QUANTIFYING THE BENEFITS OF RIVER RESTORATION FOR CHINOOK SALMON ON THE LOWER YUBA RIVER

A group project submitted in partial satisfaction of the degree of
Master of Environmental Science and Management
for the
Bren School of Environmental Science & Management,
University of California, Santa Barbara

by

JO ANNA BECK
NATHAN BURROUGHS
LEAH GONZALES
ALYSSA OBESTER
ELIJAH PAPEN

Faculty Advisor:
DR. DEREK BOOTH

MARCH 2017

Quantifying the Benefits of River Restoration for Chinook Salmon on the Lower Yuba River

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

Jo Anna Beck

Leah Gonzales

Nathan Burroughs

Alyssa Obester

Elijah Papen

The Bren School of Environmental Science & Management produces professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principal of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and an awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Dr. Derek Booth

DATE

Acknowledgements

We would like to extend our gratitude to the many individuals that contributed to this project. First and foremost, we would like to thank our faculty advisor, Derek Booth, for his expertise and guidance. Additionally, we would like to thank the following people who provided assistance by sharing their knowledge, time, and resources.

External Advisors

Gary Libecap, Professor of Economics, UC Santa Barbara
Allison Horst, Faculty at UC Santa Barbara
Joseph Merz, Cramer Fish Sciences; Professor, UC Santa Cruz

PhD Mentor

Alexa Fredston-Hermann

Client

Rachel Hutchinson, South Yuba River Citizens League

Abbreviations

AFRP — Anadromous Fish Restoration Program
BCR — Benefit-Cost Ratio
BLM — Bureau of Land Management
BMI —Benthic Macroinvertebrates
CDWF — California Department of Fish and Wildlife
DO — Dissolved Oxygen
DOC — Dissolved Organic Carbon
EPA — Environmental Protection Agency
EPT— Ephemeroptera, Plecoptera, Tricoptera
ESA — Endangered Species Act
ESA — Environmental Science Associates
ESU — Evolutionarily Significant Unit
FEMA — Federal Emergency Management Agency
LWD — Large Woody Debris
MU — Morphological Unit
NMFS — National Marine Fisheries Service
NOAA —National Oceanic and Atmospheric Administration
ODEQ — Oregon Department of Environmental Quality
SRI — Silica Resources, Inc.
SSI — Sierra Streams Institute
SWRCB — State Water Resources Control Board
SYRCL — South Yuba River Citizens League
TSS — Total Suspended Solids
USACE —United States Army Corps of Engineers
USFWS — United States Fish and Wildlife Service
USGS — United States Geological Survey
WTP — Willingness to Pay
YCWA — Yuba County Water Agency

List of Tables and Figures

TABLES

FIGURES

Table of Contents

Abstract

The Yuba River has experienced over a century of anthropogenic modification, particularly gold mining and dam construction, which have significantly impacted native aquatic and riparian species. In particular, Chinook salmon (*Oncorhynchus tshawytscha*) have experienced dramatic declines in numbers. While a variety of restoration projects have been conducted on the Lower Yuba River, no efforts to date have sought to quantify the economic benefits associated with restoration, leading to a potential undervaluation of benefits. To address this knowledge gap, the objectives of this study were to 1) characterize current water quality, ecological, and physical conditions of the river; 2) quantify the local and regional monetary benefits of a restored river landscape; and 3) compare costs and benefits across various temporal scales. We developed a "report card" to characterize current river health. We also utilized four economic methods to quantify the benefits associated with river restoration. If Chinook salmon populations in the Lower Yuba River are doubled through restoration, the results of our analysis indicate that benefits total $63 million. These benefits outweigh the costs of restoration in several of the scenarios that were considered. Results also indicate that the favorable outcome of the benefit-cost ratio is critically dependent on actual project costs. The methodologies laid forth in this study provide river scientists and managers with a framework for quantifying benefits that can aid in project comparison and selection and can help garner support and funding for future restoration work.

Executive Summary

The Yuba River Watershed once supported a thriving population of Chinook salmon. However, major anthropogenic alterations to the river system have deteriorated aquatic habitat and significantly diminished the abundance of Chinook salmon and other aquatic species. The discovery of gold in the Sierra Nevada foothills in 1848 spurred an era of intense environmental degradation. Hydraulic mining mobilized large volumes of sediment from mountainsides, increasing turbidity and overbank sediment deposition downstream. Mercury, used to extract gold from sediment, was mobilized and transported in downstream alluvium**.** This excess sediment and contaminated material warranted economic and public safety concerns which led to the construction of Englebright Dam in 1941. The dam prevented any further damage by trapping solid material in a newly created reservoir. Still, excess sediment deposited along the Lower Yuba River prior to Englebright Dam's construction altered the channel morphology, destroying native riparian vegetation and reducing off-channel juvenile Chinook salmon rearing habitat. Additionally, the dam has disconnected the lower river reaches from the upstream watershed, has altered the natural flow regime, and prevents salmon from migrating to their historical spawning grounds. Many native species have been adversely impacted, including Chinook salmon, whose populations have dramatically declined from their historic size.

In recent years, river restoration projects have attempted to increase salmon populations by improving habitat quality. Several projects on the Lower Yuba River have already been implemented, with additional proposed projects planned, designed, and awaiting approval. Within the last decade, restoration work has been conducted by the U.S. Army Corp of Engineers, the Yuba County Water Agency, and the South Yuba River Citizen's League. Restoration projects are focused on ecological improvements, but little work has been to understand the economic benefits associated with river restoration.

Healthy river systems can provide economic benefits to humans, broadly known as ecosystem services. Such river-based ecosystem services include recreational opportunities, improvements in surrounding aesthetics which increase property values, carbon sequestration, clean water, groundwater recharge, and flood-risk reduction. Although many benefits manifest from a restored river, these benefits are rarely quantified by agencies undertaking restoration work. Costs of restoration are known but the benefits of restoration are usually only qualitatively understood. For this reason, it can be difficult to raise funds, foster public support, or adequately compare project alternatives when monetary benefits are unknown. Therefore, formal economic analyses of costs and benefits can be powerful tools in helping justify future restoration efforts.

The primary objective of this study was to quantify the benefits of river restoration for Chinook salmon on the Lower Yuba River, and to compare those quantified benefits to

predicted project costs. In order to complete this task, an understanding of current conditions was required to identify limiting factors to Chinook salmon population growth. We developed an ecosystem health report card to identify thresholds for good, fair, and poor conditions in relation to Chinook salmon habitat and their physiological requirements. With this report card, combined with the current knowledge that the juvenile life stage is widely judged to be the limiting life stage of Chinook salmon on the Lower Yuba River, we then identified restoration strategies with the greatest potential to address habitat limitations of critical importance to the viability of the population.

We examined a range of restoration outcomes and resulting population increases. We used a restoration target of doubling the Fall-Run Chinook salmon population in the Lower Yuba River relative to current numbers, in accordance with targets set by U.S. Fish and Wildlife's Anadromous Fish Restoration Program (AFRP) for Central Valley streams. To calculate benefits associated with this target increase in Chinook salmon population, we utilized four well-documented methodologies to quantify the benefits of restoration: a fishery valuation, a travel cost analysis, a carbon sequestration analysis, and a hedonic property analysis. Our results indicated that restoration generates millions of dollars in annual economic benefits, with most benefits accrued from the in-river fishery. These benefits outweighed restoration costs under scenarios where project costs were low and adult salmon population increases were high. Our findings demonstrate the importance of accurately determining project costs for identifying favorable benefit-cost ratios. The wide range of costs was a key determinant in the final outcome of our cost-benefit ratios, and thus whether or not a project was economically viable.

In conclusion, using appropriate economic methods to quantify the benefits of river restoration can result in substantial economic returns that can outweigh project costs. Our work also highlights the need to better understand current conditions of the river system prior to restoration strategy selection. Most importantly, our work serves as a useful framework for quantifying the benefits of river restoration that can help river scientists and managers justify, in economic terms, why river restoration is economically beneficial.

Significance

The Yuba River watershed once supported thriving Chinook salmon populations; however, a history of significant human alteration beginning in the mid-1850s has caused a variety of physical and ecological impacts. During the California gold rush, hydraulic mining activities caused large volumes of sediment to be transported and deposited in the lowermost reaches of the river. Mercury was used in the hydraulic mining process, which resulted in the contamination of river sediment. The magnitude of mercury-contaminated sediment moving downstream through the Lower Yuba River ultimately motivated the construction of Englebright Dam, twenty-four miles upstream of the confluence of the Feather River, to protect downstream settlements and ecosystems from contaminated sediments and flooding. In the process, the Lower Yuba River was essentially disconnected from the rest of the watershed, resulting in an altered flow regime, changes in sediment transport, and an overall degraded ecosystem unable to support native flora and fauna. These cumulative physical transformations of the Yuba River have significantly damaged much of the habitat necessary for healthy Chinook salmon populations as well as other native species.

Our client, the South Yuba River Citizens League (SYRCL), is working to restore Chinook salmon habitat in the Lower Yuba River. While a variety of entities including SYRCL have undertaken restoration work over the past 10 years, no projects to date have sought to quantify the economic benefits associated with these efforts at river restoration. While the broad range of costs associated with river restoration are known, the benefits of restoration are not. This study aims to develop a framework for evaluating and monetizing the benefits of river restoration to provide an economic justification for future restoration.

The Yuba River Watershed

Study Area

The Yuba River watershed is located on the western slope of California's Sierra Nevada mountain range, encompassing portions of Sierra, Placer, Yuba, and Nevada Counties (Figure 1). At the city of Marysville, the Yuba River flows into the Feather River, which is the largest tributary of the Sacramento River.

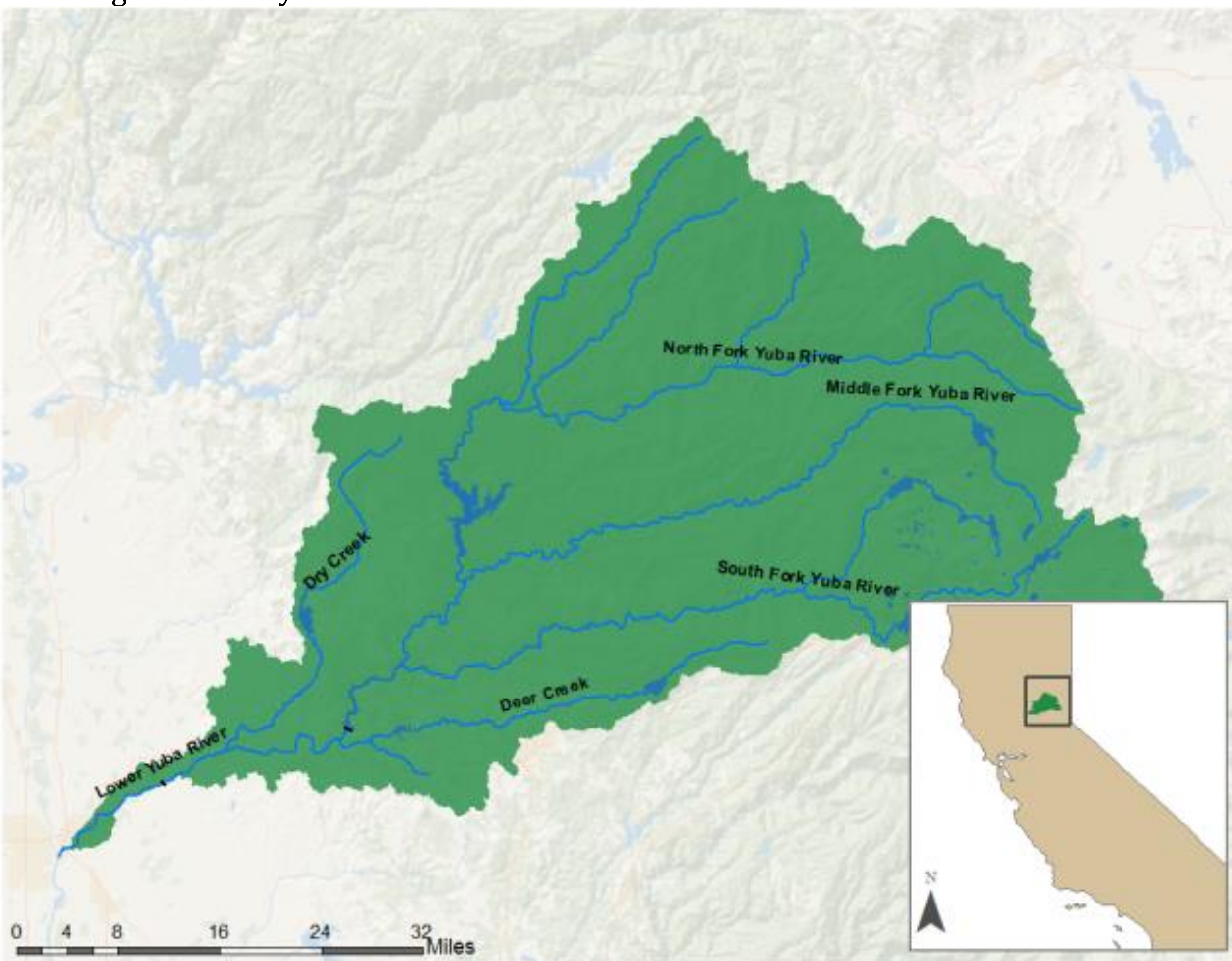

Figure 1. The Yuba River watershed. Data from the USGS National Hydrography Dataset.

Climate

The Yuba River watershed has a mixed-elevation Mediterranean climate with arid summers and cool, wet winters with heavy snowfall in the higher elevations. Most precipitation falls between November and March, and mean annual precipitation ranges from 170 cm at the crest of the mountain range to 55 cm at the confluence of the Lower Yuba and Feather Rivers (Snyder et al., 2006). This high variability in precipitation is due to orographic uplift and is caused by the steep slopes of the Sierra Nevada. Summer temperatures have been recorded to reach a high of 35^{o} C and a low of 16^{o} C. Mid-winter temperatures typically reach a high of 12^{o} C and a low of 3^{o} C (YCWA, 2009).

Topography

The watershed drains approximately 3,470 km^2 of the western side of the mountain range, with over 3,380 km of stream, creeks and rivers within the Yuba watershed system. The major sub-basins in the Yuba Watershed are the North, Middle, and South Forks of the Yuba River (Figure 2). The North Fork of the Yuba River originates near Yuba Pass at an elevation of 2,042 m, eventually flowing into the New Bullards Bar Reservoir (YCWA, 2009). The Middle Fork of the Yuba River originates at a slightly higher at 2,195 m near Meadow Lake Hill, and flows in a westerly direction to the Our House Diversion Dam near the Sierra and Nevada county intersection. The Middle and North Forks converge and become the mainstem Upper Yuba River, which flows roughly 13 km downstream to Englebright Dam (USACE, 2014). The headwaters of the South Yuba River are at an elevation of 2,195 m near Castle Peak and Donner Lake. The South Fork flows southwest until its confluence with the mainstem Yuba River at Bridgeport near Englebright Dam. The Lower Yuba River continues to flow southwest until its confluence with the Feather River in Marysville at an elevation of 18.2 m. The Lower Yuba River is defined as the 40.6 km section of river between Englebright Dam and the Feather River confluence (Figure 2).

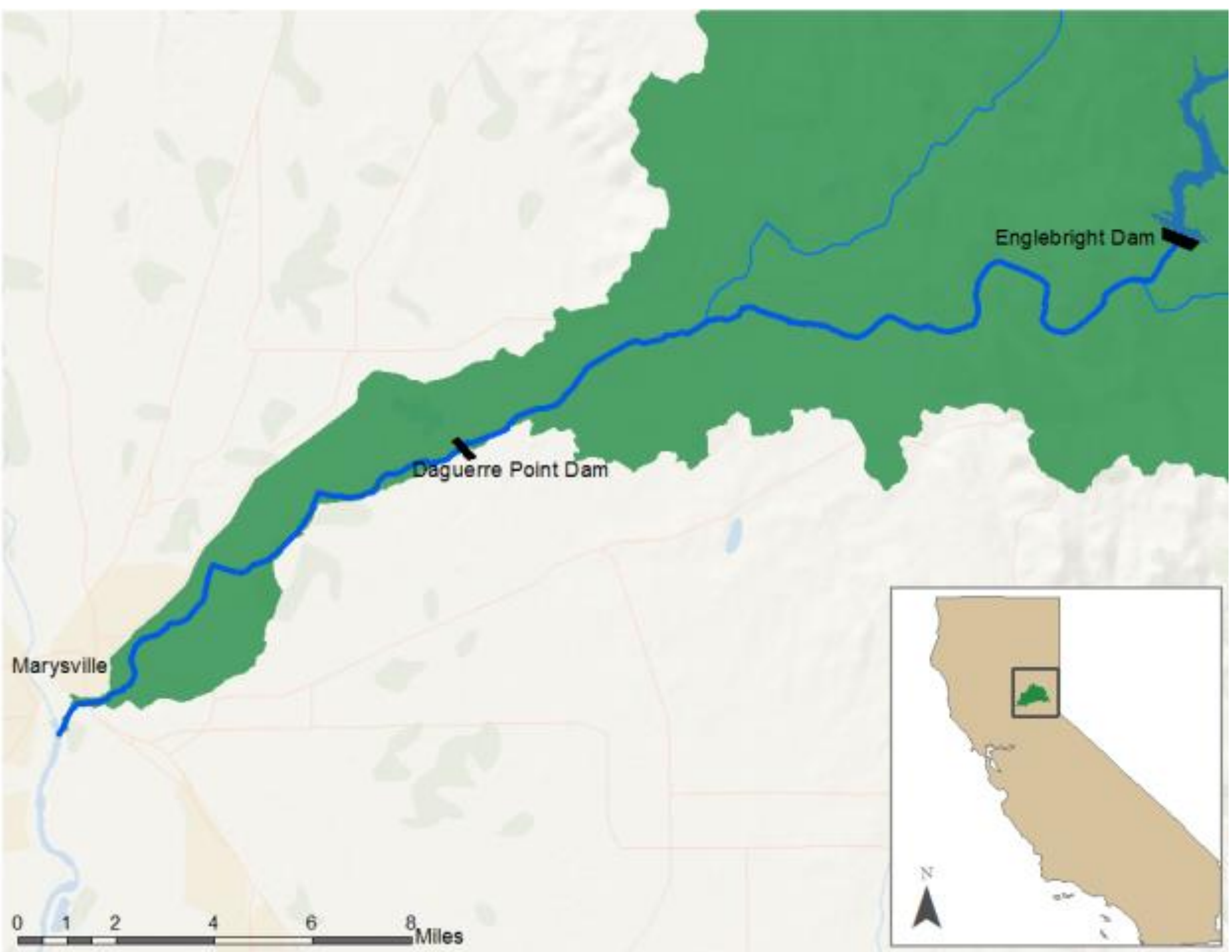

Figure 2. The Lower Yuba River. Data – USGS National Hydrography Dataset.

Eight Geomorphic Reaches

Wyrick and Pasternack (2012) identified 8 reaches in the Lower Yuba River on the basis of discharge, impacts of anthropogenic structures, and channel bed material type. Other attributes used in describing the 8 reaches are valley width (ft), percent channel bed slope, and thalweg length (ft) (i.e., following the deepest part of the channel).

The 8 reaches are as follows:

The Englebright Dam Reach is the uppermost reach on the Lower Yuba. It encompasses the river from Englebright Dam to the confluence with Deer Creek and measures 1,259 m in length. The reach is located immediately below the dam, which acts as a barrier to the downstream transport of gravel and cobble substrate needed for optimal spawning habitat. Currently the sediment on the bed of the reach is composed of angular substrate that originated from the blasting of rock when the dam was constructed. The majority of this reach is lined with steep bedrock walls and has the steepest gradient in the Lower Yuba River; its substrate is thus the coarsest of any throughout the Lower Yuba, with a median diameter of 298 mm (Wyrick and Pasternack, 2012).

The Narrows Reach extends from Deer Creek to the gravel substrate of the floodplain at Sinoro Bar, a total of 2,042 m. The Narrows Reach is bounded by steep bedrock walls and is relatively inaccessible from either bank of the river. These steep walls create Class III rapids that have prevented any survey activity or restoration efforts due to safety concerns and physical inaccessibility to the area. The confluence of Deer Creek with the Lower Yuba River is one of the better spawning locations for Chinook and steelhead (YCWA, 2013).

The Timbuctoo Bend Reach extends from the Sinoro Bar to the Highway 20 Bridge, measuring 6,337 m long. The uppermost part of the reach is confined by bedrock walls, but the valley widens downstream to form a floodplain. The river has the ability to meander as the valley widens. In the region where the channel widens, back-channel habitats are often created by scouring floodwaters. The median substrate size within this reach measures 163 mm. The reach ends where the valley naturally constricts at the Timbuctoo Bend.

The Parks Bar Reach extends from the widening of the river valley after Timbuctoo Bend to the tributary with Dry Creek, a total of 7,919 m. The river valley within this reach is wide enough to support sediment bars, islands and terraces with a median sediment size of 120 mm.

The Dry Creek Reach begins at the confluence with Dry Creek and ends at Daguerre Point Dam, measuring 3,801 m. The riverscape in this section is similar to Parks Bar

Reach and contains sediment bars, islands and terraces with a median sediment size of 88 mm. The main difference is that Dry Creek Reach has a significantly lower channel slope, which creates a braided river sections and backwater channels.

The Daguerre Point Dam Reach begins at the dam and ends where the channel significantly reduces its slope, spanning 5,639 m. The channel is widest in this reach and is mainly meandering with multiple backwater ponds and flow paths with a median substrate size of 87 mm.

The Hallwood Reach is less distinctly discriminated, as it is defined as beginning at a change in bed slope and ends farther downstream where the bed slope further decreases, a total distance of 8,382 m. The median sediment size in this reach is 61 mm. This is the longest reach defined along the Lower Yuba River and historically had a braided channel, but it is now confined into a single-thread channel constrained by levees.

The Marysville Reach is the final reach on the Lower Yuba and extends to the confluence with the Feather River, spanning the last 5,334. The Marysville Reach is channelized by flood control levees that armor both banks, but historically it was the widest part of the river with a braided planform. The extensive channelization of the river prevents floodplain formation. The bed slope is minimal and allows for slow, deep water with a median substrate size of 85 mm.

Yuba Watershed History

Hydrology

The Yuba River watershed is a predominantly snow-fed system, with a mean annual average discharge of approximately 2500 cubic feet per second (cfs) (USGS, 2016). Hydrologic conditions on the Lower Yuba River were typical of an unaltered snow-fed system from the Sierra Nevada prior to the mid-1800s (James et al., 2009). Gold mining, water diversions, and the subsequent construction of dams and levees dramatically changed hydrologic conditions on the Lower Yuba River (James et al., 2009). Modeled hydrographs of pre-1800s data suggest flows of 500-900 cfs occurring from October to January, peak flows ranging from 3500-6000 cfs in April and May, and summer base flows varying between 150-500 cfs (SYRCL, 2006).

Historic high spring flows scoured sediment and woody debris, maintained floodplains and side channels, recharged groundwater and provided important biological cues for riparian and aquatic species (James et al., 2009). The recession period between high spring flows and summer base flows also provided cues for aquatic and riparian species, such as the germination of cottonwood seedlings and salmonid spawning (Yarnell et al., 2010). The unconstrained nature of the Lower Yuba River allowed for channel meandering and the maintenance of bars, which provided instream geomorphic and hydrologic complexity (James et al., 2009; Wyrick and Pasternack, 2012). This natural and relatively undisturbed hydrologic condition supported native species and a dynamic riverine system.

Floodplain Extent

Prior to the arrival of Europeans to California, the Lower Yuba River flowed in an anastomosed dual-channel pattern (James et al., 2009). The lower reaches of the Lower Yuba River were historically the most extensively alluviated river reaches in the Sacramento Valley. As the gradient of the channel decreased in the 12 km above the confluence of the Yuba River with the Feather River, the floodplains broadened.

Anthropogenic Actions Affecting Instream Conditions

Gold Mining

In 1848, gold was discovered in California, including in Yuba County just downstream of where the Englebright Dam is located today (Lauer and McClurg, 2009). Hydraulic mining, which is the use of high-pressure water cannons to dislodge rock and sediments, began in the 1850s. During the 19th century, a large portion of hydraulic mining was unregulated; there were no regulations concerning the discharge of mining sediments and contaminants into river systems. It is estimated that 104 million cubic meters of material were mobilized into the Yuba River during this time period, and this influx of material significantly raised the elevation of the riverbed (Snyder et al., 2006; Gilbert, 1917). This initial mining surge caused broad floodplain deposition that created cutoffs in meandering areas of the river, channel avulsions, braided channels, and other major morphological changes.

The age of unregulated mining ended in 1884 with the passage of the Sawyer Decision, one of the first environmental laws in the United States. Although the Sawyer Decision did not outlaw hydraulic mining, it functionally prohibited operations by banning the discharge of mining debris into rivers and streams (Lauer and McClurg, 2009). This effective ban was almost immediately lifted by Congress due to its economic impacts, via the Caminetti Act of 1893. That Act reinstated hydraulic mining activities, provided that contaminated sediment moving downstream was controlled by debris dams.

Mercury Contamination

Mercury, also called quicksilver, was used extensively within the Yuba River watershed during 19th century hydraulic gold mining operations to assist in the recovery of gold deposits (Churchill, 2000; James, 2005; USGS, 2016). Some of the mercury introduced into the watershed over a century ago still remains within floodplain sediments, posing potential risks to the aquatic biota (James, 2005; Singer et al., 2016). Although some research has been conducted, uncertainty surrounding the extent, magnitude, and consequences of historic mercury contamination within the watershed prevail. A recent study found that mercury contained within benthic sediment was above background concentrations for most of the Lower Yuba River (Singer et al., 2016).

Mercury can pose potential health risks even at low concentrations, exacerbated by an ability to biomagnify within the food chain (Kocman et al., 2011; Wiener and Spry, 1996). Fish are especially vulnerable to certain chemical species of mercury when present within the water column. Specifically, mercury contamination becomes a concern when inorganic forms are converted into organic forms, such as methylmercury. Inorganic elemental forms were commonly used in mining operations (USGS, 2016) but can be biotransformed by aquatic microbes into methylmercury under reducing conditions. Problematic neurological health effects can occur after methylmercury exposure. In people, the ingestion of fish and shellfish tissues high in methylmercury is a common exposure vector. Pregnant women must be especially cautious, as prenatal methylmercury poisoning can cause mental disabilities in newborns (Bakir, 1973).

Dam Construction

The construction of Englebright Dam and Daguerre Point Dam has significantly impacted instream conditions on the Lower Yuba River. Englebright Dam (80 m high) was initially constructed by the U.S. Army Corps of Engineers in 1941 for the capture of mining debris, but it presently functions for flood control and water storage, as mining practices have ceased in the upper portions of the watershed. The dam obstructs upstream passage for aquatic species and significantly limiting habitat for fish rearing and spawning (USACE, 2014). This has disproportionately impacted spring-run Chinook, which depend on the cold upper reaches of the Yuba to survive hot summers. Dam construction has also altered important physical processes. Sediment and debris are captured above Englebright, preventing the transport of natural materials needed to maintain geomorphic features below the dam (USACE, 2010, 2014). Reservoir outflows often change the water temperature and lower dissolved oxygen levels downstream of the dam (Ahearn et al., 2005).

In addition to the physical barrier created by Englebright, the dam has also disrupted the natural flow regime of the Lower Yuba River by altering timing, magnitude, duration, frequency and rate of change (Poff et al., 1997; SYRCL, 2006; NMFS, 2014). Peak flows during spring are reduced and stored for release during the dry season. This alters riparian species assemblages and affects biological cues dependent on the timing and recession of springtime flows (Poff et al., 1997; SYRCL, 2006; NMFS, 2014). Flows have been cited as influencing the timing of upstream salmon migration. High flows often correlate to later salmon runs while low flows correspond with early runs (Anderson and Beer, 2009).

Daguerre Point Dam (8 m high), built by the California Debris Commission in 1906, also acts as a barrier to the movement of aquatic species on the Lower Yuba River (USACE, 2010; Pasternack et al., 2014). Although a fish ladder has been installed, the dam still poses challenges to upstream passage. Like Englebright, sediment and debris are captured upstream of this dam, creating sediment-starved areas downstream (Wyrick et al., 2012; USACE, 2010).

Levee Construction and Recent Flooding

Historically the Lower Yuba River had the capacity to maintain high flows, but once naturally high flows were coupled with a sediment-filled river channel from historic mining activities, overbank flooding became a significant threat. To protect themselves from flooding, settlers built levees along the banks of the river (Lauer and McClurg, 2009). Marysville sits approximately 18 m above sea level on the mildly sloping alluvial floor between the Sacramento Valley and the Lower Yuba and Feather Rivers (FEMA, 2011). The city and surrounding communities are located on a historical floodplain, and have thus been subjected to frequent and expensive flooding events. The magnitude of flooding has been exacerbated by hydraulic mining debris and channel modification (FEMA, 2011).

In response to a series of large floods in the early 1800s, a ring levee was constructed protecting Marysville in 1860.

Several additional levees have also been constructed throughout the Lower Yuba River valley for flood control (FEMA, 2011; Figure 3). Despite the construction of these levees, two major floods occurred in the area within the last century. In 1986, a levee failure occurred, inundating the communities of Linda and Olivehurst (FEMA, 2011). Over one thousand structures were destroyed, one death occurred, and the floods damages were estimated at $22 million (FEMA, 2011; BePreparedYuba, 2012).

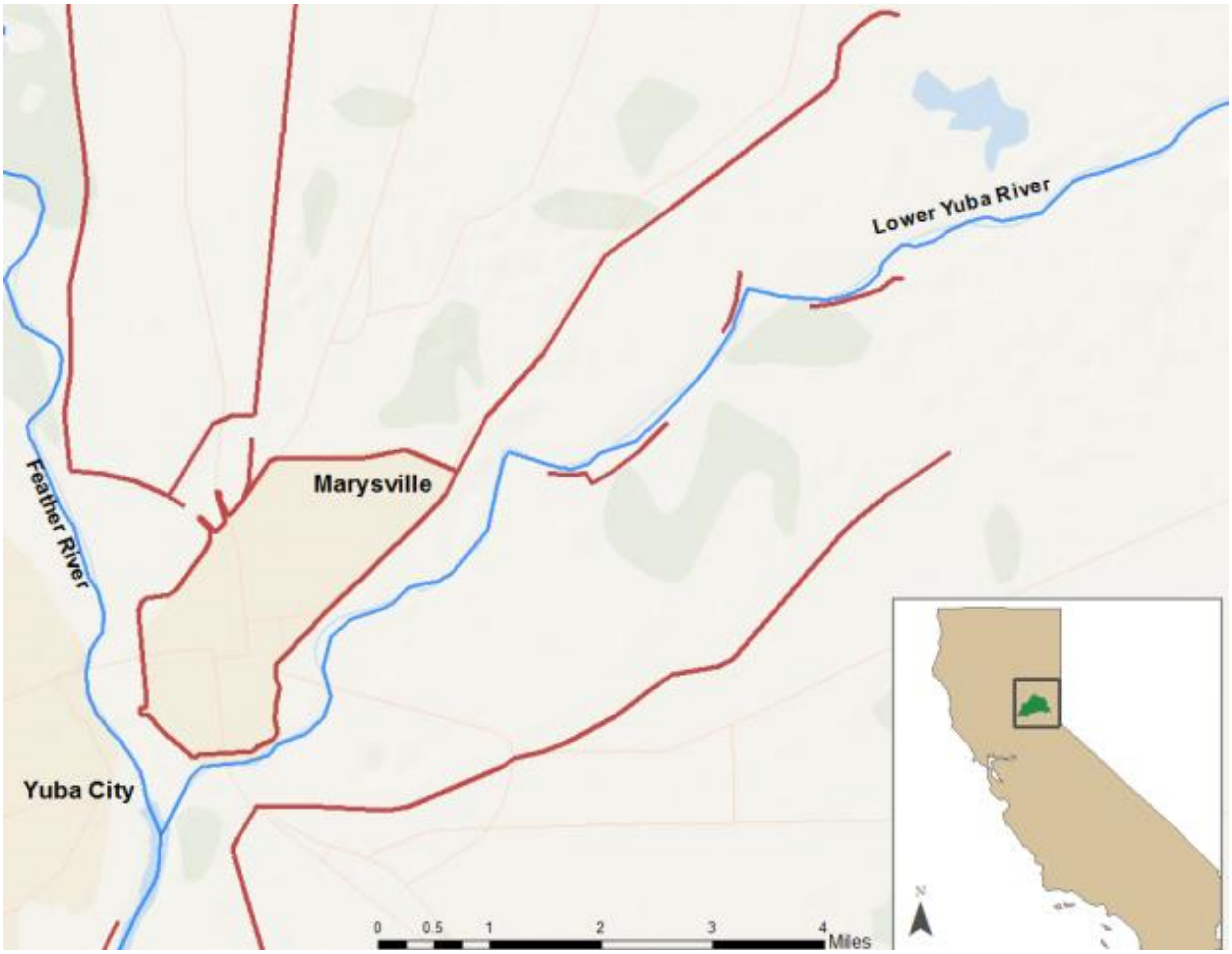

Figure 3. Levees on the Lower Yuba River. Levees indicated by red lines. Data – FEMA.

Following the 1986 flood, the Army Corps of Engineers, the State of California, and the Yuba County Water Agency worked together on the Levee Systems Evaluation Project, with the goal of repairing and strengthening levees (FEMA, 2011). However, a levee on the Feather River near Marysville failed in 1997, forcing the evacuation of 50,000 people from the area and total damages of $300 million (FEMA, 2011; BePreparedYuba, 2012). The Three Rivers Levee Improvement Authority was formed in 2004 by the Yuba County and Reclamation District, an agency responsible for financing and constructing improvements on levees, with the goal of achieving protection against 100-year and 200-year floods (BePreparedYuba, 2012; FEMA, 2011). Maintenance and improvements continue today, with $800,000 spent in summer 2016 alone (Creasey, 2016).

Salmonids on the Lower Yuba River

Pacific Salmonids Background and Life History

Pacific salmon and Pacific trout are members of the genus *Oncorhynchus*, within the Salmonidae family. Aside from a few land-locked varieties, *Oncorhynchus* are anadromous species—they spawn in freshwater, migrate to the ocean for maturation, and return to freshwater as adults to spawn. In North America, their range included watersheds extending from Southern California to Alaska. These species play an important role in freshwater ecosystems. They are an important food source for predators and scavengers in riverine areas, and they transport oceanic nutrients to forests when they die and decompose in rivers (Willson et al., 1998). Thus, salmon are often considered a keystone species in areas where they continue to thrive (Willson and Halupka, 1995). Additionally, wild-caught salmon are an important food commodity for humans, and both recreational and commercial salmon fisheries are worth hundreds of millions of dollars (Helvoigt and Charlton, 2009).

Adult salmon return from the Pacific Ocean and migrate upstream to their birth tributary stream in order to spawn. Meanwhile, they undergo a physical transformation that allow them to both swim up swift currents and produce eggs and sperm. Adult females build nests called redds in the gravel substrate with cold, shallow water. They deposit their eggs within their redds, which are then fertilized by males. Chinook salmon are semelparous, meaning they die after spawning. Eggs remain protected by gravel for several months until they hatch into avelin. Avelin still maintain their yolk, and remain within the gravel for a few weeks. Once the yolk is consumed, salmon fry emerge from the gravel. Depending on the *Oncorhynchus* species, fry remain in freshwater for anywhere between a few months and a few years before migrating downstream. As fry enter brackish and then salt water, they become smolts. Changes in their body's physiology allow smolts to survive in the ocean's salty conditions. Salmon spend between 1-8 years in the ocean before returning to freshwater. While in the ocean, salmon consume a variety of benthic species. Most commonly, Chinook salmon spend 3-4 years in the ocean before returning.

