All of the fields in the application form are required for all projects, except where specifically noted. Any supplementary information must be included at the end of this application. For forms and examples, please see Appendix B