Study 35

Floodplain Production Study

Public Draft
2014 Monitoring and Analysis Plan

SAN JOAQUIN RIVER
RESTORATION PROGRAM

September 2013

DRAFT: San Joaquin River Restoration Plan Floodplain Production Study Statement of Work

1. BACKGROUND

Two primary goals of the San Joaquin River Restoration Program (SJRRP) are: (1) Restoration Goal – To restore and maintain fish populations in "good condition" in the main stem San Joaquin River below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish, and (2) Water Management Goal – To reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the Interim Flows and Restoration Flows provided for in the Settlement.

The SJRRP is an ambitious undertaking to restore 153 miles of salmonid habitat including rearing and migration environments for juvenile spring and fall-run Chinook salmon. To achieve the Restoration Goal, the SJRRP will implement a combination of channel and structural projects along the San Joaquin River, restoration of an annual flow regime through water releases from Friant Dam, and fish reintroduction. Projects include modifications to channel capacity and incorporating floodplain habitat. The SJRRP Fisheries Management Plan (2010), which provides an adaptive framework to meet the Restoration Goal, identified an objective for the SJRRP to provide suitable habitat for all freshwater Chinook salmon life stages during a variety of water year types, and restore habitat for spawning, rearing, and migration of native species, including salmon, during winter and spring.

In 2012, a modeling exercise using the Emigrating Salmonid Habitat Estimation (ESHE) model and a two-dimensional hydraulic model (SRH-2D) was undertaken to estimate the range of habitat area required to support Chinook salmon rearing and emigration through the restoration reach. However, several key uncertainties still exist as they relate to the flow regime and configuration of floodplain habitat.

Overall Research Question

The purpose of this study will be to identify habitat characteristics and floodplain inundation regimes that can best support SJRRP salmonid rearing objectives.

To support this objective, we must further:

- *Identify when and how ephemeral floodplain habitat can be developed and managed to maximize benefits to juvenile Chinook salmon in support of the Restoration Goal;*

- *Define and identify suitable rearing habitat considering connectivity with the channel, seasonal temperature, and inundation (timing, duration, pulsing) as criteria;*

- *Develop and prioritize cover types as habitat criteria, and;*

- *Evaluate invertebrate (or other food) production specific to the San Joaquin River to better understand biological processes that will contribute to food supply (April-March*

> *time frame), ecosystem processes, and incremental contribution of floodplain inundation on downstream water temperatures (March-April time frame).*

1a. Concepts Relating Chinook Salmon and San Joaquin River Rearing Habitat
Central Valley Chinook salmon have evolved to take advantage of low elevation floodplain habitat during the juvenile rearing phase of their life history. While virtually no direct observations are available from pre-mining and flood management periods for these habitats, recent research demonstrates significant use and benefits to juveniles when floodplains activate for the appropriate times and durations and salmon are available to use them (Jeffres et al. 2008; Sommer et al, 2001). Because salmon are poikilothermic, it is thought that the combination of highly productive floodplain habitat, relatively warm water temperatures, and avoidance of inhospitable environments, such aquatic predators, turbidity and high flows, generate high survivorship and growth of juveniles.

Based on the research listed above, our hypothesis is that these processes will also be an important part of the restored San Joaquin River. Developing the appropriate amount and type of seasonal habitat and operating it at the appropriate time is paramount to the success of this endeavor.

While only limited information exists from other systems and salmon have only been released in small test groups during a period when the SJR is still disconnected, how juvenile SJR salmon will respond and benefit from ephemeral floodplain habitat is still open to debate. It is also clear that temperature and flow will likely be limiting factors that must be addressed for a successful project. It will be important for us to have a clear understanding of the Chinook salmon life stages that will be present within the SJR, how they will use available habitat, and how management will affect these relationships. In turn, it will be of paramount importance to identify when and how water release and habitat creation/enhancement can best benefit juvenile salmon due to the limitations of temperature and available water.