Steelhead have a similar life history as Chinook salmon, although they are iteroparous meaning they can spawn more than once. Additionally, steelhead have both an anadromous life cycle and a resident life cycle (rainbow trout). This polymorphic life history allows steelhead more evolutionary flexibility in the face of drought and other environmental variability.

Salmon Habitat Requirements and Human Impacts

Because salmon have a complex life history with many life stages occupying different habitats, a healthy salmon population requires many different intact habitat types. Salmon are often referred to as an ecological indicator species because their success requires a wide variety of healthy habitat (Irvine and Riddell, 2007).

The habitat requirements of adult salmon are cold, shallow, fast-moving water, and specific gravel sizes when they spawn to ensure survival of eggs and alevin. The flow requirements are to ensure a high dissolved oxygen content, and the gravel size ensures habitat protection for eggs and alevin. Native riparian vegetation along the river bank creates shade that keeps the river cool and is important in fish survival (Albertson et al., 2013). Fine sediment deposition between gravel can lead suffocation of the eggs and alevin.

Juveniles require cold water to maintain high dissolved oxygen levels and low bacterial levels. They also require macroinvertebrates within the water column to eat. Healthy riparian vegetation's fallen leaves provide an abundant food source for macroinvertebrates. Juveniles prefer feeding in stream areas with quickly moving water. Furthermore, fry require back-eddies and pools to rest in when not feeding. Habitat complexity, such as large woody debris and undercut shorelines/banks, give juveniles places to seek shelter (Albertson et al., 2013; Hafs et al., 2014; Beechie et al., 1997). Floodplains, backwaters, and side channels dramatically increase the amount of habitat area and food for fry, and allow both for an increased survival rate and larger fish (Albertson et al., 2013; Jeffres et al., 2008; Beechie et al., 1997).

Salmon stocks have significantly declined as a result of human actions. On the Lower Yuba River, hydraulic mining from the gold rush era has helped channelize the river. Channelized rivers have fewer pools and riffles for salmon, and they also have less overall available area. Additionally, channelized rivers support a smaller floodplain and fewer side channels. The hydraulic mining also destroyed the Lower Yuba River's riparian forests, which have yet to recover (Kattelmann and Embury, 1996). The extensive levee construction on the Lower Yuba has also led to increasingly channelized river conditions.

Salmon and Trout in the Yuba

The Yuba River contains two important salmonid species: Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*). Chinook salmon runs are designated into major groups, also known as evolutionary significant units (ESU), that differ spatially and temporally in spawning location. California contains six Chinook salmon ESU's. Three ESU's of Chinook salmon spawn in the Yuba River: Central Valley Fall-Run Chinook, Central Valley Late Fall-run Chinook, and Central Valley Spring-run Chinook (NMFS, 2014).

Similarly, steelhead are categorized into major groups based on spatial spawning habitat differences. These major groups are referred to as distinct population segments (DPS). One DPS of steelhead trout spawns in the Yuba River: California Central Valley steelhead trout (NMFS, 2014).

The Central Valley Spring-run Chinook is federally listed as a threatened species (*Endangered and Threatened Marine Species under NMFS' Jurisdiction*, 2017). The main reason for the decline in Spring-run Chinook is a lack of access to historical spawning grounds due to dams. On the Yuba River, Englebright Dam prevents Spring-run Chinook from accessing their historical spawning grounds in the North and South Forks of the Yuba River watershed. Spring-run on the Yuba are now confined to spawning in the two river reaches below Englebright Dam where Fall-run Chinook often also spawn (Englebright Dam reach and The Narrows reach). Thus, Spring-run redds can be compromised by Fall-run Chinook who build redds on top of the Spring-run redds, destroying eggs and killing juveniles. Yearly Spring-run returns presently number between a hundred and a few thousand.

The Central Valley Fall-run and Late Fall-run Chinook are federally listed as a species of concern (*Proactive Conservation Program: Species of Concern*, 2016). Fall-run and Late Fall-run Chinook returns generally number around ten thousand adults. The Yuba River is often considered to be one of the Central Valley's last wild salmon runs because it does not contain a hatchery, although stray fish from the Feather River hatchery occasionally spawn in the Lower Yuba River. Unlike the Spring-run Chinook, the Lower Yuba River is the historical spawning area of the Fall and Late Fall-runs.

The Central Valley steelhead trout is federally listed as a threatened species (*Endangered and Threatened Marine Species under NMFS' Jurisdiction*, 2017). Population trend data for the Central Valley steelhead is fairly limited (Williams et al., 2011), and especially limited on the Lower Yuba River. Historical runs are estimated over a million adults (McEwan and Jackson, 1996) but have since been reduced to the thousands or tens of thousands. Steelhead returns to the Feather River hatchery indicate a severe drop-off from 3,000 fish around 2003 to less than 500 fish since 2008. Steelhead on the Lower Yuba River occupy similar habitat as Chinook salmon, although their smaller sizes also allow them to spawn in smaller tributaries, such as Deer Creek.

Yuba River Salmon Life Cycles

Adult Fall-run salmon return from the Pacific Ocean to San Francisco Bay and migrate upstream from July through December. These fish spawn from early October to late December in the mainstem of the Lower Yuba River. The Late Fall-run spawns from January to Mid-April. Because there is overlap in these two runs, the data is often treated as a single salmon run. Adult Spring-run salmon return from the Pacific Ocean to the Sacramento River between March and September. This ESU is unique in that the adults "hold" over summer: they occupy deep, cold pools on the Lower Yuba River over the summer months before spawning from mid-August to October.

For Central Valley Fall-run salmon, eggs hatch within 90-150 days. After consuming their yolk sack in 2-3 weeks, fry emerge from the gravel and remain in the Lower Yuba River for a few months while eating macroinvertebrates. The majority of fry outmigration downstream occurs between January and March on the Lower Yuba River (Massa, 2004). For the Central Valley Fall-run, fry usually remain in their streams for a few months. Central Valley Spring-run can remain in freshwater for a year before entering brackish water. Most commonly, adults spend 3-4 years in the ocean before returning.

Policy Landscape and Fisheries Management

Chinook salmon and steelhead trout are both protected under the Endangered Species Act (ESA), intended to protect and recover populations of plants and animals that are at risk of extinction (Endangered Species Act of 1973, 16 U.S.C. §§1531). Some of the legal tools available to agency enforcers include the ability to list species in peril, develop action plans to protect and recover listed species, prohibit the take of a listed species, and to protect critical habitat in which a listed species resides (Endangered Species Act of 1973, 16 U.S.C. §§1532). It is important to note that the term “take” as applied to the Endangered Species Act is an umbrella term, including the common definitions of harassment, harm, pursuance, hunting, shooting, wounding, killing, trapping, capture, collection or any attempt to engage in such conduct. (Endangered Species Act of 1973, 16 U.S.C. §§1532). The federal agencies responsible for administering the ESA are the United States Fish and Wildlife Service (USFWS, Department of the Interior) for terrestrial and freshwater species and the National Marine Fisheries Service (NMFS, National Oceanic and Atmospheric Administration within the Department of Commerce) for marine species (Endangered Species Act of 1973, 16 U.S.C. §§1532). Although salmonids are anadromous, residing in both freshwater and marine environments, NMFS is the governing agency overseeing Chinook salmon and steelhead trout populations.

Beyond the ESA, there are fisheries management policies at the federal, state and regional levels responsible for maintaining fish stocks in freshwater and marine environments. The salmon fishery is protected federally under the Magnuson-Stevens Fishery Conservation and Management Act of 1976. The Magnuson-Stevens Act established the Pacific Fishery Management Council, responsible for managing sustainable fisheries by setting quotas, bag limits, and strict seasonal timelines for commercial, recreational and tribal fisheries (Lockwood, 2014). The State of California, Natural Resource Agency, Department Fish and Wildlife, and Fish and Game Commission also work together to develop state regulations for freshwater sport fishing. Some of the regulations include possession of a valid fishing license if over the age of sixteen, allowing warden inspection, and adherence to size, species and catch limits (2016-2017 Freshwater Sport Fishing Regulation, 2016).

In practice, the law is applied capriciously, and with the consideration of many competing interest groups. Currently, fishing regulations are the primary manifestation of the ESA within the Lower Yuba River. As such, the Valley District, a regulatory district containing Yuba County and other neighboring counties, are closed year-round to the take of salmon (2016-2017 Freshwater Sport Fishing Regulation, 2016). Regulation prohibits the taking of any wild steelhead trout, but hatchery steelhead allowances are a daily bag limit of two individuals and a possession limit of four individuals (2016-2017 Freshwater Sport Fishing Regulation, 2016).

Benefits of a Healthy River System

Ecosystem Services

Although the definition of “ecosystem services” varies widely (Brat et al., 2012; Costanza et al., 1997), we define it throughout this analysis to be *the direct and indirect contributions of intact ecosystems to human wellbeing*. An intact ecosystem is inextricably linked to a healthy and resilient river, thus we expect the healthier the river ecosystem, the more services it will provide (Brat et al., 2012; Costanza et al., 1997).

Pre-1850, the Lower Yuba River provided ecosystem services such as a self-sustaining fishery, a wide floodplain able to provide flood control, groundwater recharge and areas of fertile land for agriculture. The system also provided cultural services for the Maidu and several other Native American tribes reliant on the river for aesthetic and religious purposes (Bright, 1998).

In its current degraded state, the Lower Yuba River provides these ecosystem services to a reduced extent (Yuba Accord, 2009). Land-use changes along the river, continued gravel mining, the construction of dams and levees, and water diversions have degraded the state of the Lower Yuba River to a degree to which it can no longer provide these ecosystem services to their full extent (Yuba Accord, 2009).

We anticipate improvement in the following services would result from restoration actions below Englebright Dam:

- **Commercial and recreational fishery.** Improvements to in-channel habitat via gravel augmentation, large woody debris placement, riparian vegetation planting, and changes to the flow regime will likely improve habitat conditions for fish, which will likely increase continued, healthy stocks of Chinook salmon and steelhead if in fact these conditions are presently contributing to depressed populations. The Lower Yuba River contributes ~2.5% of California's ocean Chinook salmon population (TNC, 2016; CalFish, 2016), and so we expect that restoration actions here will also improve ocean fish populations and the ocean recreation and commercial salmon fisheries.
- **Property value.** A restored river system will likely increase the value of homes and property near the Lower Yuba, if enough area is restored, as property values can increase when they are located near more aesthetically pleasing natural areas (Provencher et al., 2008).
- **Recreational opportunities.** A restored and more aesthetically pleasing river system will promote an increase in recreation. This could include additional opportunities for fishing, recreational mining, boating, rafting, hiking, and camping. This increase in recreation could also benefit the regional economy.
- **Carbon sequestration.** Riparian revegetation restoration projects will, in the long term, increase the capture of carbon dioxide and other greenhouse gases (Gorte, 2009). As the climate warms, this sequestration will be an increasingly important ecosystem service as a tool in mitigating climate change impacts.
- **Groundwater recharge.** Improved floodplain habitat and backchannel connectivity will likely increase groundwater recharge (Palmer et al., 2008), providing a more sustainable supply of water for use within the basin.
- **Flood risk reduction.** Restoration projects can potentially reduce flood risk reduction, providing both economic and safety benefits downstream (Sawyer, 2017, personal communication).

Our cost-benefit analysis quantifies some of these services, when possible, so that a possible range of benefits from restoring the Lower Yuba River are considered.

Although not all ecosystem services can be quantified, monetizing these services when possible is important for garnering support for restoration work.

Restoration Goals

The goal set forth by the Anadromous Fish Restoration Program (AFRP), a program of the U.S. Fish and Wildlife Service, is to "at least double the natural production of anadromous fish in California's Central Valley streams" (USFWS, 2016). Following this guidance, we have set our target population to be a 100% increase of the current Chinook salmon population in the Lower Yuba River. Further, our goals are to choose restoration strategies that are cost-effective and sustainable. Although we explore a range of scenarios, our cost-benefit analysis focuses on this doubling target.

Restoration Efforts

Restoration on the Lower Yuba River is presently a joint effort between federal, state and local agencies. Although individual restoration projects are not always unanimously supported by all stakeholders, there is a general consensus to restore river channel morphology to pre-mining conditions for the benefit of the local salmon fishery. In the Lower Yuba River, the actively involved federal stakeholders include the United States Army Corps of Engineers (USACE), the National Marine Fisheries Service (NMFS) and the United States Fish and Wildlife Service (USFWS). The USACE is responsible for operating and maintaining Englebright Dam and Daguerre Point Dam, as well as issuing permits for in-channel activities. NMFS is responsible for the management and protection of anadromous fish. As such, they are required to intervene when project implementation and operation is in conflict with the Endangered Species Act, or when activities could have deleterious effects on threatened or endangered fish species. The USFWS has similar management goals as NMFS, and is required to protect populations of anadromous fish on a long-term, sustainable basis (Brown and Merz, 2015).

State-level stakeholders include the California Department of Fish and Wildlife (CDFW), the State Water Resources Control Board (SWRCB), and the California Department of Water Resources (CDWR). CDFW is responsible for habitat protection and maintenance, and oversees the use of fish and wildlife for recreational, commercial and educational purposes. CDFW also oversees in-channel activities by regulating streambed alteration agreements. The SWRCB regulates the discharge of dredged material and issues state water quality certifications for channel activities. The CDWR is involved in water supply and small habitat assessment in relation to dams and water diversions (Brown and Merz, 2015).

The local agencies and organizations that are involved include the Yuba County Water Agency (YCWA), the Sierra Streams Institute (SSI), and SYRCL. The YCWA manages flood control, hydroelectric power sales, recreation and fisheries enhancement. The SSI is a watershed science organization aimed at increasing watershed stewardship. SYRCL is a community-based organization that directs its efforts at working with private landowners on fish habitat restoration and other land stewardship activities (Brown and Merz, 2015).

Past Projects on the Lower Yuba River

U.S. Army Corps of Engineers Gravel Augmentation

The National Marine Fisheries Service (NMFS) required the Corps to implement the gravel augmentation as part of owning/operating Englebright Dam. In 2007 the U.S. Army Corps of Engineers conducted a pilot study for gravel augmentation within the Englebright Dam Reach. The purpose of the project was to restore gravel in an area devoid of river-rounded substrate necessary for spawning. The Army Corps of Engineers deposited 500 tons of gravel into the river to determine how quickly the sediment dispersed in the reach (USACE, 2013). The gravel augmentation site was less than one acre and confined entirely to the river channel within the reach. The results of the pilot study informed the more recent gravel augmentation injection plan (GAIP). In 2011, 5,000 tons of gravel were injected into the river. 2016 marked the fifth year of gravel augmentation and to date there have been roughly 20,000 tons of gravel injected into the Englebright Dam Reach. Every five years a biological opinion is required by NMFS and up until 2015, the Corps was required to continue with gravel augmentation. Starting in 2015, NMFS no longer required gravel augmentation, but the Corps has continued to pump gravel into the upper Englebright dam reach voluntarily. They will continue implementing gravel augmentation as a restoration strategy, attempting to create suitable spawning habitat for salmonids by returning the river closer to its natural geomorphological condition.

Hammon Bar Riparian Enhancement Project

Hammon Bar is located within the Parks Bar Reach and is one of the largest alluvial features of the Lower Yuba River (SYRCL, 2013). Pre-project inspection revealed that vegetation on Hammon Bar had a significantly lower percentage of riparian cover compared to the other lower reaches. Thus Hammon Bar was chosen as a suitable site to add native vegetation. The Hammon Bar Riparian Enhancement Project, implemented by SYRCL in 2011-2012 on Bureau of Land Management property, involved the planting of 6,389 cuttings along five acres of riparian zone. Cuttings were harvested and planted at the project site by an excavator, which dug until it reached groundwater. Subsequently, a bobcat was used to fill the pods with cuttings. Cuttings were also planted using the stinger method, where the ground is pierced to create a hole large enough for the cutting to be planted.

The project was used to demonstrate the feasibility of implementing riparian hardwood forest restoration on open bar structures along the Lower Yuba River. The expected benefits that are being evaluated from the addition of riparian cover include enhanced fish habitat from additional shade, cover, and geomorphic and hydraulic complexity (SYRCL, 2013). The willow and cottonwood cuttings had approximately 50% survivorship between years one and two (SYRCL, 2013). SYRCL is still monitoring the success of the planting efforts. In 2015 the cottonwood survivorship dropped from approximately 50% to 39% survival.

Goldfield Trails Project
The trail was installed in 2016 and will includes signage that details mining history, Native American history and current restoration work. Managers hope the Goldfield Trails Project and other similar projects will increase accessibility to the riverbanks and encourage visitation. Little information is known on the success of the project, but it is now open for the public's use.

Proposed Future Projects

There is a large amount of pending activity along the Lower Yuba River, at various stages of conceptualization and implementation. The number of proposed projects currently exceeds the number of realized projects, but in general there is surmounting inertia moving towards increased restoration efforts. Although the projects are being funded and implemented in a piecemeal fashion, the hope is that the cumulative effects of each additional project will be multiplicative, eventually leading to a sufficiently restored river.

The following are the known projects that have been proposed on the Lower Yuba River:

Channel Restoration Plan
The Channel Restoration Plan (Leedy, 2012) proposes specific projects and identifies potential target sites on the Lower Yuba River. Some of the restorative measures mentioned in the restoration plan include shot rock removal, bar recontouring, and the addition of flow obstruction structures (Leedy, 2012). The U.S. Army Corps of Engineers, along with U.S. Fish and Wildlife Service, Environmental Science Associates (ESA), and the Yuba River Council, will implement the Channel Restoration Plan in the downstream end of the Englebright Dam Reach and the upstream portion of the Narrows Reach (Yuba River Canyon Area). This portion of the restoration plan is currently under CEQA process determination and is expected to begin in 2017.

Upper Rose Bar Project
The Upper Rose Bar Project, which will be located at the end of the Englebright Dam reach near the confluence with Deer Creek (Parks Bar Reach), is designed to provide suitable spawning gravel and will follow a three-phase timeline. The project is multifaceted and will involve the cooperation of many different factions. In its first stage, the Sierra Stream Institute (SSI) and ESA will repair a drainage ditch located near a mine site while adding supplemental gravel for suitable salmonid spawning habitat. SYRCL and Western Aggregates, a sand and gravel mining company, plan on working with the Yuba River Preservation Foundation to establish a conservation easement along a three-mile stretch of land abutting the Yuba River below Parks Bar Bridge. The easement area property is currently owned by Western Aggregates but will be given to a managing group if the project is implemented. The conservation easement will

prevent further development and mining on the land (SYRCL, 2008). Another beneficial use of the acquired land includes increased public access and recreational opportunities via river access trails. Phase one will includes the easement procurement and protection from vehicular damage and unauthorized off-road activity. The second phase will focus on salmon habitat restoration through floodplain lowering and backwater channel extension. This will allow the succession of complex riparian habitat on cobble-lined banks. Western Aggregates has solicited the assistance of SYRCL's expertise in riparian habitat restoration, fisheries enhancement and overall river health. The final phase will ensure a long-term monitoring effort on the newly restored lands (SYRCL, 2008). Project completion is scheduled for 2018 (SYRCL, 2016).

U.S. Army Corps of Engineers LWD Project
The goal of this project is to add and manage large woody material in the Lower Yuba River below Englebright Dam. The addition of large woody material aims improve habitat for salmon by increasing cover, complexity and food sources. An important caveat is that large woody debris was added to the river in 2012, but was washed away in a high flow event. The U.S. Army Corps of Engineers will first implement a pilot program using large woody material from stockpiles along the New Bullards Bar Reservoir (USACE, 2012). Specific locations have been identified for large woody material placement, contingent upon vehicle accessibility. The U.S. Army Corps of Engineers will need to obtain permission from private landowners in order to gain access to the selected sites (USACE, 2012). It is unclear whether the USACE is or will be continuing their efforts to create additional salmonid habitat through the addition of large woody debris due to impacts from high flow events.

BLM and SRI Mining Long Bar Project
This proposed location of this project is on Silica Resources, Inc. (SRI) property, at the downstream edge of Long Bar Reach. The project would involve a land title change from SRI to Bureau of Land Management (BLM). The objective is to enhance floodplain habitat for the benefit of juvenile salmonids and native plant establishment. The implementation involves methods such as gravel augmentation, side channel reconnection and floodplain lowering. The proposal was scheduled to be submitted to the U.S. Fish and Wildlife Service (USFWS) in 2016 with the expected project implementation scheduled from 2016 to 2018, pending permitting (SYRCL Project Proposal). There is little information on the progress of the proposal or whether the timeline of this project remains unchanged.

Teichert Hallwood Floodplain Project
The Yuba River Management Team has partner with USFWS, Teichert, and Western Aggregates to regrade areas of active floodplain to provide additional fish habitat. The project site, Daguerre Alley, is partially located on property belonging to the Teichert Hallwood Facility gravel dredging operation. The site measures 6.47 x 105 m^2 and is a described as remnant channel. The main objective is to enhance fish habitat through topographic modifications, riparian plantings and installation of large wood structures. These restoration strategies are intended to provide high quality off-channel rearing habitat, a major limitation in the Lower Yuba River (AFRP, 2012). Anadromous Fish

Restoration Program (AFRP) has provided the grant to design the new channel construction, Cramer Fish Sciences will conduct the fish monitoring and SYRCL will manage the riparian planting efforts (AFRP, 2015).

The actual size of the project is dependent upon funding, but it could potentially restore 0.61 km^2 of floodplain habitat and 4 km of side channel habitat. The first phase of the project is projected to include side channel alteration, extensive floodplain lowering and riparian planting to restore 40 to 50 acres of floodplain habitat. The cost of the initial phase is projected at $1.6 million (AFRP, 2012). Teichart would be able to sell substrate removed from the floodplain lowering, providing incentive for a deal, as they do not currently possess permits to mine in Daguerre Alley. In return, Teichart would grant agencies access to their land to employ the restoration actions. Preliminary funding has been fronted by Pacific Gas and Electric, while funding for planning and permitting is being provided by USFWS, AFRP and the Central Valley Project Improvement Act. Implementation is expected to begin in summer 2017.

Project Objectives and Approach

In an effort to quantify benefits of river restoration on the Lower Yuba River, we have identified the following project objectives:

1. Characterize current water quality, ecological, and physical conditions of the Lower Yuba River.
2. Quantify regional benefits of a restored river landscape.
3. Compare costs and benefits across various temporal scales to inform future restoration projects.

River Health Report Card

Report Card Approach

Yuba River salmon populations currently represent a small fraction of their historic numbers. A holistic approach to river management is necessary to increase salmon populations; an approach that incorporates data regarding water quality, ecological, and physical characteristics is required to provide a foundation for management decisions. The Lower Yuba River Report Card is therefore focused on the health of our study area with respect to salmon. It is meant to provide a high level of detail about each geomorphic reach in the Lower Yuba, in a consistent way that can be used to inform a river-wide restoration plan and point restoration ecologists and environmental managers to areas requiring the most attention. The report card approach provides reach-level detail and is also systematic to allow for unbiased comparisons of analogous river reaches.

Scoring of Current Conditions

To assess current conditions, a standardized scoring method was applied for the following categories: water quality, ecological resources, and physical conditions. Parameters within each category are shown in Table 1. Each reach received a health score for these three parameters based on threshold values shown in Table 2. The health scores for each of the eight river reaches reflect our best professional judgement, after performing a literature review and using available data. The background, methods, and results for each of the parameters are discussed in more detail below.

Table 1. Parameters considered in the ecosystem health report card.

Water Quality	Ecological Resources	Physical Conditions
pH	Macroinvertebrate Diversity (No. EPT Taxa)	Spawning Substrate
Water Temperature (℃)	Riparian Cover (%)	Percent Pool (%)
Dissolved Oxygen (mg/L)		Percent Riffle (%)
Total Suspended Solids (mg/L)		Pool:Riffle Ratio
Mercury Concentration (μg/g)		

Table 2. Categories for scoring existing conditions for each reach on the Lower Yuba River for a given water quality, ecological resource or physical condition parameter.

Score	Interpretation of Score
Poor	Salmonid Adversely Impacted OR Poor Condition
Fair	Salmonid Tolerance OR Fair Condition

Good	Salmonid Preference OR Good Condition

There are some river health parameters not included in this report card. For example, an off-channel habitat parameter would fall under the physical conditions category, because off-channel habitat is important for juvenile salmonids. There does exist anecdotal evidence that off-channel habitat along the Lower Yuba River is poor (Pasternack and Wyrick, 2012), but there does not exist concrete data to score this parameter in relation to ideal salmon habitat. Therefore, this parameter was omitted from the river health report card. Nonetheless, we are confident that the chosen parameters capture the overall health of the Lower Yuba River.

Water Quality

Water Quality: pH

Background

An important indicator of water quality for salmon is pH. Chinook salmon can tolerate a pH range from 5.5 to 9.0 (fair) but prefer a pH from 6.8 to 8.0 (good) (CDWR, 2004). In this analysis, a reach receives a poor health score if the average pH is outside this "fair" range. Acidic conditions beyond salmonid tolerance can directly lead to physiological damage, such as ion regulation failure at the gill surface and respiratory failure (Fivelstad et al., 2004). A reduction in pH can also release and transform metals into more toxic forms (Fivelstad et al., 2004). The USGS states that in general, a decrease in pH coupled with an increase in dissolved organic carbon (DOC) results in higher mercury levels in fish (2000), because those conditions can mobilize mercury and facilitate its uptake and biomagnification.

Methods and Results

Data were retrieved online from YubaShed River Information System. This parameter was measured at four sites within the Lower Yuba River: 1) the intersection of Timbuctoo and Parks Bar below the Highway 20 bridge, 2) just below Daguerre Point Dam, 3) Hallwood reach and 4) Marysville reach. Because the sampling dates differ at each site, the average from the most recent year with available data was used. Average annual pH from 2017 was used for Timbuctoo, Parks Bar and Marysville, 2005 data for Hallwood, and 2001 data for Daguerre Point Dam. The results are summarized in Table 3 below.

Table 3. pH by reach and corresponding health score adapted from CDWR, 2004. Data retrieved online from YubaShed River Information System. NA = not available.

Stream Reach	pH	Score
Englebright	NA	-
Narrows	NA	-

Timbuctoo	6.6	Fair
Parks Bar	6.6	Fair
Dry Creek	NA	-
Daguerre Point Dam	7.4	Good
Hallwood	7.6	Good
Marysville	7.4	Good

Water Quality: Temperature

Background

Temperature is a significant water quality indicator for Chinook salmon. High summer temperatures can be injurious to Chinook salmon at all life stages. While acute exposure to high temperatures can be lethal, chronic exposure can lead to more subtle health and reproductive problems. This is particularly important for spring-run Chinook adults, which reside in stream habitat over summer. Chronic exposure to high temperatures has been shown to cause weight loss, illness, competitive displacement, and increased vulnerability to predation (Richter and Kolmes, 2005). In addition, stream temperature can influence other water quality parameters such as dissolved oxygen, discussed in the following section.

High temperatures have been shown to impact rearing juveniles, smoltification, adult migration and spawning more than the other life stages. For example, increased temperatures can cause premature smolting, desmoltification and alterations to emigration timing that cause increased mortality at sea (Richter and Kolmes, 2005). We could assess any one of these life-stages and base our analysis on the corresponding temperature thresholds. Because it has been determined that juveniles are the limiting factor to population growth in the Lower Yuba, this report card focuses on the juvenile life-stage compared to summer daily averages and summer daily highs to assess reach-level temperature effects on ecosystem health. Reaches where daily maximum temperature exceeded 22°C, the threshold for acute fish kills, received a “poor” score (Hicks, 2000). The Matrix of Life History and Habitat Requirements for Feather River Fish Species recommend water temperatures for juvenile Chinook less than 12.8°C (good), with a tolerance range from 12.8 - 18.0°C (fair), above which the daily average are considered poor.

Thermal regimes can be altered by development and destruction of complexity in favor of a more channelized system. Thermal refugia such as riparian shading, large woody debris and deep pools can provide the necessary temporary relief while moving around in an otherwise inhospitable environment. If a patchwork of refugia exists at regular intervals along a channel, migratory mortality and stranding events are likely to occur with less frequency (Richter and Kolmes, 2005). Because this simple analysis ignores fine-grained temperature variation, a thorough evaluation should include fine spatial components including the patchiness of shading.

Methods and Results

To address both acute and chronic concerns related to high water temperature, we calculated both summer daily averages and summer daily high temperatures within the study reaches. The summer daily average temperature is defined as the average temperature within a 24-hour period between during summer months. The summer daily high temperature is defined as the maximum instantaneous temperature occurring within a 24-hour period during summer months. Because temperature data do not exist for all of the reaches in our study area, an existing temperature model was used to calculate the expected average and high values on a finer scale (YCWA, 2013). One of the stated goals of the model is to accurately reproduce observed stream water temperatures, using the available data for calibration (YCWA, 2013). Conceptually, the model combines releases from Englebright Reservoir with inflows from Deer and Dry creeks and diversions at Daguerre Point Dam along with meteorological and detailed geomorphological attributes to initially inform temperature predictions (YCWA, 2013). The results from this model for the Lower Yuba River are summarized in Table 4 below.

Table 4. Summer daily average and summer daily high temperatures by reach and their corresponding health score adapted from Hicks (2000) and CDWR (2004). Data adapted from YCWA, 2013.

Stream Reach	Summer Daily Average (°C)	Score	Summer Daily High (°C)	Score
Englebright	11.7	Good	17.3	Fair
Narrows	11.8	Good	17.8	Fair
Timbuctoo	11.8	Good	17.8	Fair
Parks Bar	12.7	Good	20.4	Fair
Dry Creek	13.6	Fair	22.8	Poor
Daguerre Point Dam	14.2	Fair	24.3	Poor
Hallwood	14.2	Fair	24.3	Poor
Marysville	16.2	Fair	35.4	Poor

Water Quality: Dissolved Oxygen

Background

Chinook salmon require high concentrations of dissolved oxygen (DO) to meet the metabolic demands of upstream migration, reproductive requirements and to keep gravel habitat well oxygenated for immobile early life-stages. Any reduction in oxygen concentrations – from elevated water temperatures, for example – can negatively affect survival, fitness, and susceptibility to pathogens and predation (Carter, 2005). Returning adults need high DO to endure the stressful journey upstream, and will delay leaving the ocean environment until freshwater DO reaches preferred concentrations (Hallhock et al., 1970). Additionally, rearing salmon are quite active and require high DO to accommodate high activity and growth before emigration (Spence et al., 1996). Results from an EPA study found no growth rate change for Chinook salmon at a DO of 8 mg/L, a growth rate reduction of 7% at 6mg/L, and a growth rate reduction of 29% at 4 mg/L (Carter, 2005).

The early life stages of developing salmon are relatively immobile and require well-oxygenated gravel environments in order to emerge as healthy alevins. This is perhaps the most susceptible life-stage in terms of DO requirements. Development embryos and larvae require intragravel DO, which is dependent on ambient DO, interstitial space and surrounding biochemical oxygen demand (Carter, 2005). The EPA and ODEQ estimate gravel DO to be 3 mg/L lower than ambient DO when considering developing salmonid oxygen requirements (EPA, 1986; ODEQ, 1995). In one study, intragravel DO below 6 – 7 mg/L halved emerging salmon survival compared to DO above 8 mg/L (WDOE, 2003).

Raleigh et al. (1986) found that optimal DO for Chinook salmon is above 9.0 mg/L (good), and that the minimum requirement is 8.0 mg/L (fair). DO below 8.0 mg/L were given a poor health score. It should also be noted that the DO requirement may increase as temperature increases due to the increased metabolic stress associated with higher water temperatures (Raleigh et al., 1986).

Methods and Results

Data were retrieved online from YubaShed River Information System. DO was measured at four sites within the Lower Yuba River including: 1) the intersection of Timbuctoo and Parks Bar below the Highway 20 bridge, 2) just below Daguerre Point Dam, 3) Hallwood reach and 4) Marysville reach. Because the sampling dates differ at each site, the average from the most recent year with available data was used. 2017 average yearly DO was used for Timbuctoo, Parks Bar and Marysville, 2007 data for the Hallwood reach, and 2001 data for Daguerre Point Dam. The results are summarized in Table 5 below.

Table 5. Dissolved oxygen by reach and corresponding health score adapted from Raleigh et al. (1986). Data retrieved online from YubaShed River Information System. NA = not available.

Stream Reach	Dissolved Oxygen	Score
Englebright	NA	-
Narrows	NA	-
Timbuctoo	10.0	Good
Parks Bar	10.0	Good
Dry Creek	NA	-
Daguerre Point Dam	11.6	Good
Hallwood	11.4	Good
Marysville	9.8	Good

Water Quality: Total Suspended Solids

Background

Total suspended solids (TSS) is the measure of inorganic and organic particles held in the water column (Bilotta and Brazier, 2008). TSS can be comprised of silt, decaying biotic matter, and sewage (Bilotta and Brazier, 2008). Although all streams carry suspended solids under natural conditions, concentrations can be elevated through anthropogenic activities including mining, agriculture, high flow rates, erosion, urban runoff, and wastewater and septic system effluent (Bilotta and Brazier, 2008; Bash and Berman, 2001). High levels of TSS result in the damage of aquatic environments (Bilotta and Brazier, 2008). Degradation of physical conditions in streams caused by high levels of suspended solids include reduced penetration of light, with corresponding low dissolved oxygen levels, as well as infilling of channels when sediment is deposited (Spence et al., 1996; Bilotta and Brazier, 2008). As TSS man contain contaminants, high levels of TSS can also result in the release of heavy metals, pesticides, and nutrients (Spence et al., 1996; Bilotta and Brazier, 2008).

Increased suspended solids also have significant impacts on instream ecological conditions (Bilotta and Brazier, 2008; Bash and Berman, 2001). Impacts of suspended solids on adult and juvenile salmonids include increased stress, gill damage, and avoidance behavior (Bash and Berman, 2001). Eggs are highly susceptible to high concentrations of suspended solids, as suspended solids entering substrate where eggs are laid depletes oxygen, can smother eggs, and may create a barrier to fry emergence (Spence et al., 1996; Bash and Berman, 2001). Additionally, when suspended solids settle on the benthic environment, benthic macroinvertebrates – a critical food source for the juvenile life stage – can also be harmed through low dissolved oxygen levels and increased stress (Bilotta and Brazier, 2008).

TSS are not problematic for ecological conditions on the Lower Yuba River (Yuba County Water Agency, 2012; USGS, 2017). Based on USGS data from 2001-2004 and data collected by the Yuba County Water Agency in 2012, it appears that TSS are not at concentrations high enough to negatively impact water quality and ecological conditions, because negative effects to salmonid behavior and physiology typically occur only at TSS concentrations >100mg/L (Bilotta and Brazier, 2008). Consequently, no report card for TSS is presented here.

