escapement will depend upon redd count data and associated estimates of the number of adults per redd.  And as mentioned above, in streams without juvenile trapping facilities, parr population abundance and associated downstream survival estimates will be used to estimate smolt production from study stream reaches.  And smolt characteristics such as length, weight, and condition will be collected at downstream (i.e., Snake River interrogation facilities) sites as needed.

*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 5.1** 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.

*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 mimics 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 | | B, C, D |
| CPOM retention | Once | | A, B, C |
| 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] | B, C, D |
| Nutrient limitation (NDS) | Once | Once | A, B, C |
| Primary productivity | Once | Once | A, B, C |
| Leaf decomposition | | Once | A, B, C |
| Periphyton variables | Once | Once[3,4] | B, C |
| Macroinvertebrate variables | Once | Once[3,4] | B, C |
| Fish variables | Once | Once[3,4] | B, C, E |

[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; E = downstream interrogation sites (e.g., rotary screw traps and/or lower Snake River dams)
[2] Dissolved nutrients sampled immediately before, 2, and 4 weeks after SCA additions
[3] Samples collected ~30-42 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 before SCA additions, during SCA treatment in August-October, 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.

By comparing responses in replicate experimental streams distributed across the upper Salmon River basin, our study will attempt to capture and document the range of expected responses to nutrient enhancement across a large geographic area designated as critical habitat for Pacific salmon and steelhead ESU's.  Based on these data, a larger scale assessment of historic spawning streams in Idaho could then use these baseline data to determine the likely response to nutrient additions in other streams.  Results gathered from these investigations will provide the foundation for an adaptive management approach to the design of larger scale pilot or full implementation projects using SCA applications as an interim management tool to increase the freshwater productivity of upper Salmon River streams.

## *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.

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## J. Key personnel

**Andre E. Kohler, Fish and Wildlife Department, The Shoshone Bannock Tribes, P.O. Box 306, Fort Hall, ID, 83202. tel: 208-239-4566, email: akohler@shoshonebannocktribes.com**

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:

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

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:

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|---|---|
| 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)
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Imre, I, Grant, J.W.A., & **Keeley, E.R.** (2004) The effect of food abundance on territory
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