2. METHODS

2a. Conceptual Model

Several components of floodplain inundation can influence juvenile Chinook salmon. Because of the relatively shallow and rough (increased Manning's N) nature of floodplains in relationship to the main channel and the poikilothermic nature of salmon, floodplains and secondary channels can: (1) increase primary productivity through reduced solar attenuation (reduced turbidity, increased percent of water within the photic zone and increased irradiation of benthic habitat), increased water residence time and overall increased activated (wetted) habitat (Figure 1) and (2) provide quality rearing habitat for juvenile salmon which can offer refuge from relatively high velocities, turbidity, aquatic predators, and increased growth through relatively warmer temperatures and the potentially greater food available.

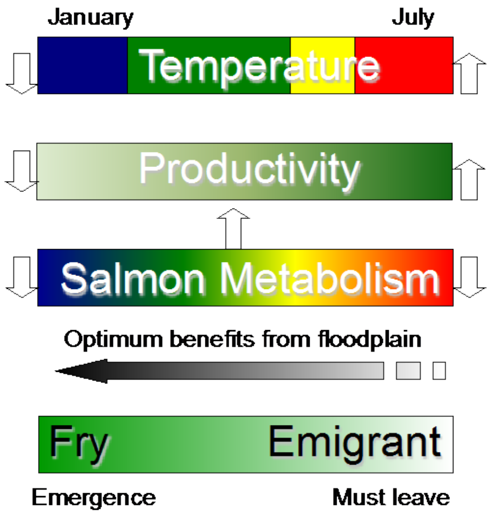

Figure 1. Expected trade-offs in juvenile salmon benefits over the entire rearing period.

Because juvenile Chinook salmon tend to migrate at two distinct stages (Figure 1), changing floodplain conditions over this time may have significantly different population effects (Figure 2).

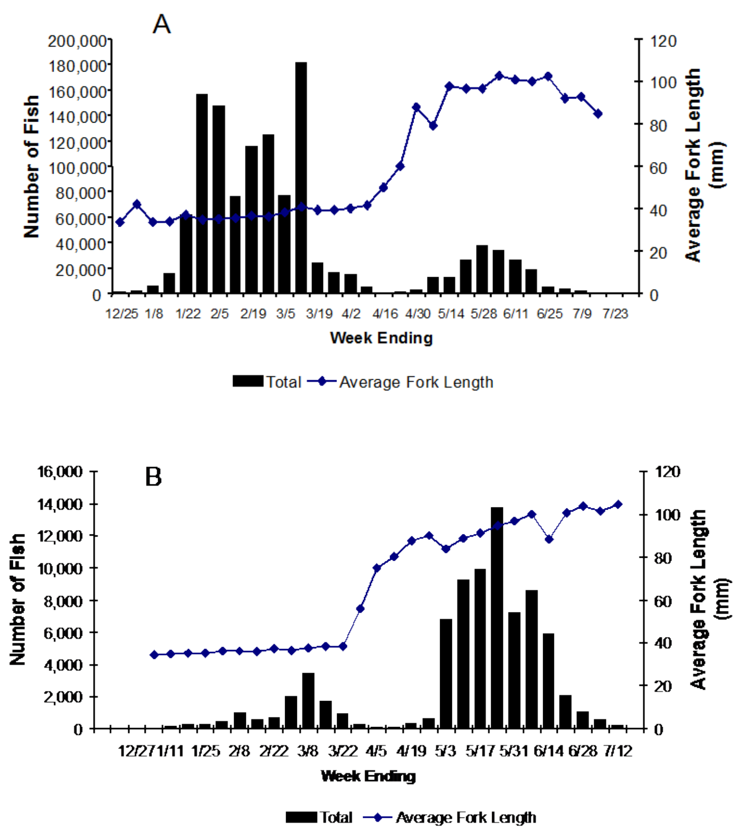

Figure 2. Examples of variable timing for fry and smolt emigrant pulses estimated from daily catch estimates at two rotary screwtraps on the lower Mokelumne River, California; A. 2005-2006 emigration period; B. 2001-2002 emigration period.