Water Quality: Mercury

Background

Mercury contamination is ubiquitous in the Yuba River watershed (Alpers et al., 2005). Mercury is found in several forms in watersheds: elemental (Hg^0), inorganic divalent (Hg^{2+}), and organic dissolved methylmercury (MeHg) (Schroeder and Munthe, 1998). The contaminated sediment of Lower Yuba River is likely in the inorganic form, which is unavailable to biota (Alpers et al., 2005). However, Hg^{2+} transforms under anaerobic conditions to the bioavailable form of mercury, MeHg (Marvin-DiPasquale and Agee, 2003). MeHg is the species of concern as it bioaccumulates in the aquatic food web by first adsorbing to phytoplankton (Krabbenhoft and Rickert, 2016). The transformation of inorganic Hg^{2+} to organic MeHg happens through a process called methylation. It is generally understood to avoid restoration in wetland habitats as these areas are conducive to methylation, given their conditions of permanent inundation, high dissolved organic carbon, and low dissolved oxygen. Increasing acidity can also increase methylation rates (Krabbenhoft and Rickert, 2016).

Mercury was not scored using the good, fair, or poor conditions like the other parameters as it is difficult to predict how to the concentrations of the toxic form of mercury, MeHg, will transform from total mercury soil samples. However, even small concentrations of total mercury in sediment can have deleterious effects in an aquatic ecosystem (Marvin-DiPasquale and Agee, 2003). Total mercury soil samples taken on the Lower Yuba River are shown below in Table 6.

Table 6. Soil samples for total mercury (μg/g) adapted from Singer et al. (2016). Shown here are the median values for samples take in the channel, bar, and historical terrace areas of the Lower Yuba River. NA = not available.

Stream Reach	Channel	Bar	Historical Terrace
Englebright Dam	NA	NA	NA
Narrows	NA	NA	NA
Timbuctoo	0.82	0.28	0.42
Parks Bar	NA	0.16	0.30
Dry Creek	NA	0.12	0.11
Daguerre Point Dam	NA	0.10	0.19
Hallwood	0.06	0.18	0.24
Marysville	NA	0.12	0.31

Ecological Resources

Ecological Resources: Benthic Macroinvertebrates

Background

Freshwater benthic macroinvertebrates (BMI) reside under submerged rocks, logs, debris, and aquatic vegetation (Sacramento River Watershed Program, 2017; USEPA, 2006). BMI include immature forms of aquatic insects, crustaceans, and worms. Many BMI taxa are highly sensitive to changes in the aquatic environment (USEPA, 2006) and thus can act as useful indicators of stream health. BMI diversity decreases with disturbance, and so we expect a more degraded river to have lower BMI diversity than a less disturbed (or a more restored) river (Lenat, 1988). BMI are the primary food source for Chinook salmon and steelhead juveniles and consume algae and aquatic vegetation, thus benefit water quality (NOAA, 2016; USEPA, 2006). Because of their sensitivity and because they serve as a food source for salmonids, we have selected BMI as an indicator to evaluate both the current state of the Lower Yuba as well as projected future conditions as the result of restoration.

Methods and Results

The Yuba County Water Agency conducted a short-term sampling of BMI data on the Lower Yuba River (Yuba County Water Agency, 2013). Thus, long term BMI data on the Lower Yuba is limited, and so results from this study are used to infer current BMI conditions as well. BMI were sampled in six of the eight geomorphic reaches: the Narrows, Timbuctoo, Parks Bar, Dry Creek, Daguerre Point Dam, and Hallwood (Yuba County Water Agency, 2013). Because no sampling occurred in the Englebright or Marysville reaches, we assume here that BMI conditions in these reaches were the same as in their closest sampled reach. All sites were sampled in mid-July 2012 using the Large River Bioassessment Protocol (Yuba County Water Agency, 2013).

To measure current BMI conditions in the Lower Yuba, we focused on results from the EPT Taxa Richness analysis. EPT Taxa Richness is the total number of EPT taxa found within the insect orders Ephemeroptera (mayflies), Plecoptera (caddisflies), and Trichoptera (caddisflies). These orders are known to be sensitive to disturbance, stress, and water quality, and thus provide an indication of stream health (Lenat, 1988). Additionally, it is well established that higher quality streams have greater EPT richness (Lenat, 1988; Sacramento River Watershed Program, 2017). Furthermore, juvenile salmonids frequently feed on Plecoptera (NOAA, 2016).

We used a standard developed by Harrington et al. for California streams to evaluate the number of EPT Taxa. A score of 19 or greater indicated good health, a score of 12-19 indicated fair health, and a score of 12 or less indicated poor health (Harrington et al., 1999). EPT health scores ranged from 6 in the upper reaches to 14 in the lowermost reaches (Table 7).

Table 7. Number of EPT taxa and corresponding health score adapted from Harrington et al. (1999). Note: reaches with "*" were not sampled by Yuba County Water Agency and score is inferred from closest reach.

Stream Reach	No. EPT Taxa	Health Score
Englebright*	6	Poor
Narrows	6	Poor
Timbuctoo	11	Poor
Parks Bar	8	Poor
Dry Creek	11	Poor
Daguerre Point Dam	7	Poor
Hallwood	14	Fair
Marysville*	14	Fair

The average EPT Taxa Richness for the Lower Yuba was 9.5. Nearby streams all received higher EPT Taxa Richness scores: Deer Creek (10.7), Middle Yuba (20.9), North Yuba (18.8), South Yuba (18.4) (Sacramento River Watershed Program, 2017).

Ecological Resources: Riparian Vegetation

Background

Riparian zones are regions abutting streams and rivers, which connect upland areas to the aquatic ecosystem via overland and subsurface flow. Although riparian zones may occupy a small proportion of the overall physical real estate, riparian vegetation can act as a buffer and disproportionately impact water chemistry (Dosskey et al., 2010). There are many processes by which riparian vegetation can influence the water quality within an adjacent river. Some of these processes include the direct uptake of aquatic chemicals, addition of woody debris and leaf litter into river channels, alteration of water movement, lowering of water temperature, and bank stabilization resulting in lower turbidity (Dosskey et al., 2010). Riparian vegetation also strongly correlates with a river's macroinvertebrate assemblage. Riparian vegetation restoration has been shown to increase invertebrate diversity (Clarke and Wharton, 2000; Iverson et al., 1993; Jahnig et al., 2009). Abundant and diverse macroinvertebrates are an important food source for juvenile salmon. Riparian vegetation inputs leaves and debris into the water column. Increased levels of organic input have been shown to increase the benthic invertebrates (Raastad et al., 1993).

Planting native riparian vegetation along the banks of a degraded river can thus be a viable option for improving water quality and ecosystem functioning. Although there is an abundance of literature defining the general effects of riparian vegetation on water quality parameters such as temperature, pH, turbidity and metal concentrations, site-specific considerations such as native species and anthropogenic history of disturbances must ultimately guide restoration actions.

Taller trees with extensive canopies are more successful at providing shade for large river systems. Shade is important because it keeps water temperatures cold for juvenile salmon. Conversely, vegetation along the streambank with shorter stature can be effective at proving more localized shade by blocking much of the incoming radiation. Beschta (1997) has noted that a mix of willows (*Salix* spp.), cottonwoods (*Populus* spp.) and other shrubs are good candidates for synergistically providing diffuse and concentrated shade simultaneously.

Currently the woody riparian species from most abundant to least abundant are as follows: various willow species (*Salix* sp. and *Cephalanthus occidentalis*), Freemont cottonwood (*Populus fremontii*), blue elderberry (*Sambucus nigra* ssp. *caerulea*); black walnut (*Juglans hindsii*); Western sycamore (*Platanus racemosa*); Oregon ash (*Fraxinus latifolia*); white alder (*Alnus rhombifolia*); tree of heaven (*Ailanthus altissima*); and gray pine (*Pinus sabiniana*) (YCWA, 2013).

Methods and Results

Percent riparian vegetation cover for each reach was calculated using spatial data provided by SYRCL. Spatial data was generated from a LiDAR Classification and Vegetation Analysis conducted by Watershed Sciences, Inc. First the total floodplain area (channel band) between the low flow (880 cfs) and high flow (21,100 cfs) waterlines was calculated for each of the reaches. The area covered by vegetation within the low and high flow waterlines was then used to find the proportion of the floodplain region covered by vegetation. For all of the reaches analyzed, riparian cover was between 20% and 40%, where Parks Bar had the lowest percent cover (21.4%) and Daguerre Point Dam had the greatest percent cover (37.2%, Table 8). Because the upper reaches of the river are difficult to access and are defined by steep slopes, riparian enhancement in those reaches was not treated as a viable remediation strategy.

Because assessing the relationship between riparian percent cover and Chinook salmon is complex, we adapted the qualitative results within YCWA, 2013 to assign health scores. These qualitative results were taken from historical aerial photography and on-the-ground surveys throughout the last century. Historical aerial photographs allowed for the analysis of percent cover for 1937, 1947, 1970, 1987 and 2010 at the reach level (YCWA, 2013). It was reported that in general, the riparian communities below Englebright Dam are healthy and recovering from a long period of anthropogenic disturbance (YCWA, 2013). An analysis of historical aerial photography revealed an estimated regrowth of riparian vegetation from 1947 to 2010, by reach, of 19% at Englebright Dam, 3% at Narrows, 65% at Timbuctoo, 51% at Parks Bar, -10% at Dry Creek, 15% at Daguerre Point Dam, 79% at Hallwood and 49% at Marysville. Although the riparian vegetation in most of the reaches has been increasing since 1947, the community composition is structurally simplistic. For these reasons, a health score of "fair" for riparian cover is assigned to each of the reaches in lieu of specified quantitative thresholds (Table 8).

Table 8. Riparian vegetation cover by reach and corresponding health score adapted from YCWA (2013). Spatial data obtained from SYRCL for analysis. NA = not available.

Stream Reach	Riparian Vegetation Cover (%)	Score
Englebright	NA	Fair
Narrows	NA	Fair
Timbuctoo	NA	Fair
Parks Bar	21.4	Fair
Dry Creek	28.7	Fair
Daguerre Point Dam	37.2	Fair
Hallwood	35.4	Fair
Marysville	33.4	Fair

Physical Conditions

Physical Conditions: Spawning Substrate

Background

The size, shape and distribution of spawning gravel can limit the reproductive success of Chinook salmon in altered river systems (Kondolf, 1993). Large angular shot-rock is an obvious hazard, capable of injuring females during redd formation as they agitate the riverbed sediment. Coarse gravel allows for well-oxygenated intragravel spaces but inadequately prevents flow-induced mechanical agitation. Fine-grained silt protects developing salmonids from high flows but can smother redds and prevent adequate oxygenation. The ideal sediment for spawning includes both coarse gravel and small particles to balance intragravel DO and physical protection from flow (Utz et al., 2013). The preferred spawning substrate used in this report card is 2.5 to 15.2 cm in diameter (good) (FERC, 2003). It should be noted that this is a simplification made for the purposes of this report with regards to data availability, and that a more detailed analysis could include the percent composition of gravel/cobble to fine sediment, with a preferred range of diameters for each.

The physical features of incoming sediment are dependent upon the mobilization of channel-bed sediment upstream. When dams, levees, and diversions alter flow and continuity, the abundance and quality of incoming sediment will also change (Merz et al., 2004).

Methods and Results

Wyrick and Pasternack (2012) provide the mean substrate size for each of the reaches along the Lower Yuba River. The results from that study are reiterated in Table 9 below. The mean substrate size below Englebright Dam had the largest diameter (29.8 cm), while Hallwood had the smallest diameter (6.1 cm). The large mean substrate below Englebright Dam is the result of the lost sediment supply and abundance of shot rock.

Table 9. Mean substrate diameter by reach and corresponding health score adapted from FERC (2003). Data obtained from Wyrick and Pasternack (2012). NA = not available.

Stream Reach	Mean Substrate Diameter (cm)	Score
Englebright	29.8	Poor
Narrows	NA	NA
Timbuctoo	16.3	Poor
Parks Bar	12.0	Good
Dry Creek	8.8	Good
Daguerre Point Dam	8.7	Good
Hallwood	6.1	Good
Marysville	8.5	Good

Physical Conditions: Pool and Riffles

Background
Pools are defined as deep areas with slow-moving water. Pools provide refuge from high temperatures and relief from fast-moving water. Riffles are shallower areas where a rapid current moves over gravel, rubble and boulders. Riffles are important to salmon because they provide suitable spawning substrate at the riffle head and provide quickly moving water laden with oxygen. A healthy river system will contain an approximately even mixture of pools and riffles interspersed throughout the channel (Platts, 1983). An approximately 1:1 pool:riffle ratio ensures habitat diversity where individuals take refuge from fast-moving water, escape hot temperatures and find good spawning areas. Although river scientists commonly interpret a 1:1 pool:riffle ratio as optimal (Platts, 1983), there is some evidence that supports adjusted regional ratios being preferable, such as 0.4:1 in the South Fork Salmon River (Platts, 1974). For the purposes of this report card, we considered an approximate 1:1 pool:riffle ratio as good (with a range of 0.6:1 to 1:0.6), 0.1:1 to 0.6:1 or 1:0.6 to 1:0.1 as fair, and a ratio more extreme as poor. In addition, pool:riffle sequences composed of cobble to gravel sized substrate have the greatest diversity and productivity of bottom-dwelling organisms in which salmonids prey (Smith et al., 1990).

According to the Habitat Suitability Index Models and Instream Flow Suitability Curves for Chinook salmon, the composition of pools within a given reach influences habitat suitability in addition to the pool:riffle ratio (USFWS, 1986). If 30% or more of the of the habitat is composed of class 1 pools during the late growing season low flow period, the reach gets a suitability score of 1.0 (optimal habitat, i.e. maximum score on the 0-1 scale), where class 1 pools are large and deep enough to provide a low velocity resting area for several adult Chinook (USFWS, 1986). If 10% to 30% of the of the habitat was composed of class 1 pools during the late growing season low-flow period, the reach received a suitability score of 0.6. If less than 10% of the of the habitat was composed of class 1 pools during the late growing season low flow period, the reach received a suitability score of 0.3. For the purposes of this report card, we used these USFWS defined bins and assign the suitability 1.0 class as good, the suitability 0.6 class as fair, and the suitability class of 0.3 as poor. Because we assumed the optimal pool to riffle ratio as 1:1 (Platts, 1983), the same suitability classes and health score designations apply to percent riffle.

Methods and Results

Wyrick and Pasternack provide the percentages of in-channel bed morphological units per reach, including percent pool and percent riffle, for each of the reaches along the Lower Yuba River (2012). The results from that study are reiterated in Table 10 below. Pools were the most dominant morphological unit in the Englebright (40.9%), Timbuctoo (20.2%) and Marysville (52.2%) reaches. Riffles were the most dominant morphological unit in the Parks Bar (19.1%) reach. Other morphological units not shown below include chute, fast glide, riffle transition, run, slackwater and slow glide. Pools reported in Wyrick and Pasternack are assumed to be class 1 pools, where a pool is defined as “an area of high depth and low velocity, and low water surface slope” (p. 39).

Table 10. Percent pool and riffle by reach and corresponding health score adapted from USFWS (1986). Data obtained from Wyrick and Pasternack (2012).

Stream Reach	% Pool	% Pool Score	% Riffle	%Riffle Score	Pool:Riffle Ratio	Ratio Score
Englebright	40.9	Good	4.4	Poor	9.3:1	Poor
Narrows	NA	NA	NA	NA	NA	NA
Timbuctoo	20.2	Fair	18.4	Fair	1.1:1	Good
Parks Bar	7.5	Poor	19.1	Fair	0.4:1	Fair
Dry Creek	6.6	Poor	10.7	Fair	0.6:1	Good
Daguerre Point Dam	5.2	Poor	13.6	Fair	0.4:1	Fair
Hallwood	8.7	Poor	12.0	Fair	0.7:1	Good
Marysville	52.2	Good	2.2	Poor	23.7:1	Poor

Summary of River Conditions

The table below summarizes the results of the river health report card for each reach of the Lower Yuba River (Table 11). There is no reach on the Lower Yuba River that receives “good” scores across all parameters, indicating a need for restoration in order to improve Chinook salmon populations. In particular, summer daily high temperatures pose threats to salmon in four of the eight reaches. Macroinvertebrate diversity is poor in most reaches of the river, and riparian vegetation is fair across the entire Lower Yuba. Additionally, % pools poor in four of the eight reaches.

Table 11. Summary of river health report card results for each geomorphic reach on the Lower Yuba River. "Poor" indicates conditions where salmon are adversely impacted, "fair" indicates tolerable conditions, and "good" indicates preferable conditions for Chinook salmon. NA = not available.

	Parameter	Englebright Dam	Narrows	Timbuctoo	Parks Bar	Dry Creek	Daguerre Point Dam	Hallwood	Marysville
Water Quality	pH	NA	NA	Fair	Fair	NA	Good	Good	Good
	Summer Daily Average Temp(°C)	Good	Good	Good	Good	Fair	Fair	Fair	Fair
	Summer Daily High Temp (°C)	Fair	Fair	Fair	Fair	Poor	Poor	Poor	Poor
	DO (mg/L)	NA	NA	Good	Good	NA	Good	Good	Good
	TSS (mg/L)	Good	Good	Good	NA	NA	Good	NA	Good
Ecological Resources	Macro-invertebrate Abundance	Poor	Poor	Poor	Poor	Poor	Poor	Fair	Fair
	Riparian Vegetation Cover (%)	Fair	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Physical Conditions	Spawning Substrate Diameter (cm)	Poor	NA	Poor	Good	Good	Good	Good	Good
	Pool (%)	Good	NA	Fair	Poor	Poor	Poor	Poor	Good
	Riffle (%)	Poor	NA	Fair	Fair	Fair	Fair	Fair	Poor
	Pool:Riffle Ratio (%)	Poor	NA	Fair	Fair	Fair	Fair	Fair	Poor

Restoration Strategies

The four highlighted restoration strategies described below were selected by reviewing the results based on the ecosystem health report card results. Additionally, completed and currently proposed restoration projects were reviewed to inform the possible scope of restoration strategies to consider, and we also reviewed literature related to life history requirements of salmonids and the types of restoration actions commonly used to improve instream conditions. Restoration strategies that had the greatest potential for increasing salmon populations were considered, specifically the strategies that increase the habitat for the juvenile salmon, which are the limiting life stage of salmon on the Lower Yuba River. Finally, when selecting restoration strategies, we also considered the relative degree of sustainability of each strategy, and whether the restoration action required long-term maintenance.

The four restoration strategies are described below. Below each strategy is a table summarizing how each river health parameter would be impacted by the restoration action. These results informed which restoration strategies were ultimately selected for recommendations and for use in the cost-benefit analysis described in later sections.

Gravel Augmentation via Gravel Sluicing

Gravel/cobble augmentation, also referred to as gravel/cobble injection, increases the available habitat for spawning adult salmonids. Gravel augmentation is defined to be the piling up of coarse sediment within or along a river, often just downstream of a dam (Wheaton, 2004). The coarse sediment is a mixture of both gravel and cobble, commonly ranging in size from 8 to 100 mm in diameter. To implement this method for the purpose of obtaining usable spawning habitat, high flows must take place post-augmentation to entrain and deposit the material as bar or riffles (Wheaton, 2004). The geomorphic goal of gravel augmentation is to reestablish sustainable sediment transport downstream of a dam during floods. This is necessary to support and maintain distinct morphological units such as backwaters, riffles and pools. The ecological goal of gravel augmentation is to create self-sustaining morphological units that have the physical characteristics necessary for the different life stages of salmonids (Pasternak, 2010). Achieving both physical and ecological goals of gravel augmentation simultaneously is difficult because if only one is achieved, this does not mean the other will be.

Injecting gravel as far upstream as possible increases the longevity of the restoration strategy (USACE, 2010). Gravel augmentation is unlikely to sustain spawning habitat in the long term, however, because it is an active restoration strategy; gravel must be continually injected into the river system because it subsequently washes downstream (Wheaton, 2004). Natural geomorphic processes of the river system need to be restored to their natural state before gravel augmentation can become a sustainable restoration strategy. In past studies, gravel augmentation has been revealed to be ineffective as the gravel settles into channel pools and is never entrained or transported (Pasternak, 2010). Thus, it is critical to have a complete understanding of the hydrogeomorphic mechanisms in place that would lead to a successful redistribution of added sediment. When implementing gravel augmentation as a restoration strategy, it is a common practice to place sediment directly into a wetted channel to create immediate spawning habitat. Additionally, large wood structures can be added in parallel with gravel placement (Wheaton, 2004).

There are multiple approaches to gravel/cobble augmentation or injection. The U.S. Army Corps of Engineers has outlined approaches as well as drawbacks while determining the best method for the Englebright Dam Reach in the Lower Yuba River (USACE 2010). Due to access, and feasibility of certain methods, the U.S. Army Corps of Engineers decided upon the gravel sluicing method. This is their preferred method of gravel augmentation due to the accuracy of gravel deposition. This involves the addition of gravel and cobble to a flexible pipe that contains water from a nearby water source or reservoir, creating a water-sediment slurry that can be piped for more direct placement by a pipe operator. On the Lower Yuba River, the entire process utilized 5 personnel and can be done at a rate of 90 to 270 metric tons (100 to 300 tons) per day. This method relies heavily on in-stream water to help transport gravel from a staging area to the river channel (USACE, 2010). One challenge is accessibility, specifically the proximity of a staging area to the river channel. The Army Corps was able to use an access road that was built for access to one of the powerhouses to reach the upper portion of the Englebright Dam Reach. This method reduces the impacts to the river channel, but machinery access remains the largest challenge.

Gravel Augmentation Impacts on River Health		
	Parameter	*Effect of Restoration*
Water Quality	pH	There is no significant impact, as the focus of this type of restoration is enhancing spawning habitat for salmon.
	Water Temperature	There is no significant impact, as the focus of this type of restoration is enhancing spawning habitat for salmon.
	Dissolved Oxygen	Addition of gravel has the potential to increase the dissolved oxygen in the tail of pools, created as the gravel is deposited on bars. Added substrate creates roughness of the substrate for increased dissolved oxygen.
	Total Suspended Solids	Placement of gravel increases the amount of suspended sediment initially, however because the placement happens only episodically it would not have a permanent impact on TSS.
	Toxics: Mercury	Placement of gravel would cause short-term increases in turbidity of released sediments from the existing river substrate and could potentially release small amounts of mercury from these sediments. Mercury could be ingested by fish and other aquatic organisms or could settle out in sediments farther downstream (USACE, 2010). Until the extent and location of mercury is better understood, effects on water quality

		can only be speculative.
Ecological Resources	Macroinvertebrate Diversity	Gravel augmentation significantly impacts the abundance and diversity of macroinvertebrates, as they are highly dependent upon the right type of substrate. New substrate placed into the river system creates new and diverse habitat for macroinvertebrates.
	Riparian Cover (%)	There is no significant impact, as the focus of this type or restoration does not create or impact riparian cover.
Physical Conditions	Spawning Substrate	Gravel augmentation significantly increases the amount of available spawning substrate for salmonid species, and because of the altered sediment transport from Englebright Dam it is the only source of spawning gravel in the upper portion of the Lower Yuba River.
	Percent Pools	The placement of gravel can help maintain river morphology, but if not done correctly with respect to the regulated flows resulting from a dammed system, can cause unexpected impacts. The geomorphic goal of gravel augmentation is to reestablish sustainable sediment transport downstream of a dam during floods. When gravel augmentation is done with the correct volume, gravel size and consideration for regulated flows it can restore fluvial processes and create desired channel morphology (GA Panel, 2005). However, there is concern that the flow regime is regulated channel morphology can be negatively impacted by pool filling resulting from lack of sediment transport (GA Panel, 2005).
	Percent Riffles	The placement of gravel into the river increases the riffle frequency. Maintaining a sustainable sediment transport allows for gravel to also be deposited throughout the river, and has the opportunity to increase riffle frequency in the reach. Gravel augmentation can occur using different placement strategies. One of these strategies includes, riffle augmentation, where gravel is placed directly onto a riffle or section of riffles within the channel to create a surface suitable for spawning (Bunte, 2004). This approach immediately crates suitable habitat for spawning and greatly increases the number of riffles within a given area of the river channel.
	Pool:Riffle Ratio	Gravel augmentation helps support the sediment transport in the river and both riffle and pool habitat increase from the addition of gravel into the system. Adding gravel will likely increase the number of riffles more than the number of pools.

Riparian Enhancement

Planting native riparian vegetation along the banks of a degraded river can be a viable option for manipulating water quality and ensuring a properly functioning ecosystem. Although there is an abundance of literature defining the general effects of riparian vegetation on water quality parameters such as temperature, pH, turbidity and metal concentrations, site-specific considerations such as native species and anthropogenic history of disturbances must ultimately guide restoration actions. In the past, the South Yuba River Citizens League (SYRCL) has planted native species including Fremont Cottonwood (*Populus fremontii*), Red Willow (*Salix laevigata*), Goodding's Willow (*Salix gooddingii*), and Arroyo Willow (*Salix lasiolepis*) (SYRCL, 2013).

Before planting riparian vegetation, managers must evaluate the suitability of a site. Firstly, if cottonwood and willow do not already exist at a proposed site, even in low densities, this is a good indicator that the site is not suitable. In general, choosing project sites that are similar to established riparian sites in terms of geomorphology, hydrology and soil chemistry will lead to higher rates of success. Secondly, in order to limit the risk of bank erosion, it is helpful when the flow through that reach is slow and the bank slopes rise upward away from the channel (can be stepped). Roughness in the understory including dense thickets of shrubland may also help alleviate conditions by slowing flow velocity and protecting retained soil in the root zone against erosion (Hoag et al., 2007).

There are many effective methods for planting riparian vegetation, and should be chosen based on the species being planted and specific site characteristics. Commonly utilized equipment include backhoes, excavators, track-mounted diggers, soil augers, planting bars and stingers (Hoag et al., 2007). When choosing a planting method, it is important to allow for good contact between the roots and soil, proper depth to water table given the species requirements and proper soil conditions to allow for mycorrhizal and/or nodule formation if applicable. A very efficient planting technique involves the stinger, which is a 3.5-inch-diameter steel bar that is attached to a backhoe capable of preparing the ground for riparian vegetation (Hoag et al., 2007). The waterjet stinger is a variant on this, which uses high pressure water to drill a hole in the stream bank and allows for excellent root to soil contact.

Riparian Enhancement Impacts on River Health		
	Parameter	*Effect of Restoration*
Water Quality	pH	There is no significant impact of riparian enhancement on pH. Sparse literature exists addressing the effect of leaf litter on river pH and the effect on a large-scale river system will be assumed to have minimal impact.
	Water Temperature	Because the water temperature ranges along the Lower Yuba River typically stay within the tolerable ranges for salmonids, it is unlikely that riparian enhancement will provide significant water temperature improvements. See Appendix X for further information.
	Dissolved Oxygen	Water temperature and dissolved oxygen concentration have an inverse relationship (Beschta, 1997). As increased vegetation will likely cool water temperatures, dissolved oxygen concentrations may increase.
	Total Suspended Solids	The presence of woody and herbaceous plants adjacent to a river can greatly reduce erosion from overland flow and floodwaters. Smaller, herbaceous cover may be beneficial for the stabilization of surface soils while the root systems of larger woody vegetation can protect

		steep slopes from mass failure events (Dosskey et al., 2010). Because turbidity is not a large water quality concern on the Lower Yuba River, the river reaches where this would apply might be limited.
	Toxics: Mercury	Plants uptake and use nutrients such as nitrogen, phosphorous, potassium, calcium, magnesium, sulfur and several other minor constituents to meet their own growth demands. Many non-nutrient chemicals, heavy metals, metalloids and other elements are also taken up through plant root tissue and sequestered (Dosskey et al., 2010). On the Lower Yuba River, this may include the uptake of mercury. Refer to section X, Mercury.
Ecological Resources	Macroinvertebrate Diversity	Riparian vegetation provides a food source for macroinvertebrates, particularly shredders, and is an important energy input that ripples through the food web and ultimately benefits salmon.
	Riparian Cover (%)	Riparian enhancement will significantly increase riparian cover.
Physical Conditions	Spawning Substrate	Riparian enhancement will not significantly increase the production of spawning substrate materials, although an accumulation of spawning gravel behind riparian debris can provide suitable spawning habitat (Merz, 2001).
	Percent Pools	Riparian vegetation is an important source of large woody debris to streams and rivers, which can cause temporary and long-term pool habitat for fish. Woody material provides cover for migrating adult salmon and can cause sediment deposits upstream of debris deposits suitable for spawning (Merz, 2001).
	Percent Riffles	Like pool creation above, riparian vegetation will add complexity to the river system via large woody debris and floodplain roughness. Both large woody debris and increased floodplain roughness are able to create riffle habitat.
	Pool:Riffle Ratio	Riparian enhancement can create both pool and riffle habitat. The ratio of pools to riffles could remain the same post-restoration if increases in rifles and pools are proportional.

Large Woody Debris Placement

Large woody debris (LWD) refers to fallen trees, root wads, stumps, logs, and branches along the edges and in streams (Senter and Pasternack, 2010). LWD can influence localized flow dynamics by creating pools of decreased water velocity that creates holding habitat for juvenile fishes (Roni and Quinn, 2000; Lassettre and Harris, 2001; Senter and Pasternack, 2010). LWD also creates suitable spawning substrate in sediment poor areas by creating sediment deposits upstream of the LWD (Merz, 2001; Roni and Quinn, 2000). Additionally, LWD on stream banks decreases erosion by trapping fine sediment (Merz, 2011; Roni and Quinn, 2000). LWD also enhances instream biological conditions by providing cover for adult and juvenile salmonids and other fish species, and provides habitat for algae and benthic macroinvertebrates which serve as significant food sources to fish (Bjornn and Reiser, 1991; Roni and Quinn, 2000). In addition, LWD also provides increased leaf litter, which serves as a food source for macroinvertebrates and fine particulate organic matter (Lassettre and Harris, 2001; Roni and Quinn, 2000).

Englebright and New Bullards Dams capture LWD and thus limit the downstream supply of LWD in the Lower Yuba River (USACE, 2014). Because of this deficit, the manual placement of LWD is a beneficial restoration strategy. In the past, the Army Corps of Engineers has placed LWD at several locations on the Lower Yuba River, using debris collected from New Bullards reservoir (USACE, 2014). Placement was done by digging shallow pits dug by an excavator, and placing pieces of LWD perpendicular to the direction of high flows (USACE, 2014). After placement of large pieces, smaller structures (including root wads) were placed in order to increase localized habitat complexity (USACE, 2014). Future placement of LWD in the Lower Yuba could follow this methodology or a similar protocol.

The primary challenge associated with LWD placement is proper anchoring of the debris stand. If LWD is not adequately anchored, debris can easily wash downstream in high flow events. The Army Corps of Engineers has not anchored or stabilized LWD in prior placement efforts (USACE, 2014), resulting in relatively short-term, unsustainable benefits.

Large Woody Debris (LWD) Placement Impact on River Health		
	Parameter	*Effect of Restoration*
Water Quality	pH	There is no significant impact of LWD on pH. Placing LWD is focused on changing the habitat characteristics of the river, and is unlikely to affect the pH of the river.
	Water Temperature	There is no significant impact of LWD on water temperature. Placing LWD is focused on changing the habitat characteristics of the river, and is unlikely to significantly affect the water temperature of the river. However, water temperature may decrease locally near LWD stands.
	Dissolved Oxygen	The placement of LWD has been recorded to both increase and decrease dissolved oxygen (DO) depending on how and where the LWD is placed, and is also dependent on particular instream conditions (Lassettre and Harris 2001, Senter and Pasternack 2010). Though placement of LWD will likely have no significant impact on DO on in the Lower Yuba, further field data will be needed to confirm this if this project is implemented.
	Total Suspended Solids	Total suspended solids (TSS) could temporarily increase during LWD placement or during storm events. However, this increase is temporary, and over a longer time scale, LWD captures fine sediment and decreases total suspended solids in the water (Lassettre and Harris, 2001).
	Toxics: Mercury	There is no significant impact of LWD placement on toxics. Placing LWD is focused on changing the habitat characteristics of the river.
Ecological Resources	Macroinvertebrate Diversity	Placement of LWD in the Lower Yuba River is expected to facilitate a significant increase in macroinvertebrate diversity by providing a direct nutrient source (Lassettre

		and Harris, 2001; Dudley and Anderson, 1982). Additionally, LWD will provide an attachment surface for filter-feeding and grazing, a refuge from high flows and predators, and as an oviposition site (Lassettre and Harris 2001, Harmon and Hua, 1986; Dudley and Anderson, 1982).
	Riparian Cover (%)	LWD placement will not affect riparian cover.
Physical Conditions	Spawning Substrate	Placement of LWD creates zones of differential scour and deposit, which results in the creation of gravel bars which are used by Chinook salmon and steelhead as spawning habitat (Lassettre and Harris, 2001; Senter and Pasternack, 2010; Roni and Quinn, 2000).
	Percent Pools	LWD placement will also improve habitat for migrating adult salmonids and juveniles by creating additional pools for holding (Lassettre and Harris 2001, Senter and Pasternack, 2010; Fausch and Northcote, 1992; Roni and Quinn, 2000).
	Percent Riffles	The placement of LWD does not typically create riffles, therefore will not change the percentage of riffles present in each geomorphic reach.
	Pool:Riffle Ratio	Because LWD placement creates pools and does not create riffles, this restoration strategy will increase the pool to riffle ratio in each geomorphic reach of the Lower Yuba.

Floodplain Lowering and Side Channel Reconnection

Increasing off-channel habitat increases the amount of habitat available for salmonid species, especially for the juvenile life stages. This can be accomplished through removing or setting back levees, reconnecting rivers with historical floodplains, reconnecting rivers to side channels via ditches or swales, creating new side channels or ponds, and restoring river movement and meandering.

Floodplain restoration seeks to reestablish historical floodplain, and is meant to augment the flow regime (Villada Arroyave and Crossato, 2010). Floodplain lowering is achieved by excavating the floodplain area abutting a stream, then steadily grading the excavated area (Villada Arroyave and Crossato, 2010). Restoration of floodplains can improve both instream and riparian habitats (Madsen, 2010).

Floodplain lowering and side channel reconnection create off-channel habitat for juvenile salmonids (Sellheim et al., 2016; Jeffres et al.,2007). In one case study, juvenile Chinook salmon reared in ephemeral floodplain habitat grew faster and bigger when compared to juveniles reared in permanent river habitats (Jeffres et al., 2007). Another objective of floodplain lowering is to dampen high water levels which occur during flooding events (Madsen, 2010). Water depth will decrease in an amount proportional to the area excavated to lower the floodplain. Over time, however, the effect on water levels fades due to sedimentation and floodplain revegetation (Villada Arroyave and Crossato, 2010).

Two significant challenges arise for these types of restoration to occur and be successful. First, public access is limited in many reaches of the Lower Yuba River. Road construction may be necessary to access a potential floodplain lowering site - this presents significant increases in project cost estimates. Second, Opperman et al. (2010) highlight the importance of a highly variable hydrograph (i.e., one that reflects seasonal precipitation) to maintain proper floodplain functioning. One major challenge of this type of restoration on the Lower Yuba River is that flow is regulated by Englebright Dam, which has dampened seasonal hydrograph variability.