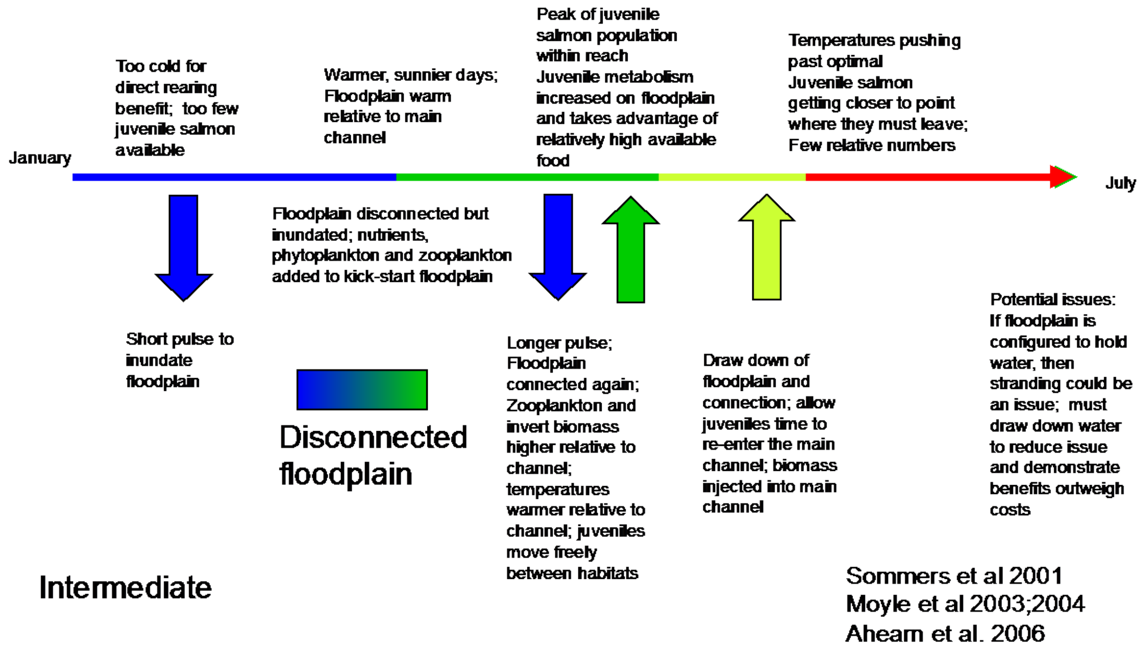

Figure 3. Direct and indirect benefits hypothesized to occur from floodplain inundation over the juvenile salmon rearing and emigration period.

In particular, if floodplains activate too early, juveniles may not be available in sufficient numbers for habitat to be beneficial or air temperatures may be so cool that floodplains may actually impede juvenile growth. Conversely, if habitats activate too late, there may also be too few juveniles to utilize the habitat, they may be beyond the period of benefit (already smolting and must leave) or temperatures may be too warm to benefit or may actually be a detriment. Under these scenarios, secondary habitat evaluation is a gaming exercise where different periods of activation may benefit, be neutral or a deficit to juvenile salmon production.

Other key components within the conceptual model include where within the longitudinal gradient of the channel secondary habitat is floodplain most beneficial, and how well do components of cover (well described in higher gradient mainstem habitats) translate to the floodplain environment for rearing Chinook salmon.

A long-term study (3-5 years) is recommended given the propensity for inter-annual variation in water availability (which will dictate SJRRP managed flows) and associated variation in spring temperature regimes, fish populations, and food web components to inform this model. Shorter-term studies create the risk of producing results that are idiosyncratic to a particular water year and virtually useless to forecast or predict Chinook salmon responses to river and floodplain management.

2b. Sampling Design and Statistical Approaches

The overall approach will be guided by sound statistical and experimental design principles that can best guide SJRRP management. Caution will be taken to design monitoring and experimental hypotheses that are not severely hampered by logistical constraints, such as the number of available fish or floodplains available for manipulation. For example, these two variables may not be known with certainty during the first year of the project. Early scoping projects, discussions with SJRRP directors, and literature reviews will help to inform the fine tuning of the approaches in the tasks outlined below. The initial study year will be very informative and assist with better understanding the logistical limitations of the study area.