Floodplain Lowering and Side Channel Enhancement Impact on River Health		
	Parameter	*Effect of Restoration*
Water Quality	pH	The focus of this type of restoration is on changing the hydraulics of the river, and it is unlikely to affect stream pH.
	Water Temperature	If a floodplain or side channels are excavated and groundwater feeds the restored area, water temperatures could decrease (Madsen 2010). The likelihood of a groundwater-fed area is dependent on reach location.
	Dissolved Oxygen	Floodplain lowering and side channel enhancement increase the surface area of the channel, there is greater opportunity for oxygen absorption. Thus, floodplain lowering may increase local dissolved oxygen concentrations (MDEQ).
	Total Suspended Solids	Mobilizing sediment is a concern during excavation of floodplains and side channels. However, after the floodplain restoration has been completed, the entrapment efficiency (the ratio between deposition and export) should increase (Kronvang et al., 2007). A restored floodplain should reduce sediment carried by overland flow (Madsen, 2010) and so the likely long term outcome is lower TSS concentrations near the project site and downstream.
	Toxics: Mercury	Legacy mercury is trapped in channel, bar, and historical floodplain sediment on the Lower Yuba River. Currently, the mercury contamination is relatively innocuous as the system is well-drained and the toxic form of mercury is unavailable to biota in its elemental form. Earth-moving restoration projects have the potential to mobilize mercury contaminated sediments, giving rise to the opportunity for elemental mercury to transform into its bioavailable form, methylmercury. Mercury concentrations tend to be the greatest in fine-grained sediments such as clay (Reimers and Krenkel, 1974). The results of a study conducted on the South Yuba River found that disturbance of fine-grained mercury-contaminated sediment would lead to mobilization of mercury to downstream environments (Fleck et al., 2011). For information on managing mercury contaminated sediment in restoration, see Appendix I.
Ecological Resources	Macroinvertebrate Diversity	Aquatic macroinvertebrates diversity would likely increase due to floodplain lowering and side channel enhancement. These strategies would likely increase retention of particulate and dissolved organic matter - the main food

		source for many macroinvertebrates species (Smock et al., 1992; Madsen, 2010).
	Riparian Cover (%)	Floodplain lowering and side channel enhancement will likely be advantageous for riparian vegetation. Restoring hydrological connectivity by excavating historical floodplains and creating side channels can create conditions favorable for riparian plant colonization (Sellheim et al., 2016).
Physical Conditions	Spawning Substrate	The focus of this type of restoration is on changing the hydraulics of the river, and does not create spawning substrate.
	Percent Pools	It is not expected that floodplain lowering would have a significant impact in the creation of pools.
	Percent Riffles	It is not expected that floodplain lowering would have a significant impact in the creation of riffles.
	Pool:Riffle Ratio	It is not expected that floodplain lowering would have a significant impact in the creation of pools or riffles.

Additional Restoration Strategies Not Included in Recommendations

Restoring degraded rivers and salmonid populations is a complex task and seldom can be accomplished by one or even a few restoration actions. Restoration recommendations are based upon a target of doubling the current population of Chinook salmon on the Lower Yuba River. To do this, restoration efforts will be focused on juvenile salmon, which are the limiting life stage. Although there are a variety of restoration actions, this analysis focuses on restoration that targets juvenile salmon and thus is not comprehensive of all available restoration actions. Based on limitations in feasibility (both financial and political) as well as prior analyses, some significant and important restoration strategies were not included in our recommendations. Two such restoration strategies are described below.

Re-establishment of Natural Flow Regimes

Englebright Dam regulates flows on the Lower Yuba river, and has historically altered the magnitude, frequency, duration, timing, and rate of change of hydrologic conditions, and has kept flows less variable over time relative to natural, non-dam conditions (Resh et al., 1988; Petts, 2009). From 1965 to 2003, flow management for environmental purposes was primarily focused on minimum flow requirements (Yuba County Water Agency, 2013). In 2008 however, a multiagency set of agreements focused on instream flow requirements of the Lower Yuba known as the Yuba Accord, was enacted (Yuba County Water Agency, 2013). The Yuba Accord established more substantial instream flow requirements across water years, and prioritized flow targets for salmonids throughout the year based on factors such as flow fluctuation, flow dependent habitat availability, habitat complexity and diversity, predation, and physical passage impediment (Yuba County Water Agency, 2013).

Because of flow management analyses, modeling, and recommendations established in the Yuba Accord, we did not explicitly analyze existing flow regimes nor make restoration recommendations for future flow regimes in our analysis. Periodic reevaluation of recommendations established by the Yuba Accord is necessary to ensure sufficient flows for salmonid survival and reproduction.

Removal of Englebright Dam

The Harry L. Englebright Dam was constructed in 1941 by the California Debris Commission. The primary reason for the dam's construction was to collect the contaminated sediments from the mining practices upstream, but eventually was authorized for the development of power generation. The dam itself stands 260 feet high and historically had a storage capacity of approximately 70,000 acre-feet. However over its lifetime, sediment has collected behind the dam, reducing the storage capacity of the dam to an estimated 50,000 acre-feet (HDR, 2013).

The California Debris Commission was decommissioned by Congress in 1986, when the United States Army Corps of Engineers assumed ownership. Although the Corps maintains the dam, they do not control water releases to the Lower Yuba River. The Yuba County Water Authority and Pacific Gas and Electric control the releases from the dam to meet instream flow requirements (HDR, 2013).

In recent years, dam removal has become a more widely-accepted restoration strategy in returning native salmonid populations to historic numbers. However, decades of sediment accumulation from the Upper Yuba watershed that now resides behind Englebright Dam is one of the biggest deterrents to removal. Additionally, much of this sediment held behind Englebright Dam is contaminated with mercury as the result of historic mining practices. If sediment were to be disturbed as the result of dam removal, the mercury would be exposed to oxygen and could then methylate and contaminate the river ecosystem. An understanding of the magnitude and range of physical and ecological responses after dam removal is a challenge and imperative for project implementation (Hart et al., 2002).

The second largest deterrent to dam removal on the Lower Yuba River is the controversial and expensive nature of removal efforts. A multitude of stakeholders are interested in the existence of Englebright Dam, including irrigators, water rights holders, recreational boaters, and local and federal government agencies. Because of this, dam removal is a politically-charged issue, further complicating removal efforts. Removal of Englebright Dam is a restoration strategy that is outside the scope of this analysis due to the magnitude of the challenges associated with implementation. Due to the federal management and ownership of the dam, removal is not considered to be a restoration strategy by the South Yuba River Citizens League.

Yuba Salmon and Habitat Relationships

Discerning the relationship between salmon habitat restoration and changes in returning adult salmon populations is challenging for several reasons. First, because salmon returns fluctuate wildly over time, relating restoration actions to adult returns is quite abstruse. Salmon have a complex life cycle with multiple life stages; each of these life stages is affected by a myriad of environmental factors impacting survival and abundance. Second, literature is sparse on the relationship between implemented restoration and local population responses. Third, to determine the correct management actions and/or restoration strategies necessary to increase adult salmon populations, information about river-specific life history is required. For example, while salmon have a wide range of habitats correlating with different life stages, generally the survival rate for only one habitat/life stage constricts the overall population abundance. Such a reduction in population numbers due the carrying capacity of a specific habitat type is called a life stage bottleneck. In order to determine the proper strategy needed to increase adult salmon populations and meet restoration targets, the life stage bottleneck specific to the Lower Yuba River should be identified.

Although there has been little research completing addressing the relationship between juvenile habitat and the resulting adult returns, there have been some recent studies that attempt to describe general salmon population characteristics. For salmon, the density-dependent life stages for salmon occur within the freshwater habitat (Milner et al., 2003). For Lower Yuba River Chinook, this would include adult spawning habitat and juvenile rearing habitat. Density-dependent forces create carrying capacities and bottlenecks at these life stages. Other studies have examined the relationship between juvenile habitat and juvenile abundance. Research has shown that riparian vegetation increases macroinvertebrate (important food source for juvenile salmon) abundance and diversity (Roni et al., 2012). Research has also shown that floodplain lowering and side channel enhancement successfully increase juvenile habitat; juvenile salmonids are frequently found in greater or equal abundances in off-channel habitat (Roni et al., 2012). This indicates that overall juvenile abundance is increased when off-channel habitat is increased. Additionally, juvenile salmonids can have higher survival rates in off-channel habitat (Jeffres et al., 2008), possibly the result of the relaxation of a bottleneck. A more detailed summary of salmon habitat literature can be found in Appendix II.

Salmon Life Cycle Model

Chinook on the Yuba have several important life stages (Figure 4): eggs, juveniles, smolts, and adult returners. Between each life stage, a survival rate can be used to calculate the abundance of one life stage as a percentage of the previous life stage abundance. For example:

Juvenile abundance = P_1 * Number of eggs
Where P_1 = Survival rate of eggs to the juvenile life stage

The demographic rates between each life stage are all less than 1, which implies a continuously decreasing population. Because salmon are semelparous, they reproduce at the end of their adult life stage. Therefore, we replace the adult survival rate with adult fecundity to calculate the number of eggs produced by that years' spawners:

Number of eggs = F_1 * Abundance of female adults
Where F_1 = Number of eggs produced per female
Assuming there are an even number of males and females (a standard assumption)

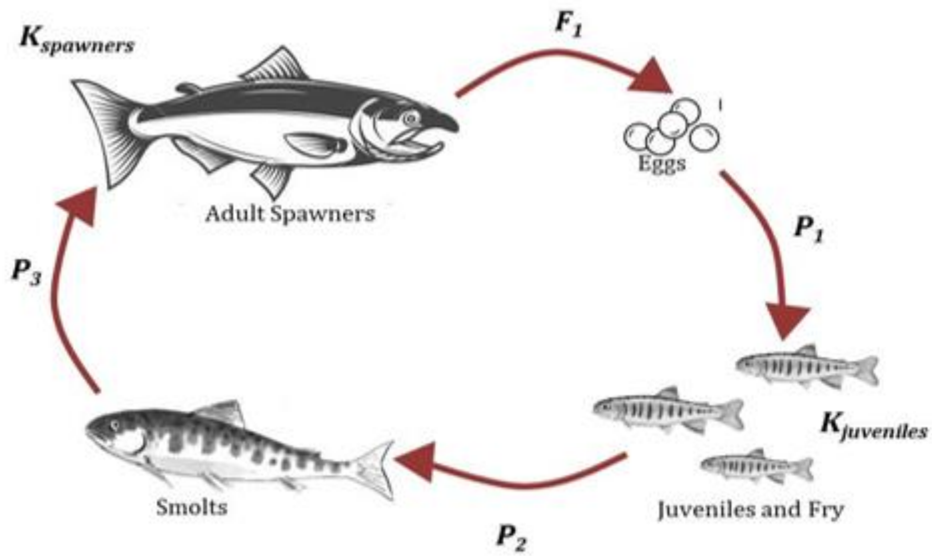

Figure 4. Salmon life cycle with important model variables. P_1 = Survival rate from egg life stage to juvenile life stage. P_2 = Survival rate from juvenile life stage to smolt life stage. P_3 = Survival rate from the smolt life stage to the adult returning life stage, also known as the ocean survival rate. F_1 = Fecundity (number of eggs produced per female, or per mating pair). $K_{spawners}$ = Carrying capacity within the river for spawning adults, determined by amount of available spawning substrate within the river. $K_{juveniles}$ = Carrying capacity within the river for the juvenile salmon life stage.

In order for a salmon population to remain relatively stable, either or both of two scenarios must be occurring:

A) The product of all three survival rates and the fecundity must be equal to 1:

Overall Survival: $P_1 * P_2 * P_3 * F_1 = 1$
Consequently, the abundance at each life stage remains constant.

B) One of the life stages is forming a bottleneck; that is, the habitat can only support a population capacity of a certain amount. If the current life stage is receiving greater numbers of survivors from the previous life stage than the current life stage can support, then there will be a die off. The life stages that are most often identified as having limiting habitat capacity are the adult spawning stage and the juvenile rearing stage (Milner et al., 2003).

If $K_{spawners} * F_1 * P_1 > K_{juvenile}$
Then the juvenile rearing habitat is creating the population bottleneck

If $K_{juveniles} * P_2 * P_3 > K_{spawners}$
Then the adult spawning habitat and substrate is creating the population bottleneck

Note, scenarios A and B are not mutually exclusive. A population experiencing a bottleneck at one life stage will inherently have a relatively lower survival rate at that life stage. In a stable population, the survival rates (and/or fecundity) from the other life-stage transitions will offset the loss.

Model Manipulation
If juveniles are the limiting life stage, doubling the juvenile habitat through restoration strategies should double the juvenile abundance, assuming juveniles occupy the new habitat, the original and new habitat have the same fish densities, and the juvenile-habitat abundance relationship is linear. This also assumes the survival rates between life stages and fecundity remain the same. Now, if the abundance of juveniles has been doubled, we would expect to see a doubling in the adult returns:

Juvenile abundance * $P_2 * P_3$ = Adult spawner abundance
2 * Juvenile abundance * $P_2 * P_3$ = 2 * Adult spawner abundance

Another way to view this is that doubling the carrying capacity will temporarily alleviate the bottleneck. For the next few generations (years), we should expect to see an increase in the juvenile abundance *and* an increase in the juvenile survival rate. There should be a temporary increase in the juvenile survival rate because the same name number of returning adults are procreating the same number of fry, which as juveniles are able to inhabit *more habitat* than previous years. A higher carrying capacity means that more juvenile fish can survive because they have more space and less density-dependent pressure. This trend will taper out once the levels of adults returning to spawn catch up; however, the higher abundances of juveniles will remain. Therefore, increased juvenile survival rates can often indicate successful habitat capacity increases.

Yuba River Life Stage Bottleneck

A more detailed version of this section can be found in Appendix III.

Adult fall-run Chinook escapement data have been collected and compiled by the California Department of Fish and Wildlife (Azat, 2016). Yearly returns average about 15,000, but adult abundances experience large fluctuations. Based on available data, the highest fish returns occurred in 1982, when 39,367 adult salmon returned to the Lower Yuba River. The lowest fish returns occurred in 1976, 2007, and 2008 when less than 10% of this maximum value (3,779, 2,604, and 3,508 adult fish, respectively) returned.

The Yuba River Management Team (RMT) used a predictive model to determine spawning carrying capacity on the Lower Yuba River (RMT 2013). They determined that the spawning carrying capacity on the Lower Yuba River 55,000 redds, or 110,000 adults. Returning to Figure 1, this means the $K_{spawners}$ = 110,000. This is far beyond the average Lower Yuba River return of about 15,000 adult salmon. This provides strong support that *adult spawning carrying capacity is **not** the limiting bottleneck for Yuba salmon*, and suggests that the juvenile habitat is instead the limiting life stage.

Although the RMT has yet to analyze juvenile carrying capacity, there does exist some (albeit limited) information on juvenile salmonids on the Lower Yuba River. Rotary screw trap (RST) data were collected for two salmon years: 2003-2004, and 2004-2005 (Massa, 2004; Massa and McKibbin, 2005). Using a trap and release methodology, it was estimated that approximately 10,000,000 juveniles passed the rotary screw trap in 2003-2004 and approximately 13,000,000 juveniles passed the rotary screw trap in 2004-2005. Based on the adult returns of the previous years, we calculated that there should have been roughly 29,000,000 juveniles passing through the RST in 2003-2004 and roughly 16,000,000 juveniles passing through the RST in 2004-2005. The discrepancy in the 2003/2004 data could indicate a bottleneck for juveniles, at least with a high predicted number of fry. In contrast, the 2004/2005 data seem to correlate reasonably well and suggests that these values are closer to the present capacity for juvenile rearing in the Lower Yuba River.

Lower Yuba River Information

Wyrick and Pasternack (2012) detail the morphological units (MUs; riffle, riffle transition, slackwater, pool, slow glide, fast glide, run, and chute) of the Lower Yuba River and their amount of area under different flow regimes (Pasternack and Wyrick, 2012). These areas are significant, as different life stages of salmon prefer different habitat types. Adult salmon prefer to spawn in riffle, riffle transition, run, and fast glide MU's. Similarly, juvenile salmon prefer different habitat types, such as feeding in riffles and resting in pools. Additionally, juveniles occur in different MU's in different densities. According to Pasternack and Wyrick 2012, there are 510 acres of total river habitat on the Lower Yuba River at 880 cfs.

Results from our ecosystem health report card indicate that the Lower Yuba River has poor macroinvertebrate EPT diversity, which can negatively impact juvenile salmonid food availability (Raastad et al., 1993). The literature also suggests a correlation between riparian plant diversity and macroinvertebrate diversity (Clarke and Wharton, 2000, Iverson et al.,1993, Jahnig et al., 2009). Fittingly, our report card also indicates poor riparian cover on the Lower Yuba River. The lack of sufficient riparian cover and macroinvertebrate diversity could be contributing to the juvenile life stage bottleneck. Thus, riparian vegetation restoration, which could increase the macroinvertebrate diversity and abundance, is a viable option for increasing juvenile habitat capacity.

Conclusions

The extensive literature review summarized above strongly suggests that the bottleneck life stage for Chinook salmon on the Lower Yuba River is the juvenile life stage. This is due to the surplus of adult spawning habitat and discrepancies in expected juveniles per adult versus actual juveniles. Floodplain restoration, side-channel enhancement, and riparian vegetation can provide good juvenile habitat. Increasing the area of these habitats will increase the carrying capacity of juvenile salmonids, which should increase the number of returning adults.

These conclusions lead us to the following assumptions for our cost-benefit analysis:

Assumption 1: The life stage limiting Chinook salmon population growth on the Lower Yuba River is the juvenile life stage. This is due to limited rearing habitat.
Assumption 2: Increasing juvenile habitat will increase the juvenile carrying capacity.
Assumption 3: The necessary restoration strategies required to increase juvenile habitat are floodplain restoration, side-channel enhancement, and riparian vegetation.
Assumption 4: The juvenile density (number of fish per square meter) will be the same in restored areas as the original river channel. Therefore, doubling the juvenile habitat will double the amount of juveniles.
Assumption 5: Survivorship between the smolt and adult spawning life stages will remain the same. Therefore, doubling the juvenile fish will double the amount of returning adults.

Selection of Final Restoration Strategies

Overall ecosystem health can be best improved by implementing restoration strategies that mitigate current reach-scale limitations for Chinook salmon population growth. Integrating multiple restoration strategies will add complexity to the river habitat and allow for increased habitat availability for salmonid species at different life stages, as each life stage of salmonids has a certain set of habitat requirements.

The Lower Yuba River Chinook salmon population has been determined to be limited by the survival of juvenile salmon. To bring back native salmon population to the Lower Yuba River, restoration strategies must focus on creating juvenile habitat. Because riparian cover, macroinvertebrate diversity, and the amount of pools available are limited on the Lower Yuba River (all important for juveniles), we ultimately selected floodplain lowering/side channel enhancement and riparian revegetation as final restoration strategies. The combination of floodplain lowering and riparian vegetation in the same location is a comprehensive approach that also mitigates erosion caused by floodplain lowering alone. We also chose these strategies because unlike gravel augmentation and the placement of large woody debris, we expect that lowered floodplains, reconnected side channels, and that riparian vegetation are self-sustaining and durable.

Going forth, we needed a baseline juvenile habitat amount to quantify the economic benefits of future restoration. The Lower Yuba River currently has 510 acres of aquatic habitat on the Lower Yuba River at 880 cfs baseflow (Pasternack and Wyrick, 2012). While flows fluctuate during the rearing season, we chose our baseline to be 510 acres at 880 cfs for a number of reasons. Due to upstream flow control measures, sustained heavy flows often do not reach the Lower Yuba River until late February, whereas peak juvenile outmigration occurs in mid-February (Massa, 2004; Massa and McKibbin, 2005). Such heavy flows do increase the overall habitat (e.g., 822 acres of aquatic habitat at bankfull 5,000 cfs). Also, any heavy early season flows often last less than a week. Excessive flow on the Lower Yuba River yields channel rearing habitat less favorable to juvenile Chinook (Gard, 2010); therefore, restoring off-channel habitat can lead to improved rearing away from the mainstem. Finally, ideally restoration increases the morphological units that support high densities of juvenile salmon, such as pools and riffles. Currently, there is far less pool and riffle habitat than 510 acres; therefore, using 510 acres as our baseline habitat will allow for conservative estimates as we quantify benefits.

Cost-Benefit Analysis

We conducted a cost-benefit analysis to compare costs and benefits of restoration. This analysis provided us with a systematic approach to evaluate project costs and associated benefits of restoration projects. In order to perform this analysis, we needed Chinook salmon population target restoration goals. The U.S. Fish and Wildlife Service sponsors the Anadromous Fisheries Restoration Program (AFRP) who sets salmon population increase goals for different rivers throughout California's Central Valley, with the primary goal being a doubling of the adult salmon population. The AFRP's goal for Fall-run Chinook salmon on the Lower Yuba River is to double the average escapement. As such, we conducted our cost-benefit analysis using a target of increasing the current salmon populations in the Lower Yuba River by 100%. In order to examine a lower and higher population target, we also considered a 50% increase in population and a 200% increase in population.

As discussed in the previous section, the Lower Yuba River currently contains 510 acres of juvenile rearing habitat. Based on our analysis of juveniles on the Lower Yuba River being the limiting life stage, and our assumption that increasing the habitat increases adult abundances at a 1:1 ratio, our three scenarios for our cost-benefit analysis are: 1) restoring 255 acres and achieving a 50% fish increase, restoring 510 acres and achieving a 100% fish increase, and restoring 1,200 acres and achieving a 200% fish increase. Although two distinct runs of Chinook salmon exist in the Lower Yuba, our calculations focus exclusively on Fall-Run Chinook salmon, as they are the most abundant.

Benefits of Restoration

We utilized four revealed preference approaches to quantify benefits associated with restoration:

1. A valuation of the river and ocean fisheries to predict how much the values of these fisheries would increase as the result of restoration.
2. A travel cost analysis, which allowed us to calculate an individual's willingness to pay for a fishing trip on the Lower Yuba River, and allowed us to predict how much how much this willingness to pay might increase as the result of restoration.
3. A carbon sequestration analysis that allowed us to calculate how much additional carbon would be sequestered as the result of restoration, and what the value of that carbon was worth.
4. A hedonic property valuation using results of a 1995 study by Streiner and Loomis, where we estimated how much property values might increase as the result of restoration.

The methods, results, and limitations for each of the four approaches to quantify benefits are described below. The order that the approaches are presented below are from greatest to least value: the fishery valuation is described first, then travel cost, then carbon sequestration and finally, hedonic property valuation.

Fishery Valuation

To estimate the economic value of restoration to the Chinook salmon fishery, we conducted an analysis of the commercial and recreational Chinook salmon fisheries. The value of the fishery using the current population was determined, as well as the value of the fishery using 50%, 100% and 200% increases in population. To determine the value that restoration provides, we calculated the difference between pre-restoration and post-restoration value. These benefits accrue as the result of increasing the number of fish in the river or ocean.

In this analysis, we examined:

1) The estimated dollar value of the recreational Chinook salmon fishery on the Lower Yuba River,
2) The estimated dollar value of the recreational ocean Chinook salmon fishery of fish derived from the Lower Yuba River, and
3) The estimated dollar value of the commercial ocean Chinook salmon fishery of fish derived from the Lower Yuba River.

River Fishery Valuation

Methods

The average value of the river recreational Chinook salmon fishery was estimated from:

1) Number of angler hours spent on the Lower Yuba River fishing for Chinook salmon (Sacramento River System Sport Fish Catch Inventory 1993 and 1994; Central Valley Salmon and Steelhead Harvest Monitoring Project 1998 and 1999).
2) Number of Chinook salmon harvested from the Lower Yuba River (Sacramento River System Sport Fish Catch Inventory 1993 and 1994; Central Valley Salmon and Steelhead Harvest Monitoring Project 1998 and 1999).
3) Average expenditure per angler day in California (2011 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation).

According to the Central Valley Angler Survey, there are a total of 56,260 angler hours on the Lower Yuba River from July 2009 to June 2010 (the most current data for the Lower Yuba River). The length of an "average angler day" represents the time, per day, an angler spends fishing for Chinook salmon on the Lower Yuba River. In this case, an angler day is equal to 4.06 angler hours. Angler hours per day were estimated by using the California Department of Fish and Wildlife annual report for the Trinity River Basin Salmon and Steelhead Monitoring Project. This report calculated the average number of hours per fishing trip on the Klamath River from 1992 to 2008. The Trinity River Basin was chosen to use as a proxy for the average number of angler hours per day because the data was the most representative of fishing effort on a river over roughly a twenty-year period. These data were averaged from 1992 to 2008, resulting in an average of 4.06 angler hours per fishing day.

Under the assumption that the average angler day catching Chinook salmon on the Lower Yuba River is 4.06 hours, the current annual value of the river recreational fishery was calculated. First, we calculated the historical number of angler days spent on the Lower Yuba River fishing for Chinook salmon for every year with data.

Number of angler hours ÷ 4.06 angler hours per angler day = Number of angler days

Then we calculated the total expenditure for Chinook salmon on the Lower Yuba River for every year with data.

Number of angler days × Average expenditure per angler day = Total expenditure

Then we calculated the historical value of each Chinook salmon within the Lower Yuba River by allocating the total expenditure evenly to each Chinook salmon harvested that year.

Total expenditure ÷ Number of Chinook salmon harvested = Value per Chinook salmon

Then we calculated the average value per Chinook for all years, which we used to estimate the current fishery valuation and the fishery valuation under various restoration scenarios where a 50%, 100% and 200% increase in fish abundance from 2014 Chinook salmon population estimate (18,080 Chinook salmon) occur. Chinook salmon estimates from 2014 were the most recent data available for the Lower Yuba River.

Value per Chinook salmon × Chinook salmon population size = Chinook salmon fishery valuation

Results

Data was available for four years, 1993, 1994, 1998 and 1999. Chinook salmon were federally listed in 1999 which prohibited harvest within the Lower Yuba River in subsequent years. The total number of angler hours for the available years of data were 2,079 hours in 1993, 1,657 hours in 1994, 3,663 hours in 1998 and 7,431 hours in 1999. We calculated the total expenditure for Chinook salmon on the Lower Yuba River to be $52,024 in 1992, $41,464 in 1993, $91,661 in 1998 and $185,950 in 1999 (in 2015 dollars). The average value per Chinook salmon was calculated to be $236. Using 2014 population data (18,080 Chinook salmon), we calculated the value of the 2014 fishery at about $4,000,000. Table 12 summarizes the pre-restoration and post-restoration values using the described methodology.

Table 12. Estimated annual value generated to the river recreational fishery from under various population scenarios.

Population Scenario	Value of Fishery	Value from Restoration
Current Conditions*	$4,266,649	NA
50% Increase	$6,399,973	$2,133,324
100% Increase	$8,533,297	$4,266,648
200% Increase	$12,799,946	$8,533,297

*Based on 2014 data

Limitations to River Fishery Valuation

The limited amount of angler survey data available for Chinook salmon on the Lower Yuba River limits the predictive accuracy of our analysis. With additional data, a more representative value per Chinook salmon could inform calculations. However, other fishery valuation studies have calculated similar or much greater values. We consider $236 per Chinook salmon quite conservative, as other benefit analyses use a value of $2,000 per fish (e.g., ECONorthwest, 2012).

Ocean Fishery Valuation

To determine the value of the ocean fishery, we found the value of both the recreational fishery and the commercial fishery. Both methods are described below.

Recreational Ocean Fishery

Methods

Average value of the ocean recreational Chinook salmon fishery was estimated from:

1) The number of chartered and private recreational Chinook salmon fishing trips in California in 2015 (Pacific Fisheries Management Council, 2015),
2) The total catch of Chinook salmon from these trips (2015) (Pacific Fisheries Management Council, 2015), and
3) The average expenditure per chartered and private recreational salmon fishing trip (NMFS, 1985).

With the assumption that the Lower Yuba River provides approximately 2.5% of all Chinook salmon to the ocean fishery (TNC, 2016; CalFish, 2016), current annual value of the recreational ocean fishery was calculated.

First, we calculated the value from chartered and private trips individually, as expenditures from these two types of trips varies.

(Chartered Chinook salmon fishing trips in 2015 × 0.025)
× (Average Expenditure per Chartered Trip)

$$= Value\ from\ Chartered\ Trips$$

$$(Private\ Chinook\ salmon\ fishing\ trips\ in\ 2015 \times 0.025) \times$$
$$(Average\ Expenditure\ per\ Private\ Trip)$$
$$= Value\ from\ Private\ Trips$$

Then, we added the value from chartered and private trips to generate a total value of the ocean recreational fishery attributable to the Lower Yuba River.

$$Value\ from\ Chartered\ Trips + Value\ from\ Private\ Trips$$
$$= Total\ Value\ of\ Recreational\ Chinook\ Salmon\ Fishery\ in\ 2015$$

This total value of the fishery in 2015 provided a baseline, pre-restoration annual value of the Chinook salmon recreational ocean fishery. Calculations were repeated with 50%, 100%, and 200% increases in salmon populations. We repeated these calculations under the assumption that any increase in Lower Yuba River salmon populations would result in a respective increase in the number of recreational ocean fishing trips as they relate to Lower Yuba River salmon populations.

$$\begin{pmatrix} Number\ of\ Chartered\ Chinook\ salmon\ fishing\ trips\ in\ 2015 \times 0.025 \times \\ Percent\ Increase\ in\ Salmon\ Populations \end{pmatrix}$$
$$\times (Average\ Expenditure\ per\ Chartered\ Trip)$$
$$= Value\ from\ Chartered\ Trips\ with\ Doubling\ in\ Yuba\ River\ Populations$$

$$\begin{pmatrix} Number\ of\ Private\ Chinook\ salmon\ fishing\ trips\ in\ 2015 \times 0.025 \times \\ Percent\ Increase\ in\ Salmon\ Populations \end{pmatrix}$$
$$\times (Average\ Expenditure\ per\ Private\ Trip)$$
$$= Value\ from\ Private\ Trips\ with\ Doubling\ in\ Yuba\ River\ Populations$$

Then, we summed these two values,

$$Value\ from\ Chartered\ Trips + Value\ from\ Private\ Trips$$
$$= Total\ Value\ of\ Recreational\ Chinook\ Salmon\ Fishery\ with\ Doubling\ of\ Yuba\ River\ Populations$$

We compared this predicted increase in value to the 2015 value of the recreational fishery to determine the additional economic value of restoration generated *annually*.

$$Total\ Value\ of\ Fishery\ in\ 2015 -$$
$$Total\ Value\ of\ Fishery\ with\ Increase\ in\ Yuba\ River\ Salmon\ Populations$$
$$= Additional\ Value\ Generated\ from\ Restoration$$

Results

The value of the ocean recreational fishery attributable to Lower Yuba River salmon populations in 2015 was $936,278. Doubling 2015 Lower Yuba River salmon population numbers generates $936,278 in additional value, with a total value of $1,872,55 (Table 13).

Table 13. Estimated annual value generated to the ocean recreational fishery from Chinook salmon restoration. NA = not applicable.

Population Scenario	Value of Fishery	Value from Restoration
Current Conditions*	$936,278	NA
50% Increase	$1,404,416	$468,139
100% Increase	$1,872,555	$936,278
200% Increase	$2,808,833	$1,872,555

*Based on 2015 data

Commercial Ocean Fishery

Methods

To determine the value of the commercial ocean Chinook salmon fishery, we used:

1) The number of pounds of Chinook salmon harvested off the coast of San Francisco from 2015 (Pacific Fisheries Management Council, 2015), and
2) The price per pound of Chinook salmon in California in 2015 (Pacific Fisheries Management Council, 2015).

With the assumption that the Lower Yuba River provides approximately 2.5% of all Chinook salmon to the fishery (TNC, 2016; CalFish, 2016), we calculated the current value of the commercial ocean fishery.

(*Number of Pounds of Salmon Harvested off the Coast of San Francisco in 2015 × 0.025*)
× (Price per Pound of Salmon in 2015)
= Total Value of Commercial Fishery in 2015

The total value of the fishery in 2015 provided us a baseline, pre-restoration value of the Chinook salmon commercial ocean fishery attributable to the Lower Yuba River. Calculations were then repeated with 50%, 100%, and 200% increases in salmon populations. We repeated these calculations under the assumption that an increase in Lower Yuba River salmon populations would result in a respective increase in the number of pounds of salmon harvested that would be derived from Lower Yuba River salmon populations.

To predict how price would change from an increase in ocean salmon populations, we used historic Chinook salmon prices (per pound, adjusted for inflation) and number of pounds harvested annually to generate a linear model (Pacific Fisheries Management Council, 2015).

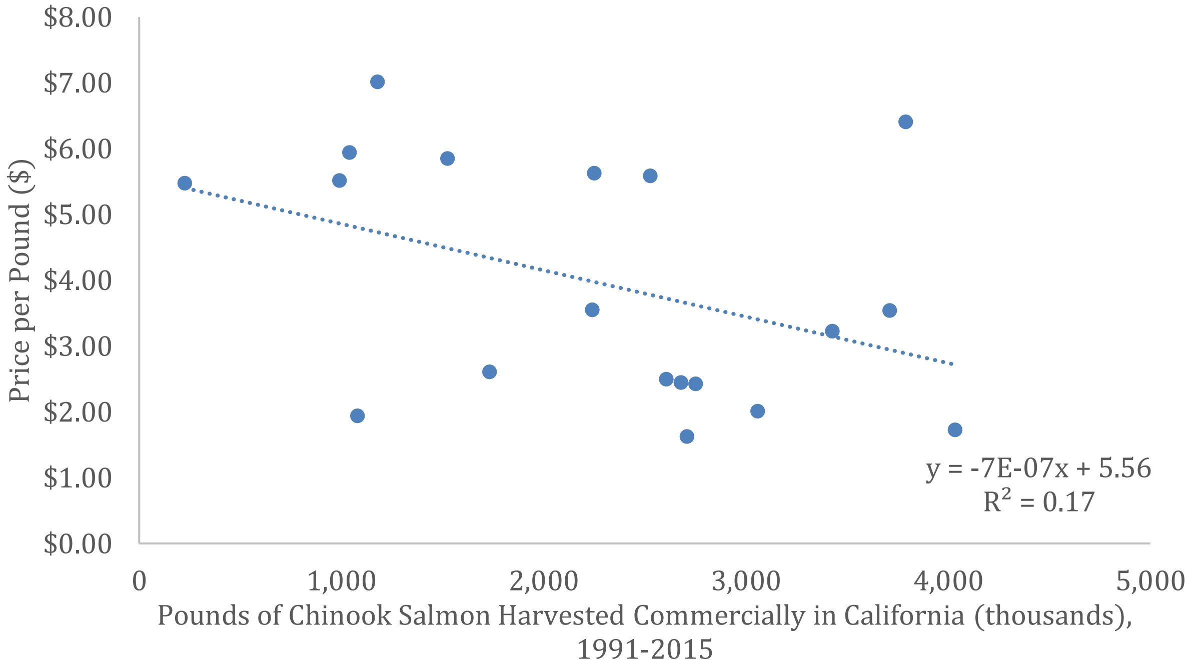

Figure 5. Number of pounds of Chinook salmon harvested commercially from 1991-2015 and price per pound. Data source: Pacific Fisheries Management Council (2015).

These data revealed no significant trend in Chinook salmon prices with catch, therefore we assumed prices of salmon would not change significantly relative to 2015 prices as the result of increases Yuba River populations following restoration. We then determined how much economic value would increase as the result of restoration.

(Number of Pounds of Salmon Harvested off the Coast of San Francisco in 2015 × 0.025)
× Percent Increase in Salmon Populations × (Price per Pound)
= Total Value of Commercial Fishery with Increase in Yuba River Populations

Lastly, we compared this value to the pre-restoration value of the commercial fishery to determine how much additional value restoration would generate *annually*.

Total Value of Fishery in 2015 –
Total Value of Fishery with Increase in Yuba River Salmon Population
= Additional Value Generated from Restoration

Results

The value of the ocean commercial fishery attributable to Lower Yuba River salmon populations in 2015 was $206,970. Doubling 2015 Lower Yuba River salmon population numbers generates $206,970 in additional value, with a total value of $413,941 (Table 14).

Table 14. Estimated annual value generated to the ocean commercial fishery from Chinook salmon restoration. NA = not applicable.