Plans for monitoring and experimental designs in the defined tasks will strive for high replication and strong treatment effects. Focusing on too many treatment effects may reduce within-group replication and the power of experimental designs. The designs will follow careful consideration of statistical models; for example, floodplains and perhaps years will be random effects, but other effects will likely be nested within or above these effects (such as flood pulses). Many of the targeted treatments and treatment levels in the tasks will not be possible in all combinations (e.g. not factorial), yet interactions could be important and thus will be tested in statistical models where appropriate. The statistical models and hypotheses will be open to evaluation by model comparison approaches and not limited solely to null hypothesis testing which can be compromised by the statistical power of designs with low replication. The former approach is typically more informative in that there is a focus on effect size of a given treatment rather than statistical significance.

3. DELIVERABLES:

- *Presentation of preliminary results for Restoration Goal Technical Feedback*
- *Annual Reports*
- *Final Comprehensive Report*
- *Documentation of:*
    - *Presentation citations & abstracts*
    - *Student products (Independent Study reports, Theses)*
    - *Publications in peer-reviewed journals*

(See Project Schedule in Section 5)

4. TASKS

TASK 1. Influence of floodplain inundation timing

Background

For floodplains to provide a productive rearing environment, the timing of flow pulses must coincide with appropriate temperatures and fish life stages (Junk et al. 1989; Bayley 1991). If flows are decoupled from fish life cycles and physiological drivers (e.g. temperature), the advantage of floodplain inundation is largely lost (King et al. 2003). Juvenile fall-run Chinook salmon rear from approximately January until the physiological transformation to smolt occurs. For spring-run, this may shift approximately 1-2 months earlier with a small percentage (estimated 10%) remaining in the upper reaches and migrating as yearlings the following year. Flood pulses early in this rearing period would provide opportunities for the greatest number of fish; however, temperatures may be too low to provide a growth advantage. Temperatures later in period may be better for growth however once fish have become smolts, their behavior changes from rearing to actively migrating toward the ocean and floodplain inundation during this period may be of less utility. Furthermore, temperature within the lower San Joaquin River may be a limiting factor by mid-April in some years, compressing the rearing period for what is acknowledge in typical Central Valley streams. Thus, it is essential to quantify the tradeoffs between an early vs. late season pulse to maximize Chinook salmon productivity (Figure 4).

Hypotheses / Questions

Question 1:

Will floodplains inundated early (February) yield survival and growth benefits (comparable to later inundation (May)?

Null Hypothesis 1:

Floodplains inundated early will not yield survival and growth rates comparable to later periods of inundation.