Population Scenario	Value of Fishery	Value from Restoration
Current Conditions*	$206,970	NA
50% Increase	$310,455	$103,485
100% Increase	$413,941	$206,970
200% Increase	$620,911	$413,941

*Based on 2015 data

The total fishery value after restoration is shown below in Table 15. The benefits of restoration range from approximately $3,000,000 to $11,000,000.

Table 15. Total annual value of the Chinook salmon fishery after restoration. Values from the "Additional Value from Restoration" columns from Tables 12, 13, and 14 were summed for each population scenario to get the total value.

Population Scenario	Total Annual Value of Restoration
50% Increase	$2,704,948
100% Increase	$5,409,896
200% Increase	$10,819,793

Challenges and Limitations of Ocean Fishery Analyses

Accurately determining how many Chinook salmon reside in the Lower Yuba River and how many from the Lower Yuba migrate to the ocean is challenging. Available data were used to determine that the Yuba River contributes 2.5% of all Chinook salmon found off the coast of California, however, determining this exact contribution was difficult and the Yuba's relative contribution to ocean populations likely varies over time. Additionally, we did not take into account survivorship in our analysis, and assumed that all fish from the Lower Yuba would successfully migrate to the ocean.

Although we found no significant relationship between pounds of Chinook salmon harvested and price of Chinook salmon, it is possible that increasing Chinook salmon populations in the Lower Yuba River would change prices of Chinook salmon in

California. However, we found no way to accurately determine this change in price with available data.

Travel Cost Analysis

The travel cost method is a revealed preference approach to quantifying benefits. Since natural areas seldom have an explicit market price, the travel cost method is a way to appraise an approximate value using geographical context and human behavior (OECD, 2006). The travel cost method assesses the value of recreation and natural spaces through several input factors such as the round trip distance traveled by visitors to the natural space, average income, zip code, and level of education. This methodology derives value for a natural space from the values expressed in the market for trips to the area of interest.

The travel cost method quantifies the willingness to pay (WTP) for an individual to travel to a recreational area. In this case the WTP quantifies what an angler would pay to travel and fish on the Lower Yuba River. The costs associated with traveling exist in two categories. Examples in the first category include cost of fuel or vehicle depreciation. The second category includes less direct costs such as the opportunity costs of missing work (OECD, 2006). To estimate the value of fishing on the Lower Yuba River, we used a benefit-transfer approach to apply a travel cost study of fishermen traveling to a river to go fishing. Benefits were measured as the total annual value of the Lower Yuba River to recreational anglers.

The value that an angler places on one fishing trip is multifaceted, as seen in the willingness to pay definition, and includes the value of the local fishery. Because the river fishery valuation as described in the previous section also accounts for the value the local fishery, these two methodologies quantify some of the same benefits and so cannot be added together to get a total benefit.

Although adding the river fishery valuation and travel cost analysis results together would be double-counting benefit measures, there are still major differences between the two methodologies. The river fishery valuation simply takes the total Chinook salmon angler expenditure and applies it to each harvested individual to get a dollar per fish value. This dollar per fish value is then applied to the total population. Comparatively, the willingness to pay calculation in the travel cost analysis ignores what each salmon is theoretically worth, but instead estimates what people are willing to spend. The travel cost analysis also explicitly considers the opportunity cost of missing work and site characteristics. The willingness to pay values are calculated using the creel survey data of the number of hours spent fishing on the Lower Yuba River per day, collected by the California Department of Fish and Wildlife.

The benefit of the fishery valuation is much greater than the benefit that was calculated for the travel cost. This is due to the fact that fishery valuation applied a dollar amount to the entirety of the instream fish population, whereas the travel cost analysis considers the instream fish population indirectly, amongst a variety of contributing factors. Since the travel cost analysis was not included in our final benefit calculations, a condensed version of this methodology is described below. For a more detailed explanation of the travel cost calculation, see Appendix III.

Methods

Annual Angler Value Before Restoration

We applied the results of an existing travel cost study to the Lower Yuba River in order to estimate the current value of the river. We used the findings of Tsournos et al. (2016) as the basis for our analysis; this study used the travel cost methodology to value fishing trips on different sections of the Sacramento River to which the Lower Yuba River is a tributary. The study focuses on quantifying the benefits that recreational anglers place on fishing using data from multiple years. While this study was not conducted on the Lower Yuba River, it is within close geographic proximity and anglers traveling to the Lower Yuba River have similar socio-economic characteristics.

Tsournos et al. (2016) divided the Sacramento River into 6 segments (Figure 6). For each river segment, researchers determined the average annual willingness to pay (WTP) per fishing trip to an angler. The average WTP per fishing trip for the segment of the Sacramento River closest to the Lower Yuba River – Section 4 – was used in our calculations. The total annual value for Section 4 was found by multiplying the WTP for a fishing trip by the number of angler fishing days per year. To improve the accuracy of this model for our area of interest, we used creel survey data from the Lower Yuba River to determine our site-specific number of angler fishing days (CDFW, 2010). We multiplied the Tsournos et al. value of willingness to pay per fishing trip by the number of angler fishing days on the Lower Yuba River to represents the travel cost value under current river conditions. the current annual value of fishing on the Lower Yuba River to be approximately $1,400,000.

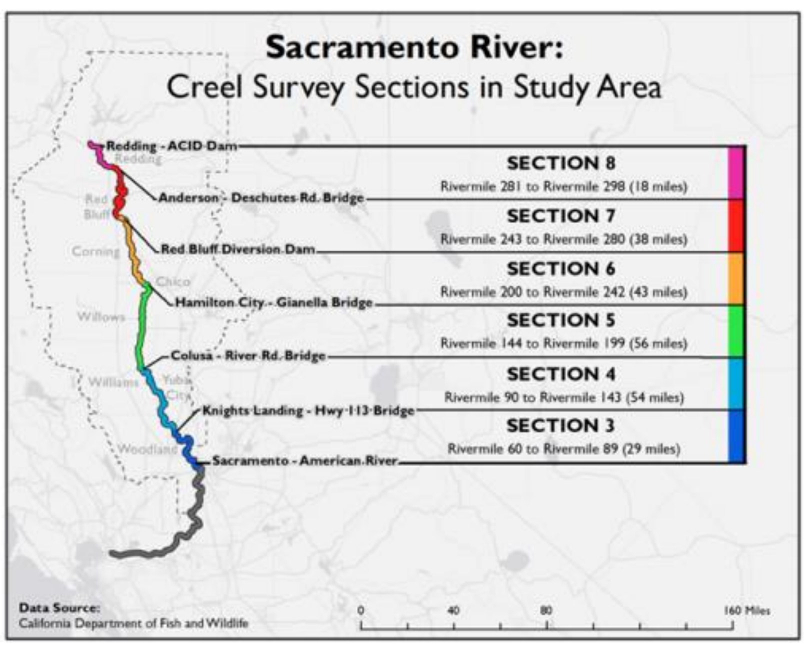

Figure 6. Study areas designated by Tsournos et al. (2016). Section 4 is used in this analysis as a proxy for the Lower Yuba River.

Annual Angler Value Post-Restoration

Restoration is expected to increase the quality and quantity of fishing, and as such there can be an expected increase in the number of fishing trips that anglers make to the Lower Yuba River. A greater number of fishing trips will also increase the annual value that anglers place on fishing the Lower Yuba River. For every 1% increase in fish population, there is between a 0.23% - 0.83% increase in fishing trips (Loomis and Fix, 1998; Loomis and Cooper, 1990). Using our target population increases (50%, 100%, 200%), we calculated the value of angler's place on the Lower Yuba River after restoration.

Results

The annual value of fishing trips to the Lower Yuba River after restoration ranges from $157,365 to $2,271,532 (Table 16).

Table 16. Results of the travel cost analysis for the Lower Yuba River.

	Population Increase Scenario					
	50% Increase		100% Increase		200% Increase	
	Low*	High**	Low	High	Low	High
Value from Restoration	$157,365	$567,883	$314,730	$1,135,766	$629,461	$2,271,532
Total Annual Value to Anglers	$1,525,758	$1,936,276	$1,683,123	$2,504,159	$1,997,854	$3,639,925

*Low refers to a 1% increase in fish population equating to 0.23% increase in fishing trips per year (Loomis and Fix, 1998)

**High refers to a 1% increase in fish population equating to 0.83% increase in fishing trips per year (Loomis and Cooper, 1990)

Limitations of Travel Cost Analysis

There are several limitations to the travel cost analysis, of which the two greatest challenges in implementing this approach are discussed here. For further discussion, see Appendix III.

- Although these rivers are hydrologically connected, they span different spatial scales. The Sacramento is the largest river in California, with average runoff equaling >20,000 cfs (USGS, 2013). The Lower Yuba River has a mean annual discharge of 2,500 cfs and is currently regulated by Englebright Dam. Although the rivers differ in size, we determined the application of Tsournos et al. study is still appropriate as the Lower Yuba River is the only tributary to the Sacramento that remains predominantly populated by native salmon species (USGS, 2009).

Negating the differences in river size and flow capacity, the willingness to pay value that was applied to the Lower Yuba does come from a portion of the Sacramento that has been altered by human activities and has yet to be a focus of restoration. With lack of sufficient data to conduct a travel cost analysis for the Lower Yuba River, we determined a benefit-transfer approach was appropriate. Additional information from the Yuba River was gathered to supplement data and generate the results of this travel cost study.

- The travel cost method is limited to calculating a value for travel to the Lower Yuba River and does not account for any other destinations that an angler may stop on the way to the river. If multiple stops are made along the way, then the willingness to pay is overestimating the value an angler places on the Lower Yuba River for a fishing trip.

Carbon Sequestration Analysis

In California, efforts are increasing to reduce carbon emissions and limit climate change effects. Voluntary carbon offsets are utilized to lower carbon footprints. Essentially, a carbon offset provides a means for a firm to voluntarily mitigate their carbon emissions through reforestation. In theory, reforestation helps remove atmospheric carbon by sequestering it as woody plant material (Gorte, 2009). As carbon offset markets gain traction, it has been suggested that river restoration projects can utilize voluntary carbon offset markets to pay for themselves (Matzek et al., 2015). Here, we analyze what monetary benefits are associated with restoring riparian vegetation along the Lower Yuba River as this vegetation stores additional carbon.

Methods

As discussed in the Selection of Restoration Strategies section above, we chose floodplain lowering and riparian vegetation as the strategies with the greatest opportunity to improve the limiting life stages of Chinook salmon on the Lower Yuba River. We examined how much carbon would be sequestered under our three riparian vegetation restoration scenarios: 255 acres, 510 acres, and 1,020 acres, which correspond to 50%, 100%, and 200% increases in restored area. We then determined the amount of carbon sequestered by an acre of using guidelines suggested by the federal government. The USDA estimates between 0.5 and 0.9 metric tons of CO_2 are sequestered per acre of riparian vegetation annually (Lewandrowski et al., 2004). The EPA estimates between 0.4 and 1.0 metric tons of CO_2 are sequestered per acre of riparian vegetation annually (EPA, 2005). We used the EPA estimates in our calculations because they provided a larger range, which increases the likelihood the Lower Yuba River revegetation falls within these values. Finally, we reviewed the price of voluntary carbon offsets currently available on the market, and found that the average price per metric ton was $5.95. We then used the following calculation to determine the amount of carbon (in metric tons) that restoration of the Lower Yuba River would sequester annually.

Acres of Vegetation Planted × Carbon Sequestered per Acre × Price of Voluntary Carbon Offset =Annual Value of Riparian Planting Projects

Results

Benefits from carbon sequestration add a modest annual benefit. We found that under the most extreme circumstances, the benefits from carbon sequestration is about $13,000 per year (Table 17).

Table 17. Estimated annual value generated from riparian planting projects on the Lower Yuba River, where a 50% increase results from an additional 225 acres of revegetation, a 100% increase results from an additional 510 acres of revegetation, and a 200% increase from 2,020 acres of additional riparian vegetation.

Number of Acres Restored	Metric Tons of Carbon Sequestered (Per Year)	Additional Annual Value of Carbon Sequestration
255	102-255	$1,338-$3,345
510	204-510	$2,677-$6,692
1,020	408-1,020	$5,354-$13,384

Limitations of Carbon Sequestration Analysis

Our analysis does not consider organic carbon held within soil, which tends to be a significant carbon sink (Matzek et al., 2015). We also did not consider carbon captured in standing dead, lying dead, or forest floor biomass, which contributes approximately 40% of carbon sequestered in riparian zones (Matzek et al., 2015). Carbon capture and storage in these areas was not included in our analysis, as these sequestration rates are highly variable and dependent on site-specific environmental conditions (Matzek et al., 2015; Rieger et al., 2011). Because of this, our calculations are likely a conservative estimate of true carbon sequestration rates as the result of riparian planting projects. Additionally, our analysis did not consider varying sequestration rates at different life stages of vegetation, and we assumed that vegetation would sequester the same amount of carbon throughout its lifespan, however sequestration rates in riparian forests increase dramatically once the vegetation is over 5 years old (Matzek et al., 2015).

Hedonic Property Valuation

Hedonic regression is a revealed preference approach of estimating value. This method deconstructs the value of a market good into its various attributes; the focus of hedonic regression is to unbundle the characteristics of a good to determine the marginal willingness to pay for each characteristic (Rosen, 1974). Freeman (1993) expanded upon the hedonic regression idea set forth by Rosen and applied it to housing values -- this methodology is known as the hedonic property method. Freeman (1993) postulated that the value of a house is a function of its structural, neighborhood, and environmental characteristics. Environmental economists use Freeman's hedonic property method to isolate the value environmental characteristics have on housing prices once structural and neighborhood characteristics are controlled for. In our case, the environmental characteristic we are interested in is how a restored Lower Yuba River might affect housing prices of adjacent residential properties.

A large body of research in environmental economics has used the hedonic property method to value environmental goods and services (Bergstrom and Loomis, 2016). However, few studies exist that estimate the impact a river has on housing value. What limited literature exists is also mixed on the effect that distance to a waterbody has on housing prices (Provencher et al., 2008). Even fewer studies exist that estimate the value a restored river has on housing prices. A prominent author of restoration valuation studies is Dr. John Loomis of Colorado State University. When asked why the hedonic property methodology was used so infrequently to quantify benefits of river restoration, he stated that many rivers run through public land, and therefore there are few opportunities to analyze a river's influence on privately-owned land parcels adjacent to the river (Loomis, 2016).

The studies that have estimated the monetary benefit of river restoration on housing values are described below. These studies quantify benefits from a wide range of restoration techniques using various temporal and spatial scales, and as such, there is not an obvious way to combine the values found.

A starting point for this analysis was Bergstrom and Loomis (2016), which provided a comprehensive literature review of studies which involved economic valuation of river restoration. Of the 38 studies reviewed, only two used the hedonic property method (Lewis et al., 2008; Provencher et al., 2008).

Lewis et al. (2008) estimated the benefits of dam removal along the Kennebec River in Maine. The site analyzed was in close proximity to a dam that was removed -- housing prices from before and after dam removal were gathered to estimate the impact of dam removal on housing value. After structural and neighborhood characteristics were controlled for, researchers found that prior to dam removal, homes suffered a price penalty for being close to the river ($2,000). After dam removal, the price penalty for homes located close to the river decreased by $134.

Provencher et al. (2008) estimated the impacts of small dam removal in south-central Wisconsin. This study compared three types of residential property sales: near an intact dam, near a removed dam, and near a free-flowing stream. The results found that housing values were higher near a free-flowing river than similar houses located near an impoundment. The authors conclude that removing a dam does not harm property values in the short term, and increases property values in the long run.

Streiner and Loomis (1995) estimated the effect stream improvements had on housing values in central California. Several general categories of restoration were analyzed, including fish habitat improvement and bank stabilization; each restoration strategy was found to impact housing values differently. Private property values were found to increase based on the restoration category, ranging from 3% to 13%: land acquisition led to a 13% increase, building an education trail saw a 12% increase, fish habitat improvement led to an 11% increase, reducing flood damage led to a 5% increase, and stabilizing stream banks led to 3% stream increase.

Methods

Based on the similarities of our study area with that of Streiner and Loomis (1995), we chose to use this as the basis of our hedonic property methodology. They present a hedonic regression that most reliably transfers to our area of study, given the proximity of their subject areas. Three northern California counties were analyzed (Solano, Contra Costa, and Santa Cruz) and included a mix of urban, suburban, and rural properties. The streams analyzed in Streiner and Loomis had an average flow of 500 cfs (up to 3,000 cfs during high winter flows), while the Lower Yuba River has a low flow >800 cfs (>20,000 cfs during high winter flows). Both are high-order, lowland rivers with high winter flows.

Property characteristics among the two study areas are also relatively similar. Both have a majority single-family residences. Streiner and Loomis analyzed rural, urban, and suburban homes with the mean assessed property value of $144,000 (1982 dollars). Residences in our study area are considered rural, with a mean assessed property value of $110,986 (1982 dollars). In the Streiner and Loomis study, parcels considered to be "adjacent to the river" were within 2,200 ft feet. This same buffer was applied to parcels on the Lower Yuba River.

Percent increases associated with fish habitat improvements from Streiner and Loomis (1995) were transferred to residential residences adjacent to the Lower Yuba River. A GIS layer of property ownership along the Lower Yuba River were obtained from the Yuba County Assessor's website. From this layer, parcel numbers were given and property ownership type, structure value, and year assessed were found. All residential properties (31 out of 429 parcels) were identified. Many properties were not assessed recently, and all structural values were adjusted to 2016 values. Furthermore, properties that were identified as "rural vacant homestead" (42 properties) were also included in this analysis. Since these properties do not have structures, the land value only for these properties were found and the 11% increase was applied. Post-restoration, these properties may be developed.

Results

As mentioned previously, housing price impacts for various stream restoration techniques were done in Streiner and Loomis (1995). Stream restoration for the benefit of fish habitat is the most similar with the restoration objectives on the Lower Yuba River - the 11% increase found in Streiner and Loomis was applied to the 31 residential structures and 42 potential residential properties to represent post-restoration housing value. These pre-restoration values were subtracted from post-restoration values and the differences were summed. The total increase in housing value because of restoration totaled $1,038,215 (Table 18).

Table 18. Total value of restoration based on hedonic property method. Parcel numbers correspond with residential parcels in the region of interest. The total value of restoration based on the hedonic property method is about $1,000,000.

Type	Value
Value from Residential Structures	$869,547
Value from Rural Vacant Homesteads	$168,668
Total Value	$1,038,215

Limitations of Hedonic Property Valuation

There are several shortcomings with hedonic pricing method in general. One flaw is on the demand-side of the market -- this method assumes that homebuyers are considering environmental information when deciding to buy a home (Lewis et al., 2008; Provencher et al., 2008). Environmental or ecological data may not be available to homebuyers, or home buyers may be unconcerned with the environment. If this is the case, hedonic property method may be placing too high an emphasis on environmental characteristics. Finally, hedonic property method may underestimate the benefit from river restoration, because property value benefits only accrue to the property owners (Young and Teti, 1984), where nonuse values are not quantified. Thus, total benefits may be underestimated. Nevertheless, this study is 20 years old and the values of restoration per household appear to be quite high. Because so few studies exist, corroborating these results is not possible.

Combining Benefits

Benefit values from the fishery valuation, carbon sequestration, and hedonic property value can be added together to get a total benefit of restoration. Fishery valuation and travel cost cannot be added as they both rely on the number of salmon in the Lower Yuba River. Benefits from the fishery valuation and the carbon sequestration are accrued on an annual basis, while the benefits from the hedonic property value are a one-time benefit.

Costs of Restoration

The costs of restoration strategies vary depending on the magnitude and type of project. Costs of each of the restoration projects include the engineering and planning costs, the permitting costs (CWA, CEQA, ESA), implementation costs and monitoring costs. As previously mentioned, the restoration projects we are focusing on are floodplain lowering/side channel enhancement and riparian plantings. Cost estimates for these projects come from a NOAA technical memo that summarizes salmon habitat restoration costs (Thomson and Pinkerton, 2008). The costs are reported in dollars per acre (Table 19).

For riparian planting costs, we considered the Lower Yuba River flat with light clearing, and for floodplain lowering and side channel reconnection costs, we considered the

Lower Yuba River a high-energy waterway. For side channel reconnection and floodplain lowering, high and low costs depend on the amount of material moved. Each of these values is multiplied by the size of the restoration scenario (255 acres, 510 acres, or 1,020 acres) to determine the overall project costs.

Table 19. Restoration cost estimates, per acre. Source: Thomson and Pinkerton, 2008.

Restoration Project Type	Low Cost Estimate (per acre)	High Cost Estimate (per acre)
Floodplain Lowering	$60,000 - $90,000	$200,000 - $300,000
Riparian Planting	$5,000 - $25,000	$30,000 - $50,000

Comparing Costs and Benefits

We assembled our cost and benefit calculations into a cost-benefit analysis. The cost-benefit analysis uses the benefit-cost ratio (BCR) to determine the economic viability of a restoration project. A BCR greater than 1 indicates that a project's benefits outweigh its costs, while a BCR less than 1 indicates that a project's costs outweigh its benefits. To determine the benefit cost ratio under our three restoration scenarios (255 restored acres and 50% increase in fish, 510 restored acres and 100% increase in fish, 1020 restored acres and 200% increase in fish), we first we converted total costs and total benefits into 2015 dollars.

Based on communication with our client, the average floodplain restoration project takes approximately three years to complete. To simulate actual project timelines, we divided project costs evenly into the first three years. Then, we assumed carbon sequestration and fishery valuation benefits began accruing in full in year 4, after the restoration project has been completed. Because riparian plantings, floodplain lowering, and side channel enhancement are considered sustainable projects, we calculated these benefits into perpetuity with a 7% discount rate (OMB, 1992). The benefit accrued from the hedonic property method is a onetime benefit accrued in year 4. We compared these benefits to project costs. An example of benefit and cost calculations for years 1 – 10, as well as the benefit and cost calculations into perpetuity for the 100% increase scenario, is shown in Table 20. The outcomes of the benefit-cost ratio under the low cost scenario is greater than 1, while under the high cost of restoration scenario the benefit-cost ratio is less than 1 (Figure 20).

Table 20. Benefits and low and high costs for years 1 – 10 and perpetuity for the 100% increase in Chinook salmon population scenario.

	100% Increase in Chinook Salmon Population		
Year	Benefits	Low Cost	High Cost
1		$14,259,054	$76,779,521
2		$12,454,410	$67,062,207
3		$11,639,635	$62,674,960
4	$4,911,567		
5	$3,861,824		
6	$3,609,181		
7	$3,373,067		
8	$3,152,399		
9	$2,946,167		
10	$2,753,427		
Perpetuity	$63,587,963	$38,353,099	$206,516,687

We found that under a scenario with 510 restored acres and a 100% increase in adult salmon abundance, the BCR for low project costs was 1.65 and the BCR for high project costs was 0.31 (Figure 7 below). In a scenario with 255 restored acres and a 50% increase in adult salmon abundance, the BCR for low project costs was 1.63 and the BCR for high project costs was 0.30. In a scenario with 1,020 restored acres and a 200% increase in adult salmon, the BCR for low project costs was 1.71 and the BCR for high project costs was 0.31.

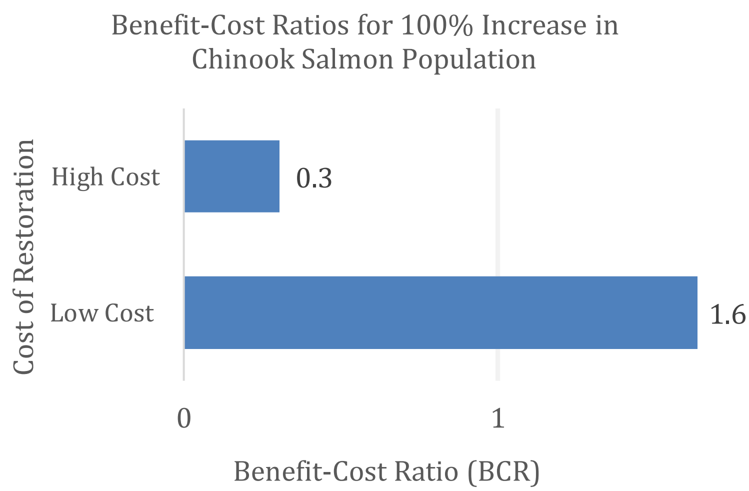

Figure 7. Benefit-Cost Ratio for the 100% increase in Chinook salmon population under the high and low cost of restoration scenarios.

Cost-Benefit Sensitivity Analysis

A significant portion of the cost-benefit analysis hinges upon whether the expected number of salmon return following restoration for adequate benefits to accrue. Additionally, results of the cost-benefit analysis reveal that the outcome is highly dependent on the cost of restoration, that is, whether a project falls under a low or high cost scenario. Further, there is variability in the different cost-benefit scenarios that is primarily impacted by the discount rate. To address these uncertainties, we performed a sensitivity analysis in order to demonstrate how salmon returns, costs, and varying discount rates impact the results of our cost-benefit analysis. In this sensitivity analysis, we answered the following questions:

1. What is the percentage increase of the adult Chinook salmon population that leads to the benefit-cost ratio equaling or surpassing 1? A benefit-cost ratio (BCR) greater than 1 indicates that it is economically feasible to undertake the restoration project.
2. How sensitive are the benefit-cost ratios to small changes in the discount rate? And at these different discount rates, how sensitive are the percentage fish returns?

Chinook Salmon Return Analysis

Our cost-benefit analysis assumes a 1:1 relationship between the amount of juvenile habitat restored on the Lower Yuba River and the number of Chinook salmon in the river; that is, if the amount of available juvenile habitat (in acres) is doubled through restoration, we expect the Chinook salmon population in the river to double. While this assumption is grounded firmly in well-established salmonid population dynamics and population ecology models, there is the potential for this relationship to not always hold. Reasons for this include: i) the population bottleneck is occurring elsewhere (namely, the adult spawning stage) or begins to act elsewhere as salmon abundance increases, ii) The juvenile abundances in new habitat are at lower densities, iii) varying hydrology prevents juveniles from reaching their carrying capacity (Poulin and Associates, 1991; Cooperman et al., 2006; Gard, 2010; Henning et al., 2006), iv) poor construction prevents off-channel habitat success (Poulin and Associates, 1991; Cooperman et al., 2006; Henning et al., 2006). Further, populations may not increase as rapidly as anticipated due to unforeseen factors, and may even decline due to stochastic events. Because of this uncertainty, we were interested in determining the minimum percentage of Chinook salmon returns where the benefit-cost ratio would equal or surpass 1, making restoration economically viable.

Our preferred scenario for restoration on the Lower Yuba is doubling the amount of available habitat, where populations also double (increase by 100%). Holding the discount rate constant at 7%, we determined that at low costs, with benefits accruing from the carbon sequestration, property improvements, and from both ocean and river fisheries, benefits outweigh costs when fish returns increase by 55% or more.

Figure 8. Chinook salmon returns required for benefit-cost ratio to at least equal one, making restoration economically justifiable. Discount rate of 7% used in all calculations. Note that under no return scenario with high costs does benefit-cost ratio equal or exceed 1.

Discount Rate Analysis

The use of a discount rate for project evaluation reflects the economic concept that costs and benefits occurring in the future may not be worth as much as those occurring in the present. This is because people prefer to consume goods and services now, and because capital invested elsewhere today could result in higher future economic returns. The discount rate for river restoration disproportionately affects benefit value, since costs are typically paid upfront and benefits accrue in the future. Discount rates vary based on the type of project being proposed and depend on where the funding is coming from. In general, a lower discount rate will be used for short-term low-risk projects compared to long-term high-risk projects.

Discount rates can significantly influence the results of a cost-benefit analysis, so choosing an appropriate rate is important. If the sources of funding are unknown or the confidence in a discount rate is low, a range of possible rates is often used. Possible funding opportunities for salmon-centric river restoration in California include the California Department of Fish and Wildlife Fisheries Grants Program, the National Oceanic and Atmospheric Administration, California State Water Resources Board, National Fish and Wildlife funds and many others. Because most of the funding opportunities came from the federal or state government, the discount rate will generally be lower when compared to private grants, reflecting the amount of risk the loaning entity perceives in regards to the project. For example, the California Department of Water Resources (CDWR) recommends using a real discount rate of 6% for state projects, based on the opportunity cost of capital (CDWR, 2008). The Association of Bay Governments used this 6% discount rate to compare a multitude of water projects including river restoration for Coho salmon and steelhead trout in California (ABAG, 2015). The Water Resources Development Act currently recommends using a real discount rate of 2.875% for federal projects, based on a mix of federal treasury bond yields (NRCS, 2017).

To test the sensitivity of the benefit-cost ratios to different discount rates, cost-benefit ratios were calculated using discount rates of 5%, 7%, 9%, 11% and 13%. The benefits of restoration include the benefits calculated using the hedonic property method, carbon sequestration analysis and the river and ocean fishery valuation method. These benefits were then compared to the range of low and high costs associated with river restoration projects to calculate the cost-benefit ratios using the range of discount rates.

The benefit-cost ratios for the high restoration costs were lower than 1.0 for every scenario modeled. Thus, the cost-benefit analysis under this scenario is not sensitive to the discount rate; the costs always outweigh the benefits indicating that there is not economic justification for restoration. However, the sensitivity analysis of the benefit-cost ratios under the low restoration costs shows a negative relationship to the discount rate. As the discount rate increases, there is a decrease in the benefit-cost ratio for every scenario (Figure 9, Figure 10).

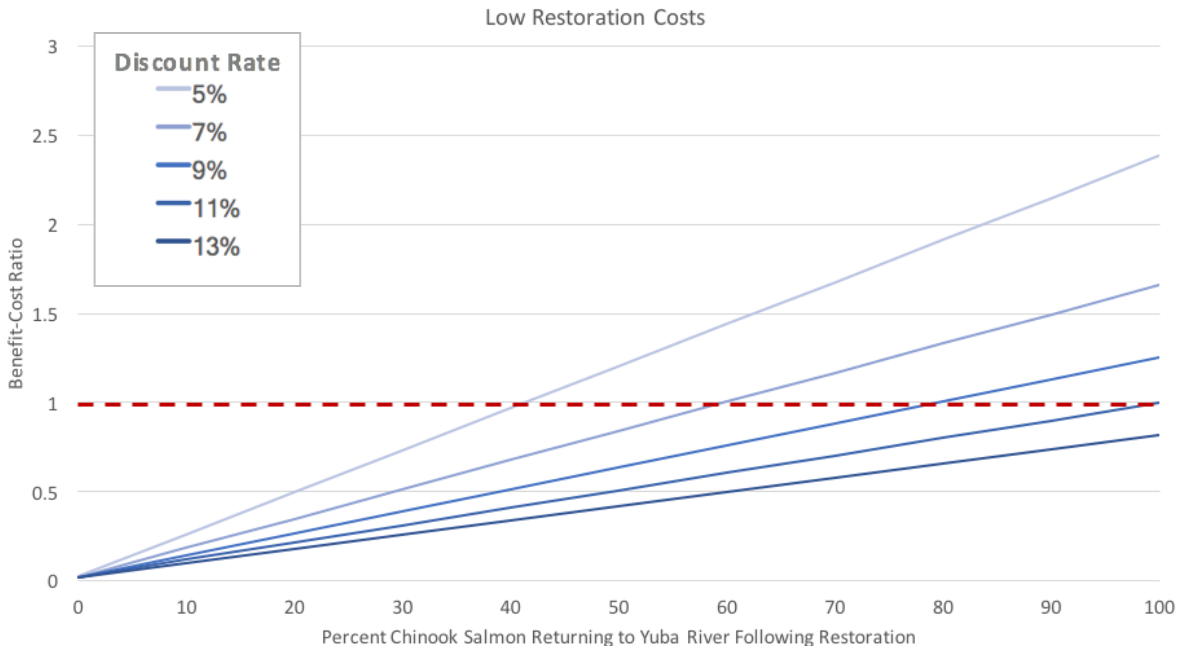

Figure 9. Benefit-cost ratios with varying discount rates (5-13%) under low restoration costs, with different scenarios of Chinook salmon returns. Percent returning refers to the percent of Chinook salmon returning following restoration which is expected to lead to a doubling of populations.

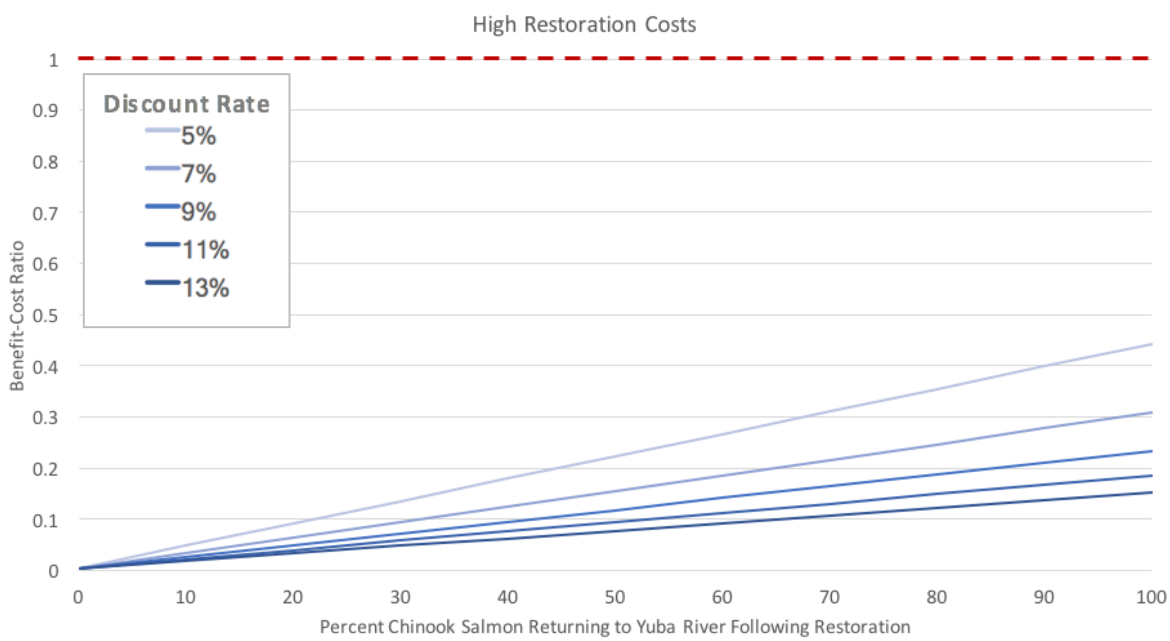

Figure 10. Benefit-cost ratios with varying discount rates (5-13%) under high restoration costs, with different scenarios of Chinook salmon returns. Percent returning refers to the percent of Chinook salmon returning following restoration which is expected to lead to a doubling of populations. Note that no scenario with high costs does the benefit-cost ratio exceed one.

To further investigate the effects of the discount rate on the cost-benefit results, the range of percent salmon returns was compared across the range of discount rates, assuming low project costs. This analysis revealed that as the discount rate increases, the percentage of salmon that need to return to obtain a benefit-cost ratio above 1 increases. At lower discount rates, fewer salmon need to return to the Lower Yuba River in order for the benefits of restoration to outweigh the costs. At a discount rate of 5%, only 45% of salmon need to return for benefits to outweigh costs (Figure 11). However, at a discount rate of 13% the salmon population needs to more than double in size for the benefits to be greater than the costs of restoration (Figure 11).