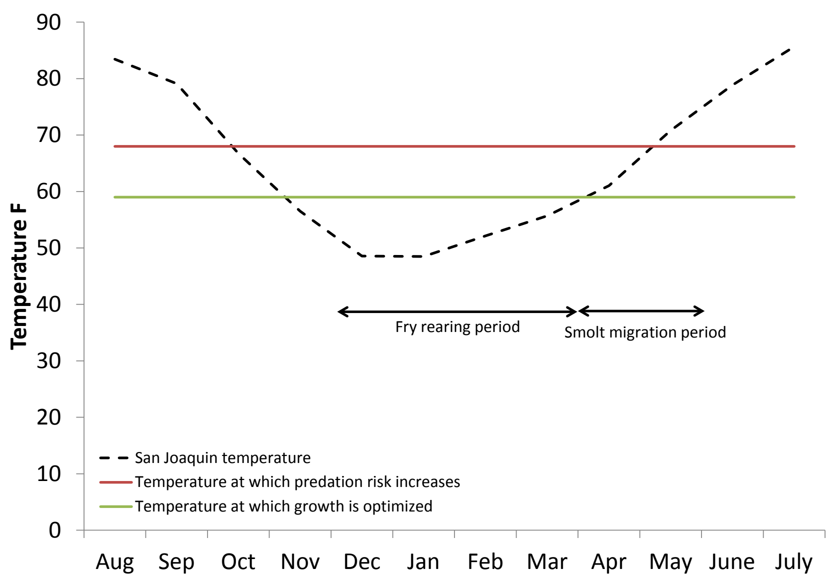

Figure 4. Conceptual model of temperature and salmon life history in the San Joaquin River. From January through March temperatures are increasing toward the optimum for Chinook salmon. The most abundant Chinook life stage during this period is rearing fry. From April through May temperature is increasing toward 68 F where predation susceptibility increases (Myrick and Cech 2004). During this period, smolts are the most abundant life stage and these fish are actively migrating toward the ocean.

Methods

Establish sets of ‘early / late’ floodplain habitats within study reaches. Through a series of net pen, tagging, otolith microstructure (see Limm and Marchetti 2009), and underwater video experiments, we will track growth and preferential use of main stem versus adjacent floodplain use (behavior, feeding, growth) by juvenile Chinook salmon. Several trials will be performed in the designated “early” versus “late” periods to identify trade-offs in growth, survival and habitat inundation timing.

Early Inundation – Establishing ‘early’ floodplain habitats. Tests the assumption that juvenile Chinook salmon will use and benefit from floodplain habitats (set up territories, feed, grow) as soon as they are available (e.g. February) and benefits above and beyond main channel habitat use will be accrued.

Late Inundation – Establish ‘late’ floodplain habitats. Allows for semi-independent assessment of whether juvenile Chinook salmon select floodplain habitats based on timing (when available) or duration of inundation.

How will Task 1 inform SJRRP management? – The timing and duration of floodplain inundation will likely require alteration to SJRRP flow management. SJRRP water releases serve multiple purposes and impact many stakeholders. A major objective of this study is to maximize the efficacy of water releases stipulated in the Settlement Agreement to maximize juvenile Chinook salmon survival and growth by providing high-quality floodplain habitat and provide strong scientific information to support adaptive management.

TASK 2. Periodicity of Floodplain Hydrology

Background

Duration- To maximize the benefit of floodplain inundation with limited water resources, it is essential to understand the duration of flooding required to provide growth and survival benefits. If inundation is too short, there is insufficient time for productive floodplain food webs to develop and little benefit is achieved (Humphries et al. 1999). However, prolonged inundation can result in diminishing returns for the amount of water needed to maintain floodplain connectivity. Additionally, water quality problems can develop when extended inundation coincides with high temperatures. Estimating optimum flood duration is needed for the San Joaquin River to provide benefits for Chinook salmon with finite water resources.

Pulsing- Reconnecting floodplain habitat in a regulated watershed presents unique challenges for creating conditions similar to natural systems, especially with limited water resources. To obtain benefits of floodplain rearing for Chinook salmon while minimizing water use, it may be possible to use pulsed rather than constant floodplain connectivity (Ahearn et al. 2006). This strategy would use an initial, early pulse to inundate floodplains. Flows would then be reduced and standing water would be allowed to initiate primary and secondary production on the disconnected but inundated floodplain. A second pulse would then be used to reconnect the floodplain, allowing juvenile salmon to access the productive waters of the floodplain. During the receding hydrograph, juveniles would return to the channel to complete their migration, along with productive waters from the receding floodplain. However, with little data to support this strategy, direct quantitative evidence is needed prior to implementation.

Hypotheses / Questions

Question 2.1:What is the relationship between length of floodplain inundation and juvenile salmon growth and survival?

Null Hypothesis 2.1:The length of floodplain inundation has no relationship to growth and survival benefits for Chinook salmon.

Question 2.2: Will pulsed or sustained water deliveries to floodplains yield greater survival and growth benefits?