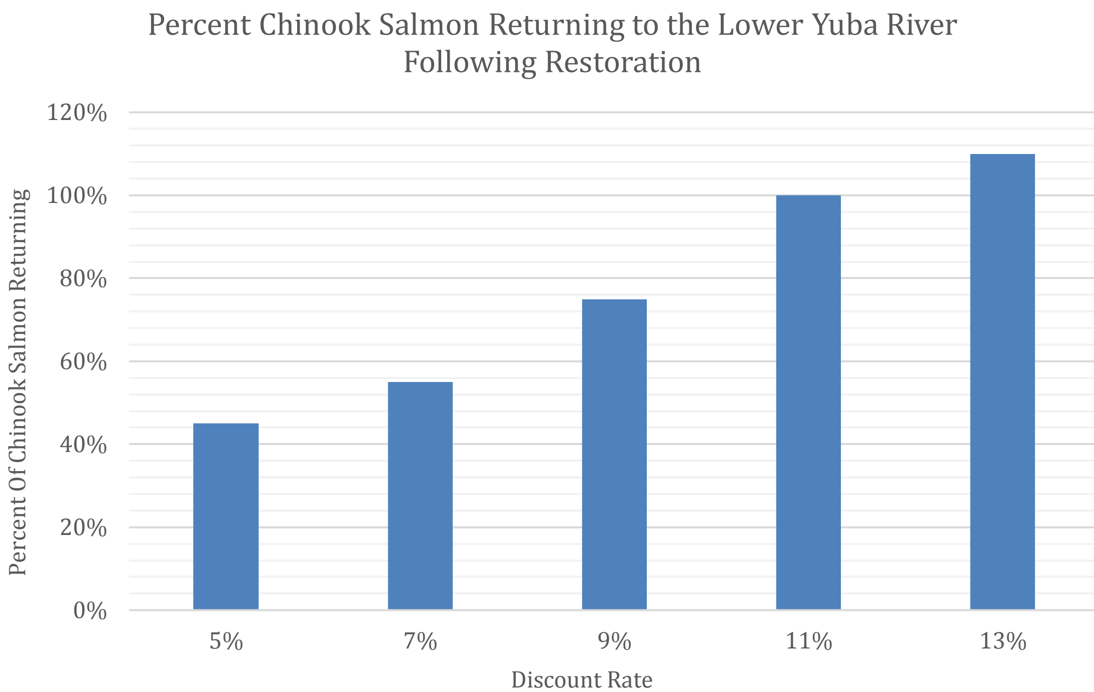

Figure 11. Percent of salmon population returns for discount rates ranging from 5%-13% to achieve a BCR of 1, assuming low project costs.

Other Considerations and Limitations

Other Valuation Approaches

We utilized four revealed preference approaches to quantify the benefits of restoring Chinook salmon populations on the Lower Yuba River. However, stated preference methods are also frequently used in cost-benefit analyses. In these analyses, individuals are asked directly via surveys how much they would be willing to pay for an improvement in a particular resource, like an increase in Chinook salmon populations. In California, Reich et al. (2012) found that individuals were willing to pay between $500 and $9,300 per year per additional salmon resulting from restoration. Additionally, when dam removal was initially considered on the Elwha River in Washington, individuals were asked how much they'd be willing to pay for dam removal that would result in improved salmon populations. Across the United States, individuals indicated that they would be willing to pay an average of $68 annually (Loomis, 1996).

A review of similar cost-benefit analyses of river restoration revealed that most evaluations of salmon utilize stated preference methods. We chose not to utilize stated preference approaches in our quantification of benefits for several reasons. First, these approaches do not employ real market transactions or consumer behavior in their analyses, and therefore lack basis in real market prices. Second, these approaches hinge upon what individuals claim they would pay or do, and not what they actually do. Thus, individuals frequently overstate their willingness to pay for a good. Lastly, this method assumes that individuals adequately understand the good in question and understand its true value. Because of these shortcomings, we did not use stated preference approaches in their cost-benefit analysis. Although there are challenges associated with the methods we utilized to quantify benefits, our results are a more accurate representation of the true monetary value of Chinook salmon than stated preference methods.

Benefits Not Captured

The benefit approaches considered in this analysis only consider Chinook salmon returns as a response to restoration. However, there are monetary benefits associated with other species along the Lower Yuba River, specifically those that are listed under the Endangered Species Act (ESA). The following species are listed as threatened under the ESA (Yuba County Water Agency, 2009):

- Layne's ragwort (*Packera layneae*)
- Vernal pool fairy shrimp (*Branchinecta lynchi*)
- Valley elderberry longhorn beetle (*Desmocerus californicus dimorphus*)
- California red-legged frog (*Rana draytonii*) Critical Habitat
- Steelhead (*Oncorhynchus mykiss irideus*), California Central Valley Distinct Population Segment (DPS)
- Chinook salmon (*Oncorhynchus tshawytscha*), spring-run Evolutionarily Significant Unit (ESU)
- North American green sturgeon (*Acipenser medirostrus*), Southern DPS

All of these threatened species would likely benefit from restoration efforts to enhance the river ecosystem. Restoration benefits these species, and they in turn add value and function to the overall ecosystem. The species mentioned above are valuable, both in intangible and monetary means, however quantifying their value was particularly more challenging that quantifying the value of Chinook salmon.

Additional benefits resulting from restoration not quantified in our analysis include flood risk reduction, groundwater recharge, sediment capture, and nutrient transport (from river to ocean). All are important benefits that add value to restoration efforts, but they were difficult to measure, especially given the spatial scale of our analysis.

Discussion

While our results encapsulate the most important economic drivers of river restoration related to Chinook salmon, the distillation of a complex ecological/economic system into a single ratio necessarily omits certain subtle details also mentioned in further detail below. Understanding the strengths and shortcomings of our results will allow for shrewd application of our major findings.

Based on our cost-benefit analysis, the greatest monetary benefit of river restoration comes from the valuation of the river and ocean salmon fisheries, which generate approximately $5 million annually in benefits. When Chinook salmon populations are doubled in the Lower Yuba River, under a low cost scenario, our analysis revealed a benefit-cost ratio of 1.65. By far, the largest contributor to total benefits was the in-river fishery valuation, while potential project costs varied wildly. Subsequently, the most significant factors influencing the benefit-cost ratio are project costs and Chinook salmon returns post-restoration. While we assume that doubling the amount of juvenile salmon habitat will double salmon populations in the Lower Yuba River, our sensitivity analysis indicated that only 60% of the population need to return for the benefit-cost ratio to exceed 1 under low project costs, thus making the project economically feasible.

Uncertainty of Restoration Outcomes

Uncertainty is an important factor when considering project viability, which we considered for a wide range of restoration strategies. These strategies include gravel augmentation, riparian revegetation, large woody debris placement, side channel reconnection, and floodplain lowering. Final project recommendations were made based on the ability of a project to create and enhance juvenile Chinook salmon habitat and the project's degree of sustainability and resiliency. In these final recommendations, we also sought to improve upon the river system capacity to recover from natural disturbance and stress. These goals differ from some current restoration work on the river, including gravel augmentation and large woody debris placement projects, which have short lifespans, require at minimum annual maintenance, and therefore are neither resilient nor sustainable. Despite the consideration of appropriate projects and their degree of sustainability and resiliency, we recognize that there exists a degree of uncertainty with any restoration project.

The probability of project failure looms over any restoration action. Failures can be manifested during or after the implementation phase, or by virtue of a project's inability to achieve a desired result. Examples of physical failures include low riparian planting survival or large woody debris purging during large storm events. Natural processes such as large earthquakes or rare flood events are capable of sullying project success if risks are ignored or minimized. Conceptual failures can also occur when the actual benefits are not commensurate with predicted benefits, despite successful implementation. Examples of conceptual failures include female spawners not utilizing added spawning gravel, juveniles not exploiting newly created pool habitat, or

population bottlenecks existing outside of the river ecosystem that result in population gains that significantly lag expected outcomes.
In order to account for the probability of both physical and conceptual project failures, an analysis of multiple outcomes is recommended. The risk of project failure can be incorporated into a cost-benefit analysis. For example, the year-one survivorship of cottonwood pods planted in 2011 within the Lower Yuba River riparian zone at Hammon Bar was 71%. (SYRCL, 2013). The expected benefit could be calculated by multiplying the benefits of having year one cottonwoods by 71%, plus a 29% chance of receiving no benefits. Cottonwood survival at year two was reported at 51%. Although the benefits of riparian enhancement could accrue in perpetuity, high tree mortality is capable of shortening the project lifetime.

Our analysis is at the river-wide scale and assumes the simultaneous implementation of multiple projects contributing to what can be called a "sufficiently restored river." While the probability of physical and conceptual project failures at any one site is difficult to predict, the cumulative interaction of multiple failures happening at the river-wide is more uncertain. Instead, we opted to perform a sensitivity analysis, looking at how a range of returning fish might affect the monetary benefits received (see Sensitivity Analysis).

Another factor influencing probability of success is project lifespans. Variability in the long-term success and lifespan of a restoration project should be considered when planning and implementing projects. Riparian vegetation and floodplain lowering were chosen as final restoration recommendations, as these projects do not require continual maintenance and are considered to be self-sustaining and reinforcing over a long timescale. There is an ever-present threat that riparian vegetation may become stripped from soil during extreme storm events or wither during periods of low flow. If these threats are realized, riparian assets can be lost and benefits may be diminished, shortened or accrue after vegetation has regenerated. Likewise, a lowered floodplain will likely remain in existence long-term, unless sufficient river meandering undercuts the bank, or regulated flow releases from Englebright Dam change and significantly increase scouring and transport of sediment downstream. Generally speaking, riparian enhancement and floodplain lowering are considered to have long lifespans.

We chose to calculate benefits of these restoration projects in perpetuity in our cost-benefit analysis. In comparison with other restoration strategies considered, we expect riparian revegetation and floodplain lowering to be significantly more resilient, sustainable, and generally have longer timescales of existence and thus longer periods of benefit accrual. Once riparian vegetation is established, we expect that some degree of regeneration will occur even after disturbance events. Similarly, if Englebright Dam were to fail or be removed, we expect that the Lower Yuba would meander and behave more dynamically, resulting in the creation of additional floodplain habitat.

While benefits were calculated in perpetuity, we considered a variety of timescales in benefit accrual and found that when benefits far into the future were discounted, these monetary benefits were essentially zero, resulting in a small margin of error when comparing benefits calculated in perpetuity to benefits accruing for 50 or 100 years. Although a degree of uncertainty exists in the lifespan of restoration work, the projects we have selected for restoration on the Lower Yuba River represent the most sustainable and resilient options for benefit accrual over a long-time scale that simultaneously exist to improve juvenile Chinook salmon habitat.

Climate change can also influence project success. In the Sierra Nevada, climate models predict 2-6°C of warming over the next century, resulting in a decrease in snowpack and more precipitation falling as rain rather than snow (Viers and Rheinheimer, 2011). Climate change will alter streamflow, place cold-water species like Chinook salmon at increasing risk of extinction, and will stress existing water regulation infrastructure (Viers and Rheinheimer, 2011). While climate change impacts were not explicitly considered when making recommendations, we expect that the restoration recommendations we have set forth will provide the Lower Yuba River system with additional resiliency needed in the face of a changing climate. It is imperative that future restoration planning efforts on the Lower Yuba River address climate change, as this adds additional uncertainty and variability to restoration work and project costs.

Although not directly included in our river health report card or in our restoration recommendations, we recognize that flow is the driving variable influencing riverine dynamics. The Lower Yuba River no longer possesses the hydrograph of a natural, undammed river. Historically, large flows occurred during the juvenile rearing season that expanded the available aquatic habitat; however, water-storing dams in the Yuba watershed have made such events less frequent, lowering juvenile survival rates (Michel et al., 2015). Therefore, all future restoration planning on the Lower Yuba River should consider that processes dependent on timing, magnitude, duration, magnitude, and quantity of flows—including riparian seedling germination and sediment scour—may be disrupted as the result of this altered hydrograph, and all restoration projects occurring on the Lower Yuba River cannot be considered entirely self-sustaining if flows are not those of a natural hydrograph. Variability in flow releases that differ from the natural hydrograph have the potential to diminish project success.

Spatial Scale of Restoration

The restoration strategies we have recommended are actions that we expect will result in the "partial restoration" of the Lower Yuba River; however, even at full implementation they would not lead to population increases significant enough to remove the Fall or Spring-Run Chinook salmon from Endangered Species Act listing. Regardless of whether all available habitat in all reaches of the Lower Yuba were to be restored, we do not expect population levels to increase sufficiently to warrant delisting. While partial restoration on a local or reach-scale is beneficial, these projects are often too small and isolated, and do not typically address watershed-wide issues. To move towards delisting this species, "full restoration" must be undertaken, which involves moving from the reach-scale to a larger, watershed-scale approach to restoration.

In the Yuba River watershed, full restoration would likely include the following actions:

- Addressing mercury contamination in the Lower Yuba River to improve water quality and limit potential mercury mobilization following restoration or high flow events,
- Removing Englebright Dam to provide upstream fish passage and to reestablish a more natural flow regime, and
- Restoring portions of the South, Middle and North Forks of the Yuba River, which historically provided spawning habitat for salmon. This would also likely include addressing mercury contamination in these tributaries.

Considering the Yuba River watershed as a whole when making restoration recommendations would address watershed-scale issues limiting Chinook salmon population growth, such as habitat availability. While restoration at this scale may be politically and economically challenging, moving towards full restoration is needed in the Yuba River watershed in order to more effectively address declines in Chinook salmon populations.

The Sacramento-San Joaquin Delta and San Francisco Bay have been postulated to act as a bottleneck on Central Valley Fall-Run Chinook because of heavy modifications (Michel et al., 2015). Research needs to examine the role these two habitats play in salmon abundance and survival. If these areas are found to be particularly detrimental to salmon populations, studies need to look at the feasibility of restoring these regions for salmon.

Further Considerations

The scale on which benefit valuation is conducted drastically affects the outcome of the cost-benefit calculations. If restoration grants were awarded with a larger scale in mind, quantifying the benefits of restoration may become more favorable. Loomis and Bergstrom (2016) found, in general, that as the size of the restoration projects increases so too does the willingness to pay for restoration.

One major challenge in quantifying the benefits of restoration on the Lower Yuba River was the small scale of the restoration projects. Some potential benefits that could have been quantified were omitted from our calculations due to their inappropriateness to be used on a small, local scale. For example, the use of an economic multiplier to determine regional impacts of restoration was omitted since the benefits would likely only to be seen locally rather than regionally. If restoration was undertaken on a larger scale, for example on the entire Yuba River watershed, it may be appropriate to then apply the economic multiplier. This would greatly increase the monetary benefits associated with river restoration for salmon.

There also exist environmental costs associated with restoration projects due to potential mercury mobilization. Environmental managers should consider the fate and transport of mercury before creating floodplain in areas with mercury-contaminated sediments. The potential harm caused by making methylmercury bioavailable in the watershed is one of the greatest sources of uncertainty in any restoration project conducted on the Lower Yuba River. More dissolved organic carbon, dissolved oxygen, water temperature, and soil mercury is data is needed to meaningfully model mercury fate and transport.

Conclusions

Quantifying benefits can be a powerful tool in the planning stages of river restoration projects. While benefit valuations are becoming more common, this type of analysis is not yet a requirement to receive state or federal restoration grants. However, the need for benefit valuation analyses in river restoration allows for concrete justification for future decision-making.

Here we have successfully provided a framework for quantifying the benefits of river restoration. We found that river restoration for salmon habitat can be economically viable if project costs are low and restoration actions successfully bring increased adult salmon returns.

Benefit valuation tools like cost-benefit analyses allow decision-makers to understand trade-offs clearly. The advantages of formal economic analysis include crystallization of costs and benefits, data gap detection, informed planning, and post-restoration examination of project success. Perhaps the most valid application of restoration benefit valuation is the comparison of benefits across competing project proposals, particularly if competing projects have significantly different cost-benefit results.

There are various environmental conditions on the Lower Yuba River that are currently unknown. To best assess the success of a restoration project, the current system must be well understood in order to identify where restoration might be most effective and what changes may occur as a result of restoration. We encourage long-term monitoring of restoration work so that a project's effectiveness can be understood on a longer time scale and so benefits measured into perpetuity may be realized. We encourage restoration practitioners to publish results of projects that are both successful and unsuccessful so that those who follow will be able to learn from their trials.

Although a growing number of agencies now use cost-benefit analyses in their decision-making process, most projects have not been sufficiently evaluated for economic benefits. For example, the U.S. Army Corps of Engineers often focuses exclusively on flood risk management benefits, which rarely have positive benefit-cost ratios (USACE, 2014b). We hope that formal economic analyses, such as the framework presented in this report, will become a routine procedure for project managers in the future. This is useful information for decision-makers requesting monetary justification for project selection and funding.

Finally, while we have taken an economic perspective to justifying river restoration, we recognize that there are benefits of a restored river that cannot be captured in strictly financial terms, and that healthy rivers themselves are inherently valuable. However, we believe that quantifying benefits in the framework we have provided in this report will allow restoration ecologists and river scientists to justify and garner the support needed for effective and widespread river restoration.

References

2016-2017 Freshwater Sport Fishing Regulation. (2016). Retrieved January 21, 2017, from https://www.wildlife.ca.gov/regulations

Ahearn, D.S., Viers, J.H., Mount, J.F., Dahlgren, R.A. (2006). Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. Freshwater Biology, 51(8), 1417–33. doi:10.1111/j.1365-2427.2006.01580.x.

Ahearn, D.S., Sheibley, Dahlgren, R.A., Anderson, M, Johnson, J., Tate K.W. (2005). Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. Journal of Hydrology, 313(3–4), 234–47. doi:10.1016/j.jhydrol.2005.02.038.

Albertson, L.K., Cardinale, B.J., Zeug, S.C., Harrison, L.R., Lenihan, H.S., Wydzga, M.A. (2010). Impacts of channel reconstruction on invertebrate assemblages in a restored river. Restoration Ecology, 19(5), 627–638. doi: 10.1111/j.1526-100X.2010.00672.x

Albertson, L. K., L. E. Koenig, B. L. Lewis, S. C. Zeug, L. R. Harrison, and B. J. Cardinale. (2013). How does restored habitat for Chinook salmon (*Oncorhynchus tshawutscha*) in the Merced River in California compare with other Chinook streams?: Habitat characteristics for Chinook salmon in a restored river. River Research and Applications 29(4):469-482.

Alpers, C., Hunerlach, M., May, J., Hothem, R. (2005). Mercury contamination from historical gold mining in California. Publications of the U.S. Geological Survey. http://digitalcommons.unl.edu/usgspubs/61

Ames, L.A. (2005). Sediment from hydraulic mining detained by Englebright and small dams in the Yuba Basin. Geomorphology, 71(1-2), 202-226.

Anderson, I.J., Saiki, M.K., Sellheim, K., Merz, J.E. (2014). Differences in benthic macroinvertebrate assemblages associated with a bloom of Didymosphenia geminata in the Lower American River. The Southwestern Naturalist, 59(3), 389-395.

Anderson, J., and Beer, W. (2009). Oceanic, riverine, and genetic influences on spring Chinook salmon migration timing. Ecological Applications, 19(8), 1989-2003.

Armstrong, J.D., Kemp, P.S., Kennedy, G.J.A., Ladle, M., Milner, N.J. (2003). Habitat requirements of Atlantic salmon and brown trout in rivers and streams. Fisheries Research, 62, 143-170.

Association of Bay Area Governments (ABAG). (2015). Integrated Regional Water Management Round 2, Implementation Grant Application Attachment 8: Benefits and Cost Analysis. San Francisco Bay Regional Water Enhancement Program.

Azat, J. (2016). California Central Valley Chinook population database report. GrandTab. California Department of Fish and Wildlife. Fisheries Branch.

Bakir, F. and Damluji, L. (1973). Methylmercury poisoning in Iraq. Science, 181, 230 - 241.

Beechie, T., Beamer, E., Wasserman, L. (1994). Estimating coho salmon rearing habitat and smolt production losses in a large river basin and implications for habitat restoration. North American Journal of Fisheries Management, 14(4), 797-811.

Beechie, T., Pess, G., Imaki, H. (2012). Estimated changes to Chinook salmon (Oncorhynchus tshawytscha) and steelhead (Oncorhynchus mykiss) habitat carrying capacity from rehabilitation actions for the Trinity River, North Fork Trinity to Lewiston Dam. Fish Ecology Division, Northwest Fisheries Science Center, NMFS, NOAA. Report prepared for USFWS.

Beechie, T. J., and Sibley, T.H. (1997). Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington atreams. Transactions of the American Fisheries Society, 126(2), 217-229

Be Prepared Yuba. (2012). History of Flooding and Flood Control. http://www.bepreparedyuba.org/pages/prepare/history.aspx

Bergstrom, J., and Loomis, J. (2016). Economic valuation of river restoration: An analysis of the valuation literature and its uses in decision-making. Water Resources and Economics. http://dx.doi.org/10.1016/j.wre.2016.12.001

Bash, J., Berman, C.H., Bolton, S. (2001). Effects of turbidity and suspended solids on salmonids. Center for Streamside Studies, University of Washington. http://ntl.bts.gov/lib/19000/19300/19329/PB2002105923.pdf.

Beschta, R. (1997). Riparian shade and stream temperature: An alternative perspective. Rangelands, 19(2), 25-28.

Beverton, R., and Holt, S.J. (1957). On the dynamics of exploited fish populations. London, Fisheries Investment Ser. 2(19): 1-533.

Bilotta, G.S., and Brazier, R.E. (2008). Understanding the influence of suspended solids on water quality and aquatic biota. Water Research, 42(12), 2849–61. doi:10.1016/j.watres. 2008.03.018.

Bjornn, Tcj, and D. W. Reiser. (1991). Habitat requirements of salmonids in streams. American Fisheries Society Special Publication, 19(837), 138.

Blackwell, C.N., Picard, C.R., Foy, M. (1999). Smolt productivity of off-channel habitat in the Chilliwack River watershed. Rep. 14. Watershed Restoration Program Ministry of Environment, Lands, and Parks and Ministry of Forests, Vancouver, BC.

Bohlin, T., Dellefors, C., Faremo, U., Johlander, A. (1994). The energetic equivalence hypothesis and the relation between population density and body size in stream-living salmonids. American Naturalist, 143(3), 478-493.

Bonnell, R.G. (1991). Construction, operation, and evaluation of groundwater-fed side channels for Chum salmon in British Columbia. Fisheries Bioengineering Symposium: American Fisheries Symposium 10: 109-124.

Bragg, D. (2000). Simulating Catastrophic and Individualistic Large Woody Debris Recruitment for a Small Riparian System. Ecology, 81(5), 1383-1394.

Bryant, M.D. (1988). Gravel pit ponds as habitat enhancement for juvenile Coho salmon. PNW-GTR-212. U.S. Forest Service, Pacific Northwest Research Station, Portland, OR.

Bunte, Kristin. (2004). State of the Science Review: Gravel Mitigation and Augmentation Below Hydroelectric Dams. Report submitted to Stream Systems Technology Center. https://www.fs.fed.us/biology/nsaec/assets/stateofthesciencereview-grvlagmntatnrpt.pdf

CalFish. (2016). CalFish Data Explorer Chinook salmon. http://www.calfish.org/DataandMaps/CalFishDataExplorer.aspx

California Department of Fish and Wildlife (CDFW). (2010). Final annual report Trinity River basin salmon and steelhead monitoring project 2008-2009 season. State of California Department of Fish and Wildlife. http://cahatcheryreview.com/wp-content/uploads/2012/08/2008_ANNUAL_REPORT_Final.pdf#page=163.

California Department of Fish and Wildlife (CDFW). (1998). A Status Review of the Spring-Run Chinook Salmon in the Sacramento River Drainage. http://www.swrcb.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/exhibits/nmfs/spprt_docs/nmfs_exh4_dfg_report_98_1.pdf

California Department of Water Resources (CDWR). (2008). Economic Analysis Guidebook. http://www.water.ca.gov/pubs/planning/economic_analysis_guidebook/econguidebook.pdf

Carter, K. (2005). The effects of dissolved oxygen on steelhead trout, Coho salmon, and Chinook salmon biology and function by life stage. California Regional Water Quality

Control Board North Coast Region. http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/060707/29appendixbetheeffectsofdissolvedoxygenonsteelheadtroutcohosalmonandChinooksalmonbiologyandfunction.pdf

California Water Science Center. (2011) "Sacramento River Basin, National Water Quality Assessment Program." United States Geological Survey. Accessed January 18, 2017. https://ca.water.usgs.gov/sac_nawqa/

Chang, Fi-John, Wen-Ping Tsai, Tzu-Ching Wu, Hung-kwai Chen, and Edwin E. Herricks. (2011). Identifying natural flow regimes using fish communities." Journal of Hydrology, 409(1–2), 328–36. doi:10.1016/j.jhydrol.2011.08.029.

Churchill, R.K. (2000). Contributions of mercury to California's environment from mercury and gold mining activities; Insights from the historical record, in Extended abstracts for the U.S. EPA sponsored meeting, Assessing and Managing Mercury from Historic and Current Mining Activities, San Francisco, Calif., p. 33-36 and S35-S48.

Clarke, S.J. and Wharton, G. (2000). An investigation of marginal habitat and macrophyte community enhancement on the River Torne, U.K. Regul. River: Resource Management 16: 225-244.

Clayton, S.R. (2002). Quantitative evaluation of physical and biological responses to stream restoration. Doctoral dissertation. University of Idaho, Moscow.

Cooperman, S., Hinch, S.G., Bennet, S., Quigley, J.T., Galbraith, R.V. (2006). Rapid Assessment of the Effectiveness of Engineered Off-Channel Habitats in the Southern Interior of British Columbia for Coho Salmon Production. Rep. 2768. DFO Canada, Vancouver, BC.

Costanza, Robert, Rudolf d'Arge, Stephen Farber, Monica Grasso, Bruce Hannon, Rudolf de Groot, Karin Limburg, et al. (1997). "The Value of the World's Ecosystem Services and Natural Capital." Nature, 387.

Creasey, A. (March, 2016). More levee work planned this summer in Marysville. Appeal Democrat.

Cummins, K., Wilzbach, M., Gates, D., Perry, J., and Taliaferro, W. (1989). Shredders andRiparian Vegetation. BioScience, 39(1), 24-30.

David D. Hart, Thomas E. Johnson, Karen L. Bushaw-Newton, Richard J. Horwitz, Angela T. Bednarek, Donald F. Charles, Daniel A. Kreeger, David J. Velinsky (2002). Dam Removal: Challenges and Opportunities for Ecological Research and River Restoration. BioScience, 52 (8), 669-682. doi: 10.1641/0006-3568(2002)052[0669:DRCAOF]2.0.CO;2

Decker, A.S., Lightly, M.J. (2004). The contribution of constructed side channels to coho salmon smolt production in the Oyster River, Nanaimo, BC, Canada. Canadian Technical Report of Fisheries and Aquatic Sciences 40.

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P., and Lowrance, R. (2010). The role of riparian vegetation in protecting and improving chemical water quality in streams. Journal of American Water Resources Association, 46(2), 261-277.

Dudley, Tom, and Norman H. Anderson (1982). A Survey of Invertebrates Associated with Wood Debris in Aquatic Habitats. Washington State Entomological Society Corvallis.

Dufour, S., Hayden, M., Stella, J., Battles, J., Piegay, H. (2014). Maintaining channel abandonment processes increases riparian plant diversity within fluvial corridors. Ecohydrology DOI: 10.1002/eco.1546

ECONorthwest. (2012). Handbook for estimating economic benefits of environmental projects. Prepared for the North Bay Watershed Association.

Elliot, J.M. (1990). Mechanisms responsible for population regulation in young migratory trout, Salmo trutta. III. The role of territorial behavior. Journal of Animal Ecology 59: 803-818.

Elliot, J.M. (1993). The self-thinning rule applied to juvenile sea-trout, Salmo trutta. Journal of Animal Ecology 62: 371-279.

Endangered and Threatened Marine Species under NMFS' Jurisdiction. (2017). Updated Retrieved January 20, 2017, from http://www.nmfs.noaa.gov/pr/species/esa/listed.htm

Environmental Protection Agency (EPA). About Remediation Technologies. Retrieved February 22, 2017, from https://clu-in.org/techfocus/default.focus/sec/Solidification/cat/Overview/

Evergreen Funding Consultants. (2003). A Primer on Habitat Project Costs. Prepared for the Puget Sound Shared Strategy. 49 pp.

Fausch, Kurt, and Thomas Northcote. (2011). Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fish and Aquatic Science, 1992.

Federal Emergency Management Agency (FEMA). Flood Information and FEMA Maps: Yuba County. http://www.co.yuba.ca.us/Departments/Community%20Development/Public%20Works/pubFEMA.aspx

Federal Remediation Technologies Roundtable (FRTR). n.d. Ex-Situ Physical/Chemical Treatment (assuming excavation), 4-19 Soil Washing. Retrieved February 22, 2017, from https://frtr.gov/matrix2/section4/4-19.html

FERC Project 2100, Oroville Facilities Relicensing. (2003). Matrix of Life History and Habitat Requirements for Feather River Fish Species SP-F3.2 Task 2. Chinook Salmon. http://www.water.ca.gov/orovillerelicensing/docs/wg_study_reports_and_docs/EWG/030221/Chinook-salmon-lifehistory.pdf

Fivelstad, S., Olsen, A. B., Stefansson, S., Handeland, S., Waagbø, R., Kroglund, F., and Colt, J. (2004). Lack of long-term sublethal effects of reduced freshwater pH alone on Atlantic salmon (Salmo salar) smolts subsequently transferred to seawater. Canadian Journal Of Fisheries and Aquatic Sciences, 61(4), 511-518. doi:10.1139/F04-002

Fleck, J.A.., Alpers, C.N., Marvin-DiPasquale, M., Hothem, R.L., Wright, S.A., Ellett, K., Beaulieu, E., Agee, J.L., Kakouros, E., Kieu, L.H., Eberl, D.D., Blum, A.E., and May, J.T. (2011). The effects of sediment and mercury mobilization in the South Yuba River and Humbug Creek Confluence Area, Nevada County, California: Concentrations, speciation, and environmental fate—Part 1: Field characterization: U.S. Geological Survey Open-File Report, 2010-1325A.

Freeman, A. (1993). Property Value Models. The Measurement of Environmental and Resource Values 367-420.

Gard, M. (2010). Flow-Habitat relationships for juvenile fall/spring-run Chinook salmon and steelhead/rainbow trout rearing in the Yuba River. U.S. Fish and Wildlife Service. Prepared by the Energy Planning and Instream Flow Branch.

Gilbert, G.K. (1917). Hydraulic-Mining Débris in the Sierra Nevada. U.S. Geological Survey Prof. Paper 105.

Gorte, R.W. (2009). U.S. Tree Planting for Carbon Sequestration. Congressional Research Service. https://fas.org/sgp/crs/misc/R40562.pdf

Gorte, R.W. (2009). U.S. Tree Planting for Carbon Sequestration. CRS Report for Congress. CRS 7-5700.

Grant, J.W.A., Kramer, D.L. (1990). Territory size as a predictor of the upper limit to population density of salmonids in streams. Canadian Journal of Fisheries and Aquatic Sciences 47: 1724-1737.

Hafs, A.W., Harrison, L.R., Utz, R.M., Dunne, T. (2014). Quantifying the role of woody debris in providing bioenergetically favorable habitat for juvenile salmon. Ecological Modeling 28, 30-38.

Harmon, Mark E., and Chen Hua. (1991). Coarse Woody Debris Dynamics in Two Old-Growth Ecosystems. BioScience, 41(9), 604–10. doi:10.2307/1311697.

Harrington, J.M., P. Ode, A. Montvalo, D. Post, C. Sheehy, and M. Dawson. (1999). An Index of Biological Integrity for first to third order Russian River tributary streams. California Department of Fish and Game, Office of Spill Prevention and Response Water Pollution Control Laboratory, Rancho Cordova, Ca.

HDR Engineering, INC. (2013). Biological Assessment for the U. S. Army Corps of Engineers Ongoing Operation and Maintenance of Englebright Dam and Reservoir on the Yuba River. Tech. N.p.: United States Army Corps of Engineers. Print.

Heaton AC, Rugh CL, Kim T, Wang NJ, Meagher RB. (2003). Toward detoxifying mercury-polluted aquatic sediments with rice genetically engineered for mercury resistance. Environ Toxicol Chem 22:2940–2947

Helvoigt, T. and Charlton, D. (2009). The economic value of Rogue River salmon. Report of ECONorthwest to Save the Wild Rogue Campaign, Ashland, Or.

Henning, J.A., Gresswell, R.E., Fleming, I.A. (2006). Juvenile salmonid use of freshwater emergent wetlands in the floodplain and its implications for conservation management. North American Journal of Fisheries Management 26: 367-376/

Henry, J.R. (2000). An Overview of the Phytoremediation of Lead and Mercury. National Network of Environmental Studies (NNEMS).

Hicks, M. (2000). Evaluating standards for protecting aquatic life in Washington's surface water quality standards. Draft discussion paper and literature summary. Washington State Department of Ecology, Olympia, Wash.

Hoag, J.C. (2007). How to Plant Willows and Cottonwoods for Riparian Restoration? USDA Natural Resources Conservation Service Boise, Idaho. Technical Note Plant Materials No. 23.

Irvine, J.R. and Riddell, B.E. (2007). Salmon as status indicators for North Pacific ecosystems. N. Pac. Anadr. Fish Comm. Bull. 4: 285-287.

Iverson, T.M., Kronvang, B. Madsen, B.L., Markmann, P., Nielsen, M.B. (1993). Reestablishment of Danish streams: Restoration and maintenance measures. Aquatic Conservation: Marine and Freshwater Ecosystems, 3(2), 73-92.

Jahnig, S. C., Brunzel, S., Gacek, S. Lorenz, A.W. Hering, D. (2009). Effects of re-braiding measures on hydromorphology, floodplain vegetation, ground beetles and benthic invertebrates in mountain rivers. Journal of Applied Ecology, 46, 406-416.

James, L. Allan, Michael B. Singer, Subhajit Ghoshal, and Mary Megison. (2009). Historical channel changes in the Lower Yuba and Feather Rivers, California: Long-Term Effects of Contrasting River-Management Strategies. Geological Society of America Special Papers 45, 57–81.

Jeffres, C.A., J.J. Opperman, and P.B. Moyle. (2008). Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes, 83:449-458.

Johnson, W.C. (2002). Riparian vegetation diversity along regulated rivers: contribution of novel and relict habitats. Freshwater Biology 47:749-759.

Kattelmann, R., Embury, M. (1996). Riparian areas and wetlands. Sierra Nevada Ecosystem Project: Final report to Congress vol. III, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources, 1996.

Kjelland, Michael E., Christa M. Woodley, Todd M. Swannack, and David L. Smith. (2015). A Review of the Potential Effects of Suspended Sediment on Fishes: Potential Dredging-Related Physiological, Behavioral, and Transgenerational Implications. Environment Systems and Decisions 35(3), 334–50. doi:10.1007/s10669-015-9557-2.

Klein, L.R., Clayton, S.R., Alldredge, J.R., Goodwin, P. (2007). Long-term monitoring and evaluation of the Lower Red River Restoration Project, Idaho, USA. Restoration Ecology 15(2): 223-239.

Kocman, D., Kanduč, T., Ogrinc, N., and Horvat, M. (2011). Distribution and partitioning of mercury in a river catchment impacted by former mercury mining activity. Biogeochemistry, 104(1/3), 183-201.