Null Hypothesis 2.2: Pulsed water deliveries will not yield benefits comparable to sustained water deliveries

Methods

Through a series of net pen, otolith microstructure, tagging, and underwater video experiments, we will track growth and preferential use of floodplains (behavior, feeding, growth) by juvenile Chinook salmon under pulsed versus sustained water deliveries. Several trials will be performed at sites inundated under the different hydrological regimes to identify trade-offs in growth and survival.

How will Task 2 inform SJRRP management? –SJRRP water releases serve multiple purposes and impact many stakeholders. Furthermore, the water available and the temperature regime expected will greatly influence the ability to successfully create viable floodplain habitat. A major objective of this study is to optimize water releases that maximize juvenile Chinook salmon benefits from floodplain habitat and provide strong scientific information to support adaptive management.

TASK 3. Floodplain habitat attributes -Morphological, physical, and structural complexity

Background

Floodplains are diverse ecosystems composed of a patchwork of different substrate and habitat types (Amoros and Bornette 2002). Understanding how growth and survival of juvenile Chinook salmon is related to floodplain habitat type is needed to guide land acquisition and habitat restoration and enhancement. We know that cover (e.g., woody debris, undercut banks, vegetation), water depth, and velocity are important components of overall juvenile salmon rearing habitat quality and carrying capacity (Bjornn and Reiser 1991). Unfortunately, most studies informing our understanding of habitat attributes come from mainstem environments in relatively high grade, alluvial streams. It is unclear how well these parameters translate to low-gradient, floodplain habitat.

Hypotheses/ Questions

Question 3.1: Will the addition of structural complexity, including the placement of woody material, variable plant communities, and secondary channels, have an effect on the growth and survival of juvenile Chinook salmon in the restoration reach?

Null Hypothesis 3.1: Habitat complexity has no relationship to Chinook salmon growth and survival benefits.

Methods

Physical habitat- Through a common garden experiment, test floodplains will be graded to inundate at varying depths (see Keeley and Slaney 1996 for acceptable ranges) during scheduled flood releases and populated with a range of cover types. During inundation periods, water velocity and depth in test floodplains will be measured across no less than three transects perpendicular to flow. Flow and depth patterns will be re-assessed with each change in floodplain hydrology, and compared to discharge patterns in the adjacent river main channel. Transect measurements will also include percent cover (e.g. as vegetation, logs, etc.). River main channel flows will be measured directly under wadeable conditions, or otherwise will use calculations derived from overall discharge (from CA DWR CDEC data) and main channel cross-sectional area.

Floodplain water temperatures will be obtained from continuously deployed HOBO Tidbit temperature loggers. Prior experience has demonstrated strong vertical temperature gradients (especially in low-flow habitats). Therefore temperature loggers will be placed at floodplain surface and bottom positions using floats and anchors.

Fish habitat preferences- Through a series of common garden experiments using net pen, otolith microstructure, tagging, snorkeling and underwater video experiments, we will track growth and preferential use of main stem versus adjacent floodplain (behavior, feeding, growth) by juvenile Chinook salmon. Observations and experiments will target physical habitat differences within floodplains (e.g. depth, flow, structure) to identify trade-offs in growth, survival and habitat use.

How will Task 2 inform adaptive management? –It is hypothesized that habitat quality (e.g., complexity, heterogeneity) has a strong influence on habitat carrying capacity and therefore the area required to support a given population of fish. This has significant implications for habitat management and overall costs of long-term habitat development, maintenance, and management, including multiple land-use scenarios for future floodplains.

TASK 4. Floodplain Food Webs

Hypotheses/ Questions:

Question 4.1: Do adjacent river and floodplain food webs consistently differ during floodplain inundation periods?

Null Hypothesis 4.1: Food webs will not differ between the river mainstem and floodplain habitats

Question 4.2: Are inter-floodplain food web differences related to floodplain management actions?

Hull Hypothesis 4.2: Food webs will not differ across floodplain habitats and floodplain management actions.