Kondolf, G. M. (1993). The size of salmonid spawning gravels. Water Resource Research 29: 2275-2285. fish_kondolf_1993_sizespawninggravels_prj.pdf

Krabbenhoft, D. and Rickert, D. (2016). Mercury contamination of aquatic systems. USGS Fact Sheet 216-95.

Kronvang, B., Andersen, I.L., Hoffmann, C.C. et al. (2007). Water Exchange and Deposition of Sediment and Phosphorus during Inundation of Natural and Restored Lowland Floodplains. Water Air Soil Pollution, 181: 115. doi:10.1007/s11270-006-9283-y

Lassettre, Neil S., and Richard R. Harris. (2000). The geomorphic and ecological influence of large woody debris in streams and rivers. University of California, Department of Landscape Architecture and Environmental Planning, Department of Environmental Science, Policy and Management.

Lauer, S., and McClurg, S. (2009). The Lower Yuba River Accord: From Controversy To Consensus. Water Education Foundation, 2009.

Lenat, David R. (1998). Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7(3), 222–33. doi:10.2307/1467422.

Lewandrowski, J. Peters, M., Jones, C. 2004. Economics of sequestering carbon in the U.S. agricultural sector. USDA Economic Research Service, Technical Bulletin TB-1909.

Lewis, L., Bohlen, C., Wilson, S. (2008). Dams, dam removal, and river restoration: A hedonic property value analysis. Contemporary Economic Policy, 26(2), 175-186.

Lockwood, J. L. (2014). An analysis of U.S./Canadian fisheries policy in regards to pacific salmon and the preservation of indigeneity in the pacific northwest.

Loomis, John B. (1996). Measuring the Economic Benefits of Removing Dams and Restoring the Elwha River: Results of a Contingent Valuation Survey. Water Resources Research, 32(2), 441–47. doi:10.1029/95WR03243.

Loomis, J. and Cooper J. (1990). Comparison of environmental quality – Induced demand shift using time-series and cross-section data. Western Journal of Agricultural Economics 15(1), 83-90.

Loomis, J. and Fix, P. (1998). Testing the importance of fish stocking as a determinant of the demand for fishing licenses and fishing effort in Colorado. Human Dimensions of Wildlife, 3:3, 46-61. doi: 10.1080/10871209809359131.

Lower Yuba Accord River Management Team (RMT). (2013). Interim Monitoring and Evaluation Program Report. http://www.yubaaccordrmt.com/Interim%20ME%20Report/Forms/AllItems.aspx

Lytle, David A., and N.LeRoy Poff. (2004). Adaptation to Natural Flow Regimes. Trends in Ecology and Evolution 19(2), 94–100. doi:10.1016/j.tree.2003.10.002.

Madsen, B. L. (2010). The Stream and Beyond: Reinstating Natural Functions in Streams and Their Floodplains. Restoration of Lakes, Streams, Floodplains, and Bogs in Europe,145-183.

Mahbub, K.R., Bahar, M.M., Labbate, M. et al. (2017). Appl Microbiol Biotechnol, 101: 963. doi:10.1007/s00253-016-8079-2

Marrugo-Negrete J, Enamorado-Montes G, Durango-Hernández J, Pinedo-Hernández J, Díez S. (2017). Removal of mercury from gold mine effluents using Limnocharis flava in constructed wetlands. Chemosphere 167:188–192.

Martens, K.D., Connolly, P.J. (2013). Juvenile anadromous salmonid production in Upper Columbia River side channels with different levels of hydrological connectivity. Transactions of the American Fisheries Society doi: 10.1080/00028487.2014.880740

Marvin-DiPasquale, M., and Agee, J. (2003). Microbial mercury cycling in sediments of the San Francisco Bay-Delta. Estuaries. 26(6): 1517-1528.

Massa, D., Alber, L., Bergman, J. (2009). Lower Yuba River Accord monitoring and evaluation plan: Annual acoustic telemetry report. Lower Yuba River Accord Planning Team.

Massa, D.A. (2004). Yuba River juvenile Chinook salmon, Oncorhynchus tshawytsha, and juvenile Central Valley steelhead trout, *Oncorhynchus mykiss,* life history survey, annual data report 2003-2004. Yuba River Salmonid Life History Study. CA Dept Fish and Game.

Matzek, V., Puleston, C., Gunn, J. (2015). Can carbon credits fund riparian forest restoration? Restoration Ecology, 21(1), 7-14

McEwan D, Jackson T. A. (1996). Steelhead restoration and management plan for California. California Department of Fish and Game.

Merz, J. (2001). Association of Fall-Run Chinook Salmon Redds with Woody Debris in the Lower Mokelumne River, California. California Fish and Game 87(2), 51-60.

Merz, J. E., Setka, J. D., Pasternack, G. B., and Wheaton, J. M. (2004). Predicting benefits of spawning-habitat rehabilitation to salmonid (Oncorhynchus spp.) fry production in a regulated California river. Canadian Journal Of Fisheries and Aquatic Sciences, 61(8), 1433-1446.

Merz, Joseph E. (2001). Association of Fall-Run Chinook salmon redds with woody debris in the Lower Mokelumne River, California. California Fish and Game.

Michel, C.J, Ammann, A.J., Lindley, S.T., Sandstrom, P.T., Chapman, E.D., Thomas, M.J., Singer, G.P., Klimley, A.P., MacFarlane, R.B. (2015). Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences 72:1749-1759

Michigan Department of Environmental Quality. Dissolved Oxygen. http://www.michigan.gov/documents/deq/wb-npdes-DissolvedOxygen_247232_7.pdf

Milner, N.J., Elliot, J.M., Armstrong, J.D., Gardiner, R., Welton, J.S., Ladle, M. (2003). The natural control of salmon and trout populations in streams. Fisheries Research 62(2), 111-115.

Morley, S.A., Garcia, P.S., Bennett, T.R., Roni, P. (2005). Juvenile salmonid (Oncorhynchus spp.) use of constructed and natural side channels in Pacific Northwest rivers. Canadian Journal of Fisheries and Aquatic Sciences. 62(12): 2811-2821.

Muniz, I.P., and Leivestad, H. (1980). Toxic effects of aluminium on the brown trout, Salmo trutta L. In Ecological impact of acid precipitation. Edited by D. Drabløs and A. Tollan. SNSF Project, Oslo-Ås, Norway. pp. 84–92.

Munn, M.D., McHenry, M.L., Sampson, V. (1996). Benthic macroinvertebrate communities in the Elwha River basin, 1994-1995. USGS.

National Marine Fisheries Service. (2014). Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead. California Central Valley Area Office. July 2014.

Natural Resources Conservation Service (NRCS). (2017). Retrieved February 21, 2017, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/econ /prices/?cid=nrcs143_009685

NOAA Fisheries. (2016). "Chinook Salmon (*Oncorhynchus tshawytscha)*: Species Description. http://www.nmfs.noaa.gov/pr/species/fish/Chinook-salmon.html

OECD. (2006). Cost-Benefit Analysis and the Environment: Recent Developments, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/9789264010055-en

OMB. (1992). Determining Discount Rates for Cost Benefit Analyses for federal programs. https://www.wbdg.org/FFC/FED/OMB/OMB-Circular-A94.pdf

Omichinski, J. (2007). Toward Methylmercury Bioremediation. Science, 317(5835), 205-206. Retrieved from http://www.jstor.org/stable/20036693

Opperman, J. Luster, R., McKenney, B., Roberts, M., and Meadows, A. (2010). Ecologically Functional Floodplains: Connectivity, Flow Regime, and Scale. Journal of the American Water Resources Association, 46(2):211-226. DOI: 10.1111/j.1752-1688.2010.00426.x

Oregon Department of Environmental Quality (ODEQ). (1995). Dissolved Oxygen: 1992-1994 Water quality standards review. Final Issue Paper. 166pp. <http://www.fishlib.org/Bibliographies/waterquality.html>.

Pacific Fisheries Management Council. (2015). Stock Assessment and Fishery Evaluation (SAFE) Documents. http://www.pcouncil.org/salmon/stock-assessment-and-fishery-evaluation-safe-documents/

Palmer, Margaret A, Catherine A Reidy Liermann, Christer Nilsson, Martina Flörke, Joseph Alcamo, P Sam Lake, and Nick Bond. "Climate Change and the World's River Basins: Anticipating Management Options." Frontiers in Ecology and the Environment 6, no. 2 (March 2008): 81–89. doi:10.1890/060148.

Panel, Gravel Augmentation. (2005). Key uncertainties in gravel augmentation: geomorphological and biological research needs for effective river restoration.

Pasternack, G. (2010). Gravel/Cobble Augmentation Implementation Plan (GAIP) for the Englebright Dam Reach of the Lower Yuba River, CA. U.S. Army Corps of Engineers. http://pasternack.ucdavis.edu/files/3413/7581/8399/USACE_GAIP_FINAL_20100930.pdf.

Pasternack, G., Wyrick, J. (2012). Landforms of the Lower Yuba River. Prepared for: The Lower Yuba River Accord Planning Team. Lower Yuba River Accord Monitoring and Evaluation Program.

Pasternack, Gregory B., Denise Tu, and Joshua R. Wyrick. (2014). Lower Yuba River Accord Monitoring and Evaluation Program Chinook Adult Salmon Spawning," Prepared for the Yuba Accord River Management Team. University of California, Davis, CA.

Petts, Geoffrey E. (2009). Instream flow science for sustainable river management. Wiley Online Library. http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2009.00360.x/full.

Platts , W. S . (1974). Geomorphic and aquatic conditions influencing salmonids and stream classification - with application to ecosystem management. Billings, MT: U. S. Department of Agriculture, SEAM Program;199.

Platts, William S.; Megahan, Walter F:; Minshall, G. Wayne. (1983). Methods for evaluating stream, riparian, and biotic conditions. Gen. Tech. Rep. INT-138. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 70..

Poff, N. LeRoy, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg. (1997). The Natural Flow Regime." BioScience 47(11), 769–84. doi:10.2307/1313099.

Poulin, V.A. and Associates. 1991. Stream rehabilitation using LOD placements and off-channel pool development. British Columbia Ministry of Forests, Land Management Report 61, Vancouver.

Proactive Conservation Program: Species of Concern. (2016). Updated August 22, 2016. Retrieved January 20, 2017, from http://www.nmfs.noaa.gov/pr/species/concern/

Provencher, B., Sarakinos, H., Meyer, T. (2008). Does Small Dam Removal Affect Local Property Values? An Empirical Analysis. Contemporary Economic Policy 26(2): 187-197.

Quinn, TP. (2005). The behavior and ecology of Pacific salmon and trout. Bethesda, Maryland: American Fisheries Society.

Raastad, J.E., Lillehammer, A. Lillehammer, L., Kaasa, H., Eie, J.A. Effect of habitat improvement on Atlantic salmon in the regulated River Suldalslagen. Regulated Rivers: Resource Management 8(1-2): 95-102.

Ransom, M.M. (2001). Economic Impacts of Salmon Fishing. USDA Natural Resources Conservation Service.

Reedy, G. Personal communication. November 17, 2016.

Reimers, R., and Krenkel, P. (1974). Kinetics of Mercury Adsorption and Desorption in Sediments. Journal. Water Pollution Control Federation, 46(2), 352-365.

Resh, Vincent H., Arthur V. Brown, Alan P. Covich, Martin E. Gurtz, Hiram W. Li, G. Wayne Minshall, Seth R. Reice, Andrew L. Sheldon, J. Bruce Wallace, and Robert C. Wissmar. "The Role of Disturbance in Stream Ecology." Journal of the North American Benthological Society 7, no. 4 (1988): 433–55. doi:10.2307/1467300.

Richards, C., Cernera, P.J., Ramey, M.P., Reiser, D.W. (1992). Development of off-channel habitats for use by juvenile Chinook salmon. North American Journal of Fisheries Management 12(4): 721-727.

Richter, A., and Kolmes, S. A. (2005). Maximum Temperature Limits for Chinook, Coho, and Chum Salmon, and Steelhead Trout in the Pacific Northwest. Reviews In Fisheries Science, 13(1), 23-49.

Ricker, W.E. Stock and Recruitment. (1954). Journal of the Fisheries Research Board of Canada 11: 559-623.

Riparian Sanctuary. River Partners. Accessed January 17, 2017. http://www.riverpartners.org/where-we-work/sanctuary/.

RMT. (2013). Aquatic Resources of the Lower Yuba River: Past, Present, and Future. Yuba Accord River Monitoring Team. Yuba Accord Monitoring and Evaluation Program. Draft Interim Report.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M., Pess, G.R. (2002). A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watershed. North American Journal of Fisheries Management 22: 1-20

Roni, P., Hanson, K., Beechie, T.J. (2008). Global review of the physical and biological effectiveness of stream habitat rehabilitation techniques. North American Journal of Fisheries Management 28(3): 856-809.

Roni, P., Morley, S.A., Garcia, P. (2006). Coho salmon smolt production from constructed and natural floodplain habitats. Transactions of the American Fisheries Society 135: 1398-1408.

Roni, P., Pess, G.R., Beechie, T.J., Hanson, K.M. (2014). Fish-habitat relationships and the effectiveness of habitat restoration. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-127.

Roni, P., and Quinn, T. (2001). Density and Size of Juvenile Salmonids in Response to Placement of Large Woody Debris in Western Oregon and Washington Streams. NRC Research Press.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in perfect competition. Journal of Political Economy, 82, 34-55.

Rosenfeld, J.S., Raeburn, E., Carrier, P.C., Johnson, R. (2008). Effects of side channel structure on productivity of floodplain habitats for juvenile Coho salmon. North American Journal of Fisheries Management, 28(4), 1108-1119.

Rosenfeld, J. S. (2005). Annual report to Habitat Conservation Trust Fund, Vancouver, B.C. Appendix 3: Effectiveness assessment of off-channel habitat structures. B.C. Ministry of Water, Land, and Air Protection, Aquatic Ecosystem Science Section, Vancouver.

Sacramento River Watershed Program. (2017). Benthic macroinvertebrates community structure. http://www.sacriver.org/aboutwatershed/reportcard/section3/section3_2/323-benthic-macroinvertebrates-community-structure

Schroeder, W. and Munthe, J. (1998). Atmospheric mercury – an overview. Atmospheric Environment. 32(5); 809-822. https://doi.org/10.1016/S1352-2310(97)00293-8

Sellheim, K. L., Vaghti, M., Merz, J. E. (2016). Vegetation recruitment in an enhanced floodplain: Ancillary Benefits of Salmonid Habitat Enhancement. Limnoloigca, 58, 94-102. doi.org/10.1016/j.limno.2016.03.001

Senter, A. E., and G. B. Pasternack. (2011). Large wood aids spawning Chinook salmon (Oncorhynchus Tshawytscha) in marginal habitat on a regulated river in California." River Research and Applications, 27(5), 550–65. doi:10.1002/rra.1388.

Sheng, M.D., Foy, M., Fedorenko, A.Y. (1990). Coho salmon enhancement in British Columbia using improved groundwater-fed side channels. Rep. 2071. DFO Canada, Vancouver.

Singer, M.B., Harrison, L.R., Donovan, P.M., Blum, J.D., and Marvin-DiPasquale, M. (2016). Hydrologic indicators of hot spots and hot moments of mercury methylation potential along river corridors. Science of The Total Environment, 568, 697-711.

Smith, C.D., D.M. Harper, and P.J. Barham. (1990). Engineering operations and invertebrates: Linking hydrology with ecology. Regulated Rivers: Research and Management 5: 89-96.

Smock, L. A., Gladden, J. E., Riekenberg, J. L., Smith, L. C. and Black, C. R. (1992). Lotic Macroinvertebrate Production in Three Dimensions: Channel Surface, Hyporheic, and Floodplain Environments. Ecology, 73, 876–886. doi:10.2307/1940165

Snyder, Noah P., Scott A. Wright, Charles N. Alpers, Lorraine E. Flint, Charles W. Holmes, and David M. Rubin. (2006). Reconstructing Depositional Processes and History from Reservoir Stratigraphy: Englebright Lake, Yuba River, Northern California. Journal of Geophysical Research: Earth Surface 111(F4):F04003. doi:10.1029/2005JF000451.

Sommer, T.R., Nobriga, M.L., Harrell, W.C., Batham, W., Kimmerer, W.J. (2001). Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences, 58(2), 325-333.

South Yuba River Citizens League (SYRCL). (2006). State of the Yuba: An Assessment of the Yuba River Watershed. South Yuba River Citizen's League (2013). Hammon Bar Riparian Enhancement Project Report.

Spence, B.C., and G.A. Lomnicky, R.M. Hughs, and R.P. Novitzki. (1996). An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, Oregon. Available from the National Marine Fisheries Service, Portland, Oregon.

Spence, B. C., and Hughes, R.M. (1996). An ecosystem approach to salmonid conservation. ManTech Environmental Research Services, Corporation http://whatsupstream.com/assets/D-051874.pdf.

Steffy, L. (2009). A water quality and biological assessment of the watersheds surrounding Whitney Point Lake, Broome and Cortland Counties, N.Y. Susquehanna River Basin Commission. Publication 264.

Streiner, C., Loomis, J. (1995). Estimating the benefits of urban stream restoration using the hedonic price method. Rivers, 5(4), 267-278.

Su Y, Han FX, Chen J, Sridhar BM, Monts DL. (2008). Phytoextraction and accumulation of mercury in three plant species: Indian mustard (Brassica juncea), beard grass (Polypogon monospeliensis), and Chinese brake fern (Pteris vittata). International Journal of Phytoremediation, 10(6), 547-560.

Su Y, Shiyab S, Monts D. (2007). Phytoextraction and accumulation of mercury in selected plant species grown in soil contaminated with different mercury compounds. International Journal of Phytoremediation. WM '07 Conference in Tucson, AZ.

Tangahu, B.V., Sheikh Abdullah S.R., Basri H., Idris M., Anuar N., Mukhlisin M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. International Journal on Chemical Engineering, 2011.

The Nature Conservancy (TNC). (2016). California Salmon Snapshots: Fish Population Data. http://www.casalmon.org/fish-population-data

The Sierra Fund. (2008). Mining's Toxic Legacy: An Initiative to Address Mining Toxins in the Sierra Nevada. http://www.conservation.ca.gov/dlrp/watershedportal/ReportsEvents/Documents/Miningstoxiclegacy.pdf

Thomson, C.J., Pinkerton, C. (2008). Habitat restoration cost references for salmon recovery planning. U.S. Dep. Commerc., NOAA Tech. Memo. NMFS-SWFSC-425, 75 p.

Thomson, C.J. and Huppert, D.D. (1987). Results of the Bay Area Sportfish Economic Study (BASES), NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-78. http://docs.lib.noaa.gov/noaa_documents/NMFS/SWFSC/TM_NMFS_SWFSC/NOAA-TM-NMFS-SWFC-78.pdf

Titus, R., Brown, M., Lyons, J., Collins, E., and Koerber, L. (2010). Central Valley Angler Survey. California Department of Fish and Wildlife. Accessed November 2016. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=33186.

Tsournos, P., Miller, R., and Chaundry, A. (2016). Economic value of the Sacramento River to freshwater anglers: A Zonal Travel Cost Approach.

U.S. Department of the Interior. (2015). Assessment of anadromous fish production in the Central Valley of California between 1992 and 2014. Report prepared by the U.S. Fish and Wildlife Service and Bureau of Reclamation, Comprehensive Assessment and Monitoring Program. Sacramento, California. 119 pp.

U.S. Environmental Protection Agency (USEPA). (1986). Ambient Water Quality Criteria for Dissolved Oxygen. Office of Water. EPA 440/5-86-003. 35pp. http://www.epa.gov/cgi-bin/claritgw?op Display&document=clserv:OAR:0579; &rank=4&template=epa>

U.S. Environmental Protection Agency (USEPA). (2006). Benthic macroinvertebrates in wadeable streams. Washington, DC.

U.S. Environmental Protection Agency (USEPA). (2005). Greenhouse Gas Mitigation Potential in U.S. forestry and Agriculture, Office of Atmospheric Programs EPA 430-R-05-006

U.S. Geological Survey (USGS). (2000). Mercury in the Environment Fact Sheet 146-00 https://www2.usgs.gov/themes/factsheet/146-00/

U.S. Geological Survey (USGS). 2016. USGS Water Conditions for California: Yuba River NR Marysville. https://waterdata.usgs.gov/ca/nwis/uv?site_no=11421000

United States Geological Survey (USGS) Water Data Support. 2017. https://waterdata.usgs.gov/nwis/inventory/?site_no=11418000

U.S. Army Corps of Engineers. (2012). Lower Yuba River Large Woody Material Management Plan Pilot Study.

U.S. Army Corps of Engineers. (2014). Yuba River Ecosystem Restoration Section 905(b) Analysis.

U.S. Army Corps of Engineers. (2010). Lower Yuba River Gravel Augmentation Project Yuba and Nevada Counties, California. RUSLE - an online soil erosion assessment tool. Retrieved October 18, 2016, from http://www.iwr.msu.edu/rusle/kfactor.htm

U.S. Army Corps of Engineers. (2014b). DRAFT Integrated Feasibility Report and Environmental Impact Statement. Skokomish River Basin, Mason County, Washington. Ecosystem Restoration. Seattle District.

USEPA. (2006). In Situ Treatment Technologies for Contaminated Soil: Engineering Forum Issue Paper. EPA 542-F-06-013.

USGS. "USGS Gage #11447650 on the Sacramento River at Freeport, CA (Water-Data Report 2013)". Water Resources of the United States.

Utz, R. M., Mesick, C. F., Cardinale, B. J., and Dunne, T. (2013). How does coarse gravel augmentation affect early-stage Chinook salmon Oncorhynchus tshawytscha embryonic survivorship?. Journal Of Fish Biology, 82(5), 1484-1496. doi:10.1111/jfb.12085

Vaughan, W., and Russel, C. (1982). Valuing a Fishing Day: An Application of a Systematic Varying Parameter Model. Land Economics, 58(4), 450-463.

Viers, H.A., and Rheinheimer, D.A. (2011). Freshwater conservation options for a changing climate in California's Sierra Nevada. Marine and Freshwater Research 62, 266-278.

Villada Arroyave, J.A., Crosato, A. (2010). Effects of river floodplain lowering and vegetation cover. Water Management, 163(9), 457-467. doi:10.1680/wama.900023

Wang Y, Stauffer C, Keller C, Greger M. (2005). Changes in Hg fractionation in soil induced by willow. Plant Soil 275:67–75. doi:10.1007/s11104-004-6108-x

Washington State Department of Ecology (WDOE). (2002). Evaluating Criteria for the Protection of Freshwater Aquatic Life in Washington's Surface Water Quality Standards: Dissolved Oxygen. Draft Discussion Paper and Literature Summary. Publication Number 00-10- 071. 90pp.

Water Education Foundation (2009). Water Quality in Streams. Journal Of The American Water Resources Association, 46(2), 261-277.

Webster, C., Huckins, C., and Shields, J. (2008). Spatial Distribution of Riparian Zone Coarse Woody Debris in a Managed Northern Temperate Watershed. The American Midland Naturalist, 159(1), 225-237.

Wheaton, J. M., Pasternack, G. B., and Merz, J. (2004). Spawning Habitat Rehabilitation -I. Conceptual Approach and Methods. International Journal of River Basin Management 2, no. 1 (March 2004): 3–20. doi:10.1080/15715124.2004.9635218.

Wiener, J.G. and Spry, D.J. (1996). Toxicological significance of mercury in freshwater fish. Environmental Contaminants in Biota: Interpreting Tissue Concentrations. Boca Raton, FL: Lewis Publishers.

Williams, T.H., Lindley, S.T., Spence, B.C., Boughton, D.A. (2011). Status review update for Pacific salmon listed under the endagered species act: Southwest. 17 May 2001 - Update to 5 January 2001 report. National Marine Fisheries Service.

Willson, M.F., Gende, S., and Harston, B.H. (1998). Fishes and the forest. BioScience, 48(6), 455-462.

Willson, M.F. and Halupka, K.C. (1995). Anadromous fish as keystone species in vertebrate communities. Conservation Biology, 9(3), 489-497.

Wilson Landing Unit of the Sacramento River Wildlife Area. River Partners. Accessed January 17, 2017. http://www.riverpartners.org/where-we-work/wilson-landing/index.html.

Wohl, E., P. L. Angermeier, B. Bledsoe, G. M. Kondolf, L. MacDonnell, D. M. Merritt, M. A. Palmer, N. L. Poff, and D. Tarboton. (2005). River restoration, Water Resour. Res., 41. W10301, doi:10.1029/2005WR003985.

Wyrick, J. R., and Pasternack, G. B. (2012). Landforms of the Lower Yuba River. Prepared for the Yuba Accord River Management Team. University of California, Davis, CA.

Yarnell, S M., Viers, J.H., Mount, J.F. (2010). Ecology and management of the spring snowmelt recession. BioScience, 60(2), 114–27. doi:10.1525/bio.2010.60.2.6.

Young and Teti. (1984). The Influence of water quality on the value of recreational properties adjacent to St. Albans Bay, Vermont. Staff Report No. AGES 831116. Washington, DC: USDA. Economic Research Service. Natural Resource Economics Divisions.

Yuba County Water Agency (YCWA). (2009). Technical Memorandum 7-7 Threatened, Endangered and Fully Protected Species. Yuba River Development Project FERC Project No. 2246.

Yuba County Water Agency(YCWA). (2012). Technical Memoranda: TM 02-03 – Water Quality. http://www.ycwa-relicensing.com/Technical%20Memoranda/Forms/AllItems.aspx?RootFolder=%2FTechnical%20Memoranda%2FTM%2002-03%20-%20Water%20QualityandFolderCTID=andView=%7B866DD5CD-3ED9-4114-B727-74CA4CEB4483%7D

Yuba County Water Agency (YCWA). (2013). Technical Memorandum 2-6 Water Temperature Models. Yuba River Development Project FERC Project No. 2246.

Yuba County Water Agency (YCWA). (2013). Technical Memorandum 3-2, Aquatic Macroinvertebrates Downstream of Englebright Dam. Yuba River Development Project. http://www.ycwa-relicensing.com/Technical%20Memoranda/TM%2003-02%20-%20Aquatic%20Macroinvertebrates%20Below%20Englebright%20-%20FINAL%20POSTED%20042513/TM%203-2.pdf

Yuba County Water Agency (YCWA). (2013). Technical Memorandum 6-2 Riparian Habitat Downstream of Englebright Dam. Yuba River Development Project FERC Project No. 2246.

Yuba County Water Agency (YCWA). (2009). Yuba River Development Project, FERC Project No. 2246: Section 3 - General Description of the River Basin.

Yuba Shed. (2016). WQ Field: Dissolved Oxygen SYRCL LY 2001-2016. Retrieved January 30, 2017, from http://yubashed.org/viewdata/data/wq-field-dissolved-oxygen-syrcl-ly-2001-2016 Yuba Shed. (n.d.). Retrieved January 30, 2017.

Yuba Shed. (2016). WQ Field: pH SYRCL LY 2001-2016. Retrieved January 30, 2017, from http://yubashed.org/viewdata/data/wq-field-ph-syrcl-ly-2001-2016

Appendices

Appendix I: Mercury Remediation

Because mercury contamination is widespread in the watershed, any organization doing restoration will be required to monitor for mercury contamination as a condition of permitting requirements. If after soil samples are analyzed and mercury concentrations come back higher than background levels, the project is postponed and a mercury remediation plan must be developed. Below is a Figure X from Singer et al. (2016) that shows how the soil samples collected compared to background mercury concentrations. If floodplain restoration occurs in the Lower Yuba Fan below Daguerre Point Dam, there is potential for samples to be above the background level.

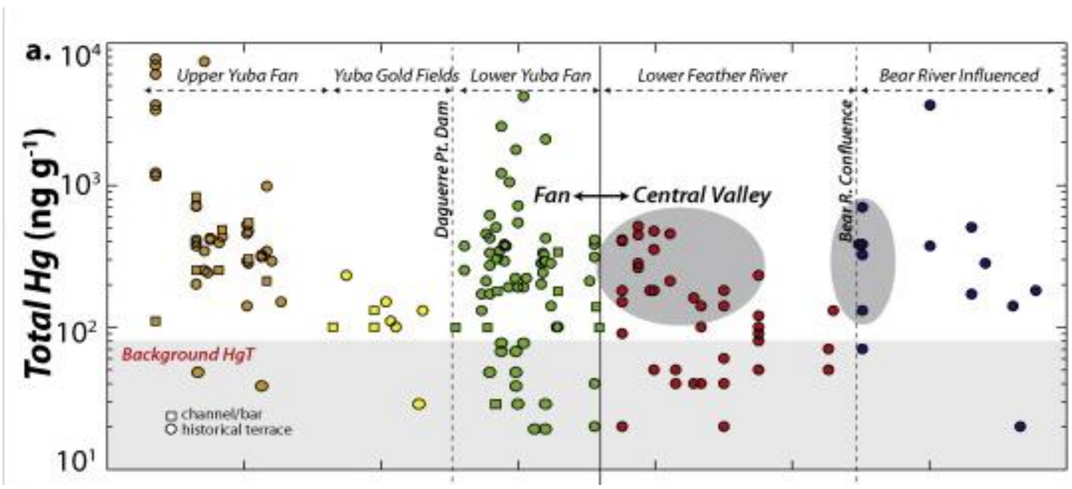

Figure I-1. Soil samples analyzed for mercury in the Lower Yuba River. The gray area represents background concentrations of total mercury (ng/g).

There are several commonly employed methods for remediating mercury contamination. Some of these conventional cleanup strategies are more applicable to localized plumes of contamination and others more applicable to widespread distribution. Because mercury on the Lower Yuba River is widespread and mainly exist within the sediment, dry screening and soil washing treatment (Mahbub et al., 2017) would be typical options. Dry screening capitalizes on the idea that mercury adheres to small particle sizes, by simply separating excavated material based on grain size (EPA, n.d.) Similarly, soil washing is an ex-situ strategy where fine soil is separated from bulk material in an aqueous solution, often enhanced by the addition of pH-adjusting chemicals (EPA, n.d.: FRTR, n.d.). The larger, clean material can be returned to the site while the contaminated water, clay and silt particles require further treatment and safe disposal. Although widely used, dry screening and soil washing strategies are expensive, often require multiple washes, and generate waste. These conventional strategies are slowly being phased out in favor of two other methods, phytoremediation and in-situ bioremediation, where possible.

Phytoremediation is the use of plants to cleanup organic and inorganic contaminants in the environment. These plants can bioengineered in order to maximize mercury resistance and transformation ability. The modification of *Oryza sativa* with the merA gene from a bacterial strain has been found to reduce ionic mercury to the less toxic elemental form (Heaton et al., 2003). This approach is inexpensive and environmentally benign compared to conventional strategies. For example, the estimated cost of remediating a cubic meter of contaminated sandy-loam was $30 to $50 for phytoremediation, compared to $200 for conventional excavation/disposal methods (Henry, 2000) Phytoremediation of mercury works because certain plant species are capable of exuding organic compounds that support the microbial communities within the rhizosphere, and in exchange the microbes facilitate the uptake of mercury into the plant (Henry, 2000; Mahbub et al., 2017). Vegetative soil has been shown to host 1 to 100 times the number of mercury remediating microorganisms compared to unvegetated soil (Henry, 2000).

The two main categories of phytoremediation applicable to mercury include phytoextraction and phytovolatilization (Tangahu et al., 2011). Phytoextraction is the accumulation of mercury in plant tissue. In order to avoid the recontamination of mercury when an individual dies, drops leaves or adds other organic material back into the environment, managers will typically harvest and dispose of plants periodically (Tangahu et al., 2011). Phytovolatilization is the uptake and subsequent transpiration of a toxic substance into the atmosphere. Although this process can remove mercury from a project site, the consequences of dry deposition elsewhere should be considered. Although there is ample evidence supporting the existence of phytovolatilization mechanisms within plant structures, the extent to which mercury actually volatilizes remains unclear (Henry, 2000). The processes of phytoextraction and phytovolatilization will happen simultaneously when plants begin the remediation process. Plants species that have been studied and possess the capability to phytoremediate mercury include various *Polypogon monospeliensis*, *Brassica juncea, Pteris vittatam,* various willow species and many others (Wang et al., 2005; Su et al., 2007, 2008).

Another mercury remediation strategy that has been showing promise within the last few decades is *in situ* bioremediation. This strategy exploits pre-existing bacteria that specialize in producing a methylmercury-degrading enzyme called MerB (Omichinski, 2007). In essence, the MerB is important because it is capable of facilitating the cleavage mercury-carbon bonds (Omichinski, 2007). Besides MerB, there are several functional genes present on the mer operon that encode for proteins important to mercury resistance, transport and transformation (Mahbub et al., 2017). Although microbes capable of Hg remediation already exist within the environment, managers can add cultured colonies into the subsurface through a process called bioaugmentation. Natural and laboratory grown microbes can also benefit from strain-specific environmental conditions, and enough electron-donors and carbon-sources to facilitate the desired reaction. One recent study found that 60% of soil-bound mercury was removed from a contaminated site when bioaugmented and supplied with a nutrient amendment (Marrugo-Negrete et al., 2017).

Appendix II: Literature Evidence of Salmon-Habitat Relationships

Although there has been little research completing addressing the relationship between juvenile habitat and the resulting adult returns, there have been some recent studies that attempt to relate juvenile habitat to juvenile abundance. A summary of the main points related to this topic are summarized in the brief annotated references below.

Milner et al. (2003)
Milner et al. (2003) provides an overview of in-stream salmon habitat requirements, population relationships, and other factors that regulate in-stream salmon populations. Within rivers and streams, it is widely accepted that there are density-dependent and density-independent factors that influence juvenile salmon abundance. Examples of density-dependence include territorial competition and limited food availability, while examples of density-independence include climate variability. Early juvenile life stages generally experience density-dependence and ocean life stages experience density-independence.

Milner et al. (2003) makes the interesting note that "carrying capacity, as determined by habitat features (Armstrong et al., 2003) is independent of density, but creates a bottleneck, typically for space and food, that increases competition, thus leading to density-dependence." This implies that habitat capacity itself falls into a "special category" that nonetheless "stimulates density-dependent [factors] to operate." Habitat carrying capacity can limit a salmon life cycle at two stages: adult spawning capacity, and juvenile habitat capacity.

Milner et al. (2003) also discusses an interesting concept known as "self-thinning." In some populations, when space and food are constant (maximum habitat capacity), there is an inverse relationship between the number of fish and the mean weight of the fish. That is, as the number of fish decreases, the mean weight increases. This occurs when juvenile salmonids are experiencing a bottleneck on their growth (Elliot, 1990). Various studies have demonstrated the concept of self-thinning resulting from either space limitation (Grant and Kramer, 1990) or the energy equivalence hypothesis via maximum available energy within a system (Bohlin et al., 1994; Elliot, 1993).

The last important thing Milner et al. (2003) discusses is stock-recruitment relationships. Usually, either the Ricker Model (Ricker, 1954) or the Beverton-Holt Model (Beverton and Holt, 1957) are used. The Ricker Model and the Beverton-Holt Model are particular ways to explain the stock-recruitment relationship between juveniles and adults. In short, each describes how many juvenile fish are expected to be produced by the previous year's returning adults when density dependence factors are causing a bottleneck for the juvenile life stage. When modeling salmon populations under either model, a doubling in the overall juvenile habitat predicts a doubling in the juvenile abundance due to a relaxation of the life stage bottleneck. This in turn predicts a doubling of the adult returns due to a linear relationship between the juvenile and adult life stages.