Background

The organic matter sources in floodplains are likely to vary based on variables such as existing terrestrial vegetation, soils (nutrient storage), inundation depth, water clarity and especially flooding duration. Organic matter retention and production in floodplains is also likely to be affected by connectivity with the river main channel. This task aims to inventory floodplain organic matter sources and consumers. Sampling and analyses will be conducted to best determine whether food web constituents are ‘autochthonous’ versus ‘allochthonous’. Autochthonous organic matter is produced within the floodplain, such as periphyton and decaying pre-inundation terrestrial plant litter. Allochthonous organic matter will be considered as material that is imported from the river while hydrologically connected to the floodplain. Both would likely increase with flooding duration.

Methods

Organic matter- Organic matter from floodplains and the river main channel will be collected, sorted, and processed for analysis of stable isotope ratios of C and N. Resolving food webs from stable isotope signatures relies upon the ability to discriminate organic matter sources based on the ratios of ^{13}C:^{12}C and ^{15}N:^{14}N ($\delta^{13}C$ & $\delta^{15}N$ respectively). Recent sampling from SJRRP Reach 1A-B has shown us that periphyton, seston, FPOM, and CPOM have very distinct $\delta^{13}C$

and $\delta^{15}N$ signatures. Initially, floodplain organic matter may reflect the influence of C and N stable isotope ratios imported from the river as seston and inorganic C and N. Longer periods of floodplain inundation will likely cause divergence in the stable isotope signatures of organic matter, as floodplain organic matter decomposes and liberates terrestrially-derived C and N, and as autochthonous periphyton and phytoplankon develop in the floodplains. Therefore, organic matter samples will be taken at early and late periods of floodplain inundation. Additional interim sampling may be included depending on resources and logistical constraints.

Consumers-Invertebrates- Invertebrate consumers will be collected concurrently with organic matter and processed for determination of $\delta^{13}C$ and $\delta^{15}N$ signatures. Published information on consumer feeding habits and isotope mixing models will be used to estimate the proportions of invertebrate C and N from the various organic matter sources. River invertebrates will be sampled with combinations of drift and plankton nets, and D-frame nets in wadeable areas. Prior sampling has demonstrated that river invertebrate diversity is very low and dominated by baetid mayflies.

The import of river invertebrates to floodplains will be assessed with drift nets placed at water inputs to floodplains. Floodplain invertebrates will be sampled primarily with D-frame nets using either current delivery or active sweeps of substrate. Invertebrate assemblages will be compared across floodplains as well as between floodplains and the adjacent river main channels using ANOSIM and indirect gradient ordination procedures.

Juvenile Chinook Salmon- The position of juvenile Chinook salmon in floodplain food webs can be determined through diet analysis and/or stable isotope signatures of fast-turnover tissue such as blood plasma or fins. If abundant in floodplains, juvenile Chinook salmon will be sampled from floodplains soon upon floodplain inundation in order to determine a baseline stable isotope signature. Secondary samples will be taken if fish are determined to reside in floodplains for at least 30 days. Otherwise, diet and tissue samples will be taken from juvenile Chinook salmon used in cage experiments as described in an earlier task.

How will Task inform adaptive management?- Management of floodplain hydrology and physical attributes will likely alter floodplain habitats leading to variation in organic matter and invertebrate consumer assemblages. It is likely that there will be an interaction, such that alterations to the physical habitat (such as grading for depth variation & adding vegetation) will produce stronger effects over longer vs. shorter inundation periods. However, monitoring and experiments are needed to best quantify the variables accounting for increased secondary production and thus prey for juvenile salmon.

TASK 5. Floodplain Production: Energy Pathways to Salmon

Background

Efficient floodplain management and juvenile Chinook salmon production may be intricately linked through fish energy budgets. Prior research demonstrates that juvenile salmonids can survive and grow better in floodplains compared to river main channels. However, much less is known about the factors which link floodplain hydrology and physical factors with juvenile salmonid production. Floodplain hydrology can influence water temperature and currents.

Complex floodplain habitat (e.g. cover/vegetation) in concert with higher water temperatures can also foster increased prey abundance and production. These core variables act directly on the energy balance of fish.

Warmer floodplain temperatures (up to a point) relative to the river main channel allow more efficient fish metabolism, and reduced water currents alleviate the energy needed to maintain position or navigate compared to main channel flows. In this project we therefore advocate a bioenergetics-based approach to estimating the influence of these core floodplain variables on juvenile Chinook salmon survival and growth.

Hypotheses/Questions:

Question 5.1: How does production in floodplains vary with inundation timing & periodicity, floodplain physical characteristics, and complexity/cover?

Null Hypothesis 5.1: Floodplain production does not vary across floodplains.

Question 5.2: What are the most important factors affecting floodplain production over time?

Null Hypothesis 5.2: Floodplain production is constant over time.

Question 5.3: Does floodplain (secondary) production predict juvenile Chinook biomass and production? Is juvenile Chinook salmon energy demand met by floodplain secondary production?

Null Hypothesis 5.3: Juvenile Chinook salmon growth is independent of floodplain production.

Methods

Organic matter biomass & production- Organic matter biomass will be determined as mass/area across transects within floodplains. Samples will particularly target areas that vary in depth. Litter bag experiments can be used to determine the breakdown rate of detritus, and thus it's potential incorporation into the floodplain food web. Measurements of chlorophyll *a* will be used to generate ratios of photosynthetically active organic material to detritus. Primary production experiments using clear and dark enclosed chambers will be used to estimate primary production based on net oxygen generation.

Secondary production (invertebrates)- Secondary production by invertebrates will be estimated from samples described in Task 4 and water temperature measurements. Identification of invertebrate taxa, body size, and temperature are sufficient variables to estimate production rates. Production rate estimates will be improved by using cohort-summation methods over multiple sample events. Samples from drift nets to quantify the import of drifting invertebrates will be calculated separately as allochthonous sources of floodplain production. Terrestrial insects that alight on floodplain surface waters may also be considered potential prey for fish. This input source will be quantified with pan traps.

Juvenile Chinook salmon production- The measurements and estimates of floodplain habitat variables in this and prior tasks will allow for calculations of the production potential of juvenile

Chinook salmon. These calculations will be estimated from a combination of fish bioenergetics and habitat models. These estimates can be compared to actual juvenile Chinook salmon growth either from free ranging fish or those used in net-pen experiments described in a prior task.

How will Task inform adaptive management?

Floodplain management options are outlined in the prior tasks. A food web and bioenergetics approach aims to characterize the mechanistic links between floodplain management and juvenile Chinook salmon production.

5. SCHEDULE

The following table outlines the objectives for project initiation, completing the five defined tasks, as well as presentation of results and feedback.

Annual reports are scheduled after the initial project year. Reporting will also include presentation of preliminary results, Restoration Goal Technical Feedback Annual Reports and a final comprehensive report.

Other results-oriented products may be produced as opportunities arise. We will provide documentation of project results developed as:

- *Presentation citations & abstracts*
- *Student products (Independent Study reports, Theses)*
- *Publications in peer-reviewed journals*

	2013				2014				2015				2016				2017	
OBJECTIVE	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2
Kick off meeting																		
Reconnaissance/ Preparation																		
Identify potential floodplains																		
Permit acquisition																		
Floodplain manipulation																		
Task 1. Influence of floodplain inundation timing																		
Obtain fish																		
Field preparation																		
Run experiment																		
Data analysis and reporting																		
TASK 2. Periodicity of Floodplain Hydrology																		
Obtain fish																		
Field preparation																		
Run experiment																		
Data analysis and reporting																		
TASK 3. Floodplain habitat attributes																		
Obtain fish																		
Field preparation																		
Run experiment																		
Data analysis and reporting																		
TASK 4. Floodplain Food Webs																		
Field preparation																		
Run experiment																		
Data analysis and reporting																		
TASK 5. Floodplain Production																		
Field preparation																		
Run experiment																		
Data analysis and reporting																		
Presentation of Preliminary Results																		
Technical Feedback																		
Annual Reports																		
Final Comprehensive Report																		
Publications																		