Roni et al. (2012)
Roni et al. (2012) is a NOAA technical memorandum entitled "Fish-habitat relationships and the effectiveness of habitat restoration." The document attempts to synthesize the current literature regarding 1) the "understanding of the relationship between habitat quantity and quality and salmon production," 2) quantifiable "improvements in salmon production and survival that can be expected with different restoration actions," and 3) using "models to help identify habitat factors limiting production and quantify population-level responses to restoration." Roni et al. (2012) also advises that "while modeling approaches are useful, there is much uncertainty in all models, and quantifying this uncertainty with Monte Carlo simulations and sensitivity analysis can provide useful information to managers," indicating that a sensitivity analysis could be an important part of our CBA analysis. The literature reviewed by Roni et al. (2012) focuses on the effectiveness of habitat improvement; the article contains all literature was published between 2006 and 2013, primarily in the Pacific Northwest, but including other studies as well. Previous reviews on the same topic include Roni et al. (2002) and Roni et al. (2008).

With regards to riparian vegetation, there is a strong correlation between riparian vegetation abundance, diversity, and restoration with the macroinvertebrate assemblage (Clarke and Wharton, 2000; Iverson et al., 1993; Jahnig et al., 2009). Macroinvertebrates are food source for juvenile salmon, and therefore their abundance and diversity is important. The literature suggests that increases in invertebrate correlate strongly with juvenile salmon survival (Raastad et al., 1993). Therefore, riparian plantings seem to be an important restoration strategy for juvenile salmon. Interestingly, "techniques designed to restore floodplains (e.g., river widening, also termed levee setback) are also thought to benefit riparian forests" (Roni et al., 2008).

Side-channel and floodplain enhancement are two other related restoration strategies that have potential to increase juvenile salmon abundances. Much of the research studying side-channel and floodplain restoration has been performed in similar locations, therefore, we will treat the two strategies as one. The majority of the studies focus on coho salmon, but there are also studies about Chinook salmon. Many studies have found that coho salmon densities in side channels are equal to or greater than main channel densities (Blackwell et al., 1999; Bryant, 1988; Decker and Lightly, 2004; Roni et al., 2006; Rosenfeld, 2005; Morley et al., 2005; Sheng et al., 1990; Bonnell, 1991). Sheng et al. 1990 also found that channels filled to carrying capacity each year. Studies have also shown that coho salmon survival rates increase in side channel habitat (Cederhold and Peterson, 1989, 1988). The reduction in side channel habitat has been determined responsible for the reduction in coho smolt production in Washington's Skagit basin. These trends have also been observed in Chinook salmon populations. Juvenile Chinook reared in floodplain habitat have higher growth rates

(Jeffres et al., 2008; Sommer et al., 2001). Jeffres et al. (2008) also notes that juvenile Chinook growth rates are very low in tidally-influenced areas, indicating that floodplain and side channel restoration can increase survival rates by preventing juveniles from washing into the Delta. Although there is less information, Chinook salmon were also found to have equal or higher densities in off-channel habitat or increased mainstem habitat from channel remeandering (Richards et al., 1992; Klein et al., 2007).

Multiple studies suggest that connectivity to the main channel is the most important criteria for the success of off-channel habitat as rearing grounds (Cooperman et al., 2006; Poulin and Associates, 1991; Henning et al., 2006). Additionally, off-channel construction (e.g. morphological unit composition) can play an important role in salmon abundance, size, and survival (Peterson, 1982). This reflects Roni et al.'s (2002) warning that "the optimal depth, morphology, and design of off-channel habitats is unknown." Also, Rosenfeld et al. (2008) found that, while coho parr density remained constant regardless of channel size, the overall smolt density decreased as channel area increased; this decrease was observed once restoration projects surpassed 10,000 square meters.

Roni et al. (2012) also has a succinct description of how to model salmon populations. There are two options: stage-specific or life-cycle. With regards to the Lower Yuba River, stage-specific salmon modeling is more applicable because we have higher resolution data. State-specific models "estimate the spawning or rearing capacity of habitats at each life stage, then use uniform survival numbers from that life stage to the smolt stage to compare capacities among life stages." Roni et al. (2012) highlights Beechie et al. (2012) as a case example for stage-specific life cycle models, noting that on Trinity River, "the most optimistic restoration scenario, which increases habitat quality, increases sinuosity, and constructs tens of kilometers of side channels, more than doubles the potential juvenile salmonid production."

Appendix III: Yuba River Life Stage Bottlenecks

Chinook salmon populations on the Lower Yuba River have been studied fairly extensively. Much of the information has been collected by the River Monitoring Team associated with the Lower Yuba River Accord, Dr. Greg Pasternack at UC Davis, and the California Department of Fish and Wildlife.

Adult Escapement
Adult fall-run Chinook escapement data has been collected and compiled by the California Department of Fish and Wildlife (Azat, 2016). Yearly returns average about 15,000, but adult abundances experience large fluctuations. Based on available data, the highest fish returns occurred in 1982, when 39,367 adult salmon returned to the Lower Yuba River. The lowest fish returns occurred in 1976, 2007, and 2008 when less than 10% of this maximum value (3,779, 2,604, and 3,508 adult fish, respectively) returned.

Life-Stage Bottleneck

Salmon life-stages that occur on the Yuba River include spawning and fry/juvenile. The Lower Yuba River Accord River Management Team released an Interim Monitoring and Evaluation Report (RMT, 2013). That report, particularly Chapter 7 (Summary, Conclusions, and Recommendations Section), contains important information pertaining to Yuba River salmon life-stages from which is summarized below.

Chinook salmon spawning site selection and spatial distribution is clustered rather than randomly distributed. Chinook salmon prefer spawning in several morphological unit types: riffle, riffle transition, run, and fast glide. Water temperature is also a significant factor in spawning site selection. Specifically, 83% of redds were located in water below 56°F, and 97% were located in water below 58°F, the upper tolerance for Chinook redds. In September, the upper reaches of the Lower Yuba River are cooler, and cold temperatures move down river over the course of the year. In 2009/2010, 74% of redds were located above Daguerre Point Dam; in 2010/2011, 81% of redds were located above Daguerre Point Dam.

Using the above information, the River Management Team used a predictive model to determine spawning carrying capacity on the Lower Yuba River. They determined that, at 660 cfs (approximate flow regime in late-fall when Chinook are creating their redds), there is 6.6 million ft^2 available for spawning. On average, each redd plus its unoccupied buffer covers 119.5 ft^2. Therefore, spawning carrying capacity on the Lower Yuba River was determined to be 55,000 redds, which corresponds to 110,000 adult returns. Returning to Figure 1, this means the $K_{spawners}$ = 110,000. This is far beyond the average Lower Yuba River return of about 15,000 adult salmon. This provides strong support that *adult spawning carrying capacity is **not** the limiting bottleneck for Yuba salmon*, and suggests that the juvenile habitat is in fact the limiting life stage.

Unfortunately, spawning carrying capacity is all that the Yuba RMT has analyzed thus far. Still on their to-do list is to investigate the relationship between habitat suitability and carrying capacity for juvenile salmonids on the Lower Yuba River. This information would be especially useful in our analysis. However, since it does not exist, we must move on without it.

Juvenile Information
Although the RMT has yet to analyze juvenile carrying capacity, there does exist some (albeit limited) information on juvenile salmonids on the Lower Yuba River.

Rotary screw trap (RST) data were collected for two salmon years: 2003-2004, and 2004-2005 (Massa, 2004; Massa and McKibbin, 2005). Using a trap and release methodology, it was estimated that approximately 10,000,000 juveniles passed the rotary screw trap in 2003-2004 and approximately 13,000,000 juveniles passed the rotary screw trap in 2004-2005.

The other Lower Yuba River juvenile salmonid data available come from a study that examined the flow-habitat relationships for juvenile salmonids on the Lower Yuba River (Gard, 2010), prepared by the U.S. Fish and Wildlife Service (USFWS). Fish samples were taken at different flow velocities and depths. These numbers were then calibrated using a 2-dimensional hydraulic habitat model to calculate available habitat. Then, juvenile abundances were modelled at different flows. Gard (2010) habitat modeling shows that the juvenile carrying capacity at different locations on the Lower Yuba River depends on flow regimes that influence water depth and velocity, but the raw juvenile density data was not collected with the intention to estimate a juvenile carrying capacity.

Juvenile Analysis
In 2003, 28,316 adult salmon returned to the Lower Yuba. Using life stage survival rates from Quinn (2005), we calculated the estimated number of fry/juveniles produced from that year's run:

$$28{,}316 \text{ adult spawners} * S * F_1 * P_1 = 29{,}057{,}600 \text{ juveniles}$$

Where:
S = Sex Ratio = 0.5
F_1 = Fecundity = 5401
P_1 = Egg to Fry Survival = 0.38

In 2004, 15,269 adult salmon returned to the Lower Yuba. Using the same life stage survival rates, we calculated the estimated number of fry/juveniles produced from the prior year's run:
15,269 adult spawners * S * F_1 * P_1 = 15,668,900 juveniles

Where:
S = Sex Ratio = 0.5
F_1 = Fecundity = 5401
P_1 = Egg to Fry Survival = 0.38

The 2003 Yuba salmon run should have spawned about 29 million juveniles. Instead, RST data from 2003/2004 estimates that only about one third of this number of juveniles migrated down the Lower Yuba River. The 2004 salmon run should have spawned about 15 million juveniles, and RST data from 2004/2005 estimates that 13 million juveniles migrated down the Lower Yuba River. The discrepancy in the 2003/2004 data could indicate some sort of bottleneck for juveniles, at least with a high predicted number of fry. In contrast, the 2004/2005 data seem to correlate reasonably well and suggests that these values are closer to the present capacity for juvenile rearing in the Lower Yuba River.

Lower Yuba River Information
Wyrick and Pasternack (2012) detail the morphological units (MUs; riffle, riffle transition, slackwater, pool, slow glide, fast glide, run, and chute) of the Lower Yuba River and their amount of area under different flow regimes (Pasternack and Wyrick, 2012). These areas are significant, as different life stages of salmon prefer different habitat types. Adult salmon prefer to spawn in riffle, riffle transition, run, and fast glide

MU's. Similarly, juvenile salmon prefer different habitat types, such as feeding in riffles and resting in pools. Additionally, juveniles occur in different MU's in different densities. If one could properly determine the appropriate densities of juveniles per MU, one could then calculate the juvenile carrying capacity ($K_{juvenile}$). Unfortunately, information this specific is lacking. According to Pasternack and Wyrick (2012), there are 510 acres of total river habitat on the Lower Yuba River at 880 cfs.

Results from our ecosystem health report card indicate that the Lower Yuba River has poor macroinvertebrate EPT diversity, which can negatively impact juvenile salmonid food availability (Raastad et al., 1993). The literature also suggests a correlation between riparian plant diversity and macroinvertebrate diversity (Clarke and Wharton, 2000, Iverson et al.,1993, Jahnig et al., 2009). Fittingly, our report card also indicates poor riparian cover on the Lower Yuba River. The lack of sufficient riparian cover and macroinvertebrate diversity could be contributing to the juvenile life stage bottleneck. Thus, riparian vegetation restoration, which could increase the macroinvertebrate diversity and abundance, should help increase the juvenile habitat capacity.

Appendix IV: Travel Cost Analysis

The Tsournos et al. (2016) study focuses on quantifying the benefits that recreational anglers place on fishing using data from multiple years and anglers traveling to different sections of river as well as; river conditions, fish habitat, and recreational opportunities. These angler characteristics vary spatially across sections of the Sacramento River (Figure XXX the map of sections of sac river below). Transferring this value to the Lower Yuba River assumes that the rivers themselves are comparable where anglers value each the same. Negating the differences physical differences between the Sacramento and the Lower Yuba River, the willingness to pay value that was applied to the Lower Yuba does come from a portion of the Sacramento that has been altered by human activities and has yet to be a focus of restoration. There has been a significant effort to restore portions of the Sacramento River aimed at improving habitat for endangered species. A majority of these restoration efforts are located upstream of the section of the Sacramento used as a proxy for willingness to pay for the Lower Yuba River where all of the upstream sections have a greater willingness to pay for fishing due to site characteristics and quality of fishing (Tsournos et al., 2016). A portion of the increased willingness to pay could be attributed to areas that have been improved through restoration.

Tsournos et al. (2016) estimated the total annual value to recreational anglers for each of the sections above. The total annual value for each section is found by multiplying the willingness to pay for a one-day fishing trip by the number of angler fishing days per year. The willingness to pay per fishing trip found for their Section 4 of the Sacramento River was applied to the Lower Yuba River, because of its geographic proximity.

To improve the accuracy of this model for our area of interest, we used creel survey data from the Lower Yuba River to determine site-specific number of fishing days. Creel surveys (also known as angler surveys) are conducted by the California Department of Fish and Wildlife. These surveys collect data such as number of hours an angler spends fishing per day, the species caught and the number of fish caught to estimate fishing efforts and populations of fish. Angler hour data from the Lower Yuba River was divided by the average number of hours spent fishing per day to calculate the number of fishing angler fishing days per year. The number of angler days was multiplied by the WTP for a fishing trip on the lower Yuba River to find the annual value (or benefit) that anglers place on fishing the Lower Yuba River.

Based on 2009 - 2010 California Department of Fish and Wildlife data, the number of angler hours for the entire year is 56,260. Using an average of 4.06 hours spent fishing per day, the number of angler days per year for our area of interest is 13,857 (Table IV-2; CDFW 2010). Multiplying the willingness to pay per fishing trip found by Tsournos et al. and the total number of angler days calculated from California Department of Fish and Wildlife the current annual value of fishing on the Lower Yuba River to be approximately $1,400,000.

Post restoration

Large scale restoration along the Sacramento has increased the quality of habitat for indicator species, specifically salmon. Tsournos et al. (2016) found that the willingness to pay per fishing trip to the Sacramento increased the further up the mainstem that an angler traveled. This increased willingness to pay can be attributed to the less impacted river upstream as it is farther from a large city center and due to the extensive restoration efforts that cover large spatial scales of the Sacramento River. Two such restoration projects include the Wilsons Landing Unit Riparian Restoration Project and the Riparian Sanctuary Restoration Project (River Partners).

Two models were used to infer the relationship between angler visitation rate and increased fish stock (increased population) after restoration. This relationship is necessary to calculate the value to anglers for fishing on a restored Lower Yuba River; and because each model found a different relationship, both studies were used to calculate a range of benefits from river restoration. Increasing fish populations increases the total amount of catchable fish. To translate this relationship to annual value for anglers to fish the Lower Yuba River, predicted population returns from 50% to 200% increases in fish populations were analyzed.

Loomis and Fix (1998) used an angler-use model to determine the relationship between the number of angler hours and increased number of catchable fish (Model A). Model A found that a 100% increase in catchable fish corresponded to a 23% increase in the number of angler hours per day. This relationship was applied to the expected increase in population of salmon as a result of restoration on the Lower Yuba River (Loomis and Fix, 1998). These percent increases were multiplied by the increase in visitation rate to calculate the expected percentage increase in angler use, measured as the percent increase in the number of angler hours. This increase will be divided by the average number of hours per fishing day to calculate the increase in total annual number of angler days per year, assuming that the duration of an angler fishing day remains constant. The expected increase in the number of angler days was then multiplied by the willingness to pay per fishing trip to the Lower Yuba River calculated by Tsournos et al. (2016) to obtain the increased annual value to anglers for fishing the Lower Yuba River post restoration (Equation 1).

$$(\textit{Number of Angler Hours} \times 23\%) \times \frac{\textit{Angler Hours}}{\textit{Per Day}} \times \textit{WTP Per Day}$$
$$= \textit{Value of 100\% Increase in Population}$$

Equation 1. Annual value to anglers for fishing on the Lower Yuba River based on the relationship determined by Model A.

Loomis and Cooper (1990) used a travel cost model to estimate demand for fishing based on visitation data collected by the California Department of Fish and Wildlife (Model B). The results of Model B indicated that the demand for fishing trips as a function of the fishing quality. Results show that a 100% increase in the number of catchable fish corresponds to an increase of 41% to 83% in the number of fishing trips per year. This relationship was used to calculate an expected increase in the annual value to anglers for fishing the Lower Yuba River. The increase in the number of fishing trips corresponds with the increase in the number of fishing days per year that an angler travels to fish. Where it is assumed that each additional fishing trip equates to one angler day. The percentage increase in the number of fishing days (Loomis and Cooper, 1990) was used to calculate a new total number of angler fishing days, and then multiplied by the willingness to pay per fishing trip to the Lower Yuba River calculated using the Tsournos et al. 2016 value, to obtain the range in annual value for fishing the Lower Yuba River post restoration (Equation 2, Equation 3).

$$(\textit{Number of Angler Hours} \times 41\%) \times \frac{\textit{Angler Hours}}{\textit{Per Day}} \times \textit{WTP Per Day}$$
$$= \textit{Value of 100\% Increase in Population}$$

Equation 2. The low estimate of annual value to anglers for fishing on the Lower Yuba River based on the relationship determined by Model B.

$$(\textit{Number of Angler Hours} \times 83\%) \times \frac{\textit{Angler Hours}}{\textit{Per Day}} \times \textit{WTP Per Day}$$
$$= \textit{Value of 100\% Increase in Population}$$

Equation 3. The high estimate of annual value to anglers for fishing on the Lower Yuba River based on the relationship determined by Model B.

<u>Assumptions</u>
To implement the travel cost method to quantify the benefit to anglers to fish on the Lower Yuba River, assumptions that were made include:

1) **The length of an angler day catching Chinook salmon on the Lower Yuba River is equal to 4.06 angler hours**. Angler hours per month were estimated

by using the Central Valley Angler Survey from July 2009 through June 2010 because this is the most current creel data for the Lower Yuba River. This survey results indicate a total of 56,260 hours for both reaches in the Lower Yuba River. Angler hours per day were estimated by using the California Department of Fish and Wildlife annual report for the Trinity River Basin Salmon and Steelhead Monitoring Project. This report calculated the average number of hours per fishing trip on the Klamath River from 1992 to 2008. The Trinity River Basin was chosen to use as a proxy for the average number of angler hours per day because the data was the most representative of fishing effort on a river over roughly a twenty-year period. These data were averaged from 1992 to 2008, resulting in an average of 4.06 angler hours per fishing day.

2) **Each fishing trip is one day.** This assumption was made to keep the willingness to pay per fishing trip constant. Angler fishing data, collected by the California Department of Fish and Wildlife, is measured in hours, and converted to days to obtain an annual angler value. In this analysis, one fishing trip to the Lower Yuba River is equal to one angler day.
3) **The willingness to pay for a fishing trip on the Lower Yuba River is $100**. The willingness to pay value of $100 calculated for fishing on the Sacramento River (Tsournos et al., 2016) was applied to the Lower Yuba River. An assumption was made that any additional expenditure to travel to the Lower Yuba River, instead of the Sacramento River, was insignificant for those traveling to the portion of the Sacramento River that has the Lower Yuba as a tributary so that the willingness to pay per fishing trip of $100 could be transferred to the Lower Yuba River.
4) **Creel Survey data encompasses the entirety of the Lower Yuba River**. The creel surveys that measure the number of angler hours per month only span from Marysville to the Highway 20 Bridge. This is not the entirety of the Lower Yuba River, however spans a majority of the accessible fishing locations so it was assumed that the creel survey was representative of the entire Lower Yuba River.
5) **Willingness to pay of $100 is the average individual**. Socio-economic characteristics were obtained based on respondent's zip code and then averaged within the zip code area.

Results

The total annual value of fishing on the Lower Yuba after restoration ranges from $1,465,393 to $2,979,286 using the Loomis and Fix 1998 results (Table IV-1). The total annual value of fishing on the Lower Yuba River, using the Loomis and Cooper 1990 results ranges from $1,527,750 to $7,136,429 after restoration (Table IV-2).

Challenges and Limitations

Implementing the travel cost method posed some challenges and limitations, including:

- Using the WTP per fishing trip to quantify the increased WTP from an increase in fish stock. To address this challenge, we chose to use results from two other studies to correlate the impact to visitation rate, measured in both angler hours and angler fishing trips from any increase in fish stock (population) from river restoration.

- Willingness to pay (WTP) may vary with the aggregate number of angler days. There is not a defined relationship between the number of angler days and the willingness to pay and could impact the annual value that anglers place on fishing on the Lower Yuba River.
- Willingness to pay for a fishing trip may not be transferrable across all rivers in a particular geographic region. Meaning that an angler's willingness to pay for fishing on one river may not be the same as the willingness to pay on an adjacent river, stemming from differing preferences of site characteristic etc.
- Creel survey data was collected on an annual basis but has now become less regular, and does not capture all the reaches in the Sacramento River region. The most recent survey for the Lower Yuba River are from 2011. This creates a margin of error in our calculations because of the assumption that the number of fishing days per year remained the same from 2011 to 2015.

Table IV-1. Benefits from restoration on the Lower Yuba River. Where a 100% increase in catchable fish is equal to 23% increase in the number of angler hours (Loomis and Fix 1998).

Month	Yuba River (Number of Angler Hours/Month)	50% Increase	100% Increase	200% Increase
July	6632	763	1525	3051
August	3321	382	764	1528
September	3651	420	840	1679
October	9622	1107	2213	4426
November	2544	293	585	1170
December	2845	327	654	1309
January	1780	205	409	819
February	1870	215	430	860
March	10268	1181	2362	4723
April	4663	536	1072	2145
May	3574	411	822	1644
June	5490	631	1263	2525
Total	56260	6470	12940	25880
Total Angler Days	13857	1594	3187	6374
Total Annual Value to Anglers	$1,385,714	$1,545,071	$1,704,429	$2,023,143
Additional Annual Value to Anglers	-	$159,357	$318,714	$637,429
****Where 1% Increase in Catchable Fish Is Equal To 0.23% Increase In The Number Of Angler Hours.**				

Month	Yuba River (Number of Angler Hours/Month)	Number of Angler Days (4.06 Hours/Day Fishing)	50% Increase		100% Increase		200% Increase	
			Low	High	Low	High	Low	High
July	6632	1633	335	678	670	1356	1339	2712
August	3321	818	168	339	335	679	671	1358
September	3651	899	184	373	369	746	737	1493
October	9622	2370	486	984	972	1967	1943	3934
November	2544	627	128	260	257	520	514	1040
December	2845	701	144	291	287	582	575	1163
January	1780	438	90	182	180	364	360	728
February	1870	461	94	191	189	382	378	765
March	10268	2529	518	1050	1037	2099	2074	4198
April	4663	1149	235	477	471	953	942	1907
May	3574	880	180	365	361	731	722	1461
June	5490	1352	277	561	554	1122	1109	2245
Total	56260	13857	2841	5751	5681	11501	11363	23003
Total Annual Value to Anglers		$1,385,714	$1,669,786	$1,960,786	$1,953,857	$2,535,857	$2,522,000	$3,686,000
Additional Annual Value to Anglers		-	$284,071	$575,071	$568,143	$1,150,143	$1,136,286	$2,300,286

**** WHERE 1% INCREASE IN THE NUMBER OF CATCHABLE FISH EQUALS AN INCREASE IN OF 0.41% TO 0.83% INCREASE IN FISHERMAN TRIPS PER YEAR, WHERE EACH TRIP EQUALS ONE ADDITIONAL FISHING DAY.**

Table IV-2. Benefits from restoration on the Lower Yuba River, where a 1% increase in catchable fish results in 0.41% to 0.83% increases in fisherman trips per year. Each fishing trip equals one additional angler day (Loomis and Cooper, 1990).

Methodology
Zonal Travel Cost Approach from Tsournos et al. (2016)

To determine the value that visitors place on the Sacramento River, the authors estimated each angler's consumer surplus (willingness to pay). The willingness to pay was calculated as the difference between the maximum amount an individual was willing to pay to fish (per day) and the expenditures paid for fishing.

Secondary data for demographics and travel cost estimates were used to help build the visitation rate regression. Creel surveys included zip code information and demographic information was obtained based on zip codes. Demographic information includes median income, average age, percent white, and percent college education attainment. Cost estimates were obtained from AAA. Average cost-per-mile estimates were used; these costs included the fuel costs, maintenance, depreciation, registration and insurance costs.
Visitor interviews collected information such as:

- Date
- Number of people in fishing party
- Hours of fishing
- River mile (location) of interview
- Fish species sought
- Number and species of fish caught
- Home zip code of the anglers

The direct travel cost to consumers was calculated by multiplying the cost per mile traveled by the number of miles traveled. The opportunity cost was calculated by multiplying the average hourly wage rate by one third and multiplying by the number of hours of travel. To equate the opportunity cost of time from nominal costs to real time, the opportunity cost was multiplied by the consumer price index. This allowed the travel costs to be compared over time.

The statistical results from the model and the visitor day use from CDFW allowed for the estimation of the current value of the freshwater fishing recreation opportunities. WTP per visitor day the approximation developed by Graham-Tomasi, Adamowics and Fletcher (1990)

if $\beta1 > -1$: WTP = $1/-\beta1$, where the coefficient for $\beta1$ (the travel cost coefficient) is -0.00995.
Estimating annual visitor days for each section was done by expanding the daily count in the creel sample using the formula that CDFW uses to estimate total fishing hours. To do this, weekend sample counts are multiplied by the ratio of weekend days in a month divided by the days sampled. The same is then calculated for the weekday counts.

Lower Yuba River Creel Data

The *Central Valley Angler Survey- Creel Data for the Yuba River* report was used to determine the number of angler hours spent fishing on the Lower Yuba River. The report documents angler hours from July 1, 2009 to June 30, 2010. The portion of the Yuba River sampled was broken into two reaches; the Marysville to Daguerre Point Dam reach and the Daguerre Point Dam to 1 mile upstream of Highway 20 Bridge reach. Although these two reaches do not make up the entirety of the Lower Yuba River, it is assumed that the estimates reflect fishing on the entire river section.

Surveying was completed on each survey section on 8 randomly selected days per month, 4 weekend days and four weekdays, chosen at random. Weekend days and weekdays data were separated due the significant increase in the angler effort on weekend days. Three sets of field data were collected to calculate angler effort and catch; hourly angling effort, angler counts, and angler catch data. Expanded estimates of angler hours as determined by the Central Valley Angler Survey, July 2009 through June 2010 resulted in a total of 56260 hours for both reaches in the Lower Yuba River.

Annual Value to Anglers in the Lower Yuba River

The total number of angler hours in the Lower Yuba River is 56,260 hours. To convert the number of angler hours to angler days, since an angler day is not 12 hours, it was divided by the average number of hours spent fishing per day. The total number of angler days, using an average of 4.06 hours per day, is 13,857 angler days per year(Appendix xx). Next the projected number of angler days was multiplied by the WTP for fishing trips to the Lower Yuba River. This equates to, $1,385,714, the total annual value to anglers in the Lower Yuba River for fishing for 2010 estimates.

Increased Fish Population and Angler Hours

To calculate increased value to anglers from fisheries restoration, the nexus between increased fish populations (fish density) and the number of angler hours needs to be correlated. While there is little literature on the relationship between increased fish stock and angler effort (measured in hours) there are numerous studies that show the statistical significant relationship between angler catch rates and visitation. The relationship between the angler catch rates and visitation rate can be used to link the expected increase in fish population from restoration to an increased willingness to pay for fishing. One of these studies, focused in Montana, found that a 1% increase in trout catch rates increased visitation by 0.3% (Duffield, Loomis and Brooks, 1987). Other studies have reported significant relationships between the number of catchable fish and the increase in angler use, measured in hours or the increase in angler visits to specific sites. Below are two such studies.

Loomis and Fix (1998) used an angler use model to test whether angler effort is sensitive to trout stocking, where trout stocking is used to support a trout population by increasing stock size. The model analyzes the variation in the extent of visitation across different sites based on different stocking levels at the corresponding sites. The model predicts the angler use, which is measured as the total angler hours. Regressed angler use shows a positive relationship between the increase in catchable trout and the stream angler use. A 1% increase in the number of catchable trout resulted in a 0.23% increase in stream angler use.

Another study, focused near the Lower Yuba River, found that a 1% increase in trout catch rates resulted in a 0.41% to 0.83% increase in the number of fishing trips on the North Fork Feather River, in California (Loomis and Cooper, 1990). The study uses the visitation data collected from the California Department of Fish and Wildlife from on-site surveys from 1981 to 1985 to estimate the demand for trout fishing along the North Fork of the Feather River using a travel cost model. This study takes into consideration the habit formation of visitation patterns and is empirically tested in the study. Recreationists rarely have complete information on the quality of a site, and base decisions on preexisting experience or knowledge of the site. Further analysis of the resulting regression coefficients indicated that the current demand for fishing trips is a function of fishing quality and helps further test the power of habit formation (Loomis and Cooper, 1990).

Appendix V: Hedonic Property Valuation

In Table V-1 and V-2 are all of the parcels numbers used in the hedonic property analysis.

Table V-1. Value of restoration from 31 residential properties along the Lower Yuba River. The total value equals $869,547.

Parcel Number	Date Recorded	Value of Structure	2015 Value	Structure Value, Post Restoration	Value of Restoration
20097002000	2004	$98,481	$124,448	$138,137	$13,689
18130022000	2014	$207,444	$209,171	$232,180	$23,009
5500010000	2012	$205,000	$213,137	$236,582	$23,445
18240009000	2011	$145,960	$154,894	$171,933	$17,038
20440017000	2014	$281,224	$283,566	$314,758	$31,192
6180041000	2009	$125,394	$139,521	$154,868	$15,347
6180052000	2011	$399,579	$424,037	$470,682	$46,644
6180064000	2007	$274,791	$316,359	$351,159	$34,800
6180003000	2015	$130,000	$130,927	$145,329	$14,402
6180007000	1973	$36,186	$194,546	$215,946	$21,400
6180010000	2014	$207,000	$208,724	$231,684	$22,960
6170136000	2008	$94,505	$104,778	$116,303	$11,526
5370021000	1976	$103,516	$434,271	$482,041	$47,770
5370022000	1988	$145,661	$293,917	$326,247	$32,331
6190043000	2016	$64,664	$63,856	$70,880	$7,024
6140044000	2004	$203,500	$257,157	$285,444	$28,287
6140035000	1986	$192,573	$419,422	$465,558	$46,136
6140088000	2015	$251,232	$253,023	$280,856	$27,833
6140089000	2014	$245,339	$247,382	$274,594	$27,212
18240037000	2013	$18,422	$18,877	$20,954	$2,076
5570026000	2014	$623,866	$629,061	$698,258	$69,197
5570008000	2002	$746,380	$990,354	$1,099,293	$108,939
5570027000	2004	$306,000	$386,683	$429,218	$42,535
5570028000	2012	$420,937	$437,645	$485,786	$48,141
5570029000	2014	$502,234	$506,417	$562,122	$55,706
10290017000	2008	$8,108	$8,989	$9,978	$989
10290019000	2008	$30,338	$33,636	$37,336	$3,700
10300053000	2007	$86,140	$99,171	$110,079	$10,909
10284033000	2009	$278,823	$321,002	$356,312	$35,310
					$869,547

Table V-2. Value of restoration from 42 parcels designated "vacant rural homestead" along the Lower Yuba River. The total value equals $168,668.

Parcel Number	Date Recorded	Value of Property	2015 Value	Property Value, Post Restoration	Value of Restoration
5550006000	1997	$19,229	$29,277	$32,498	$3,221
5500011000	2013	$65,000	$65,791	$73,028	$7,237
5500012000	2014	$67,309	$67,040	$74,415	$7,374
6180058000	2011	$65,226	$68,373	$75,894	$7,521
6180009000	2014	$79,577	$79,260	$87,978	$8,719
6190020000	2008	$17,365	$19,017	$21,109	$2,092
5270192000	2006	$12,044	$14,087	$15,636	$1,550
5540007000	1996	$15,820	$23,774	$26,389	$2,615
5280076000	2014	$72,486	$72,197	$80,139	$7,942
6180063000	2000	$851	$1,165	$1,293	$128
6170133000	2006	$2,216	$2,591	$2,876	$285
6170134000	2006	$3,807	$4,453	$4,942	$490
5540006000	1996	$16,474	$24,757	$27,480	$2,723
5280046000	2003	$47,547	$60,931	$67,633	$6,702
5540002000	1996	$12,658	$19,022	$21,115	$2,092
5270182000	2003	$18,335	$23,496	$26,080	$2,585
6180060000	2012	$31,830	$32,689	$36,285	$3,596
6180056000	2014	$111,677	$111,232	$123,468	$12,236
6180055000	2010	$65,000	$70,286	$78,018	$7,731
6180054000	2014	$46,598	$46,412	$51,517	$5,105
6180059000	2012	$31,830	$32,689	$36,285	$3,596
5540001000	1996	$13,825	$20,776	$23,061	$2,285
6220094000	1997	$25,321	$37,199	$41,291	$4,092
5280065000	2012	$60,000	$61,620	$68,398	$6,778
6190042000	2016	$19,185	$18,945	$21,029	$2,084
6160010000	2015	$65,991	$65,650	$72,871	$7,221
5540005000	1996	$15,502	$23,296	$25,859	$2,563
5570039000	2010	$92,683	$100,221	$111,246	$11,024
5540004000	1996	$15,920	$23,924	$26,556	$2,632
5270181000	2003	$30,233	$38,743	$43,004	$4,262
5270180000	2003	$34,320	$43,980	$48,818	$4,838
5270188000	2005	$26,486	$31,977	$35,495	$3,517
5540003000	1996	$12,171	$18,290	$20,302	$2,012
6180061000	2014	$46,598	$46,412	$51,517	$5,105
18240015000	2005	$4,798	$5,793	$6,430	$637
5270187000	2005	$13,359	$16,129	$17,903	$1,774
5270200000	2008	$25,892	$28,356	$31,475	$3,119

5570030000	2006	$26,618	$31,132	$34,556	$3,425
5570019000	2006	$23,454	$27,432	$30,449	$3,017
20020099000	2006	$21,314	$24,928	$27,671	$2,742
					$168,668

Appendix VI: Sensitivity Analysis

		Discount Rate									
		5%		7%		9%		11%		13%	
		Costs									
	Percent Increase in Population	Low	High	Low	High	Low	High	Low	High	Low	High
Benefit Cost Ratio	0	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00	0.02	0.00
	10	0.26	0.05	0.19	0.03	0.14	0.03	0.12	0.02	0.10	0.02
	20	0.50	0.09	0.35	0.06	0.27	0.05	0.22	0.04	0.18	0.03
	30	0.73	0.14	0.51	0.10	0.39	0.07	0.31	0.06	0.26	0.05
	40	0.97	0.18	0.68	0.13	0.51	0.10	0.41	0.08	0.34	0.06
	50	1.20	0.22	0.84	0.16	0.64	0.12	0.51	0.09	0.42	0.08
	60	1.44	0.27	1.00	0.19	0.76	0.14	0.61	0.11	0.50	0.09
	70	1.68	0.31	1.17	0.22	0.88	0.16	0.70	0.13	0.58	0.11
	80	1.91	0.35	1.33	0.25	1.01	0.19	0.80	0.15	0.66	0.12
	90	2.15	0.40	1.49	0.28	1.13	0.21	0.90	0.17	0.74	0.14
	100	2.38	0.44	1.66	0.31	1.25	0.23	1.00	0.19	0.82	0.15

Table VI-1. Benefit cost ratios of river restoration for low and high cost ranges using a range of discount rates from 5%-13%. The benefit cost ratios are shown for varying percentage salmon population returns from 0% to 100%, or doubling of the current population.

Discount Rate	*Percent Fish Returns*
5%	45%
7%	55%
9%	75%
11%	100%
13%	110%

Table VI-2. Percent of salmon population returns for discount rates ranging from 5%-13%, increasing by increments of 2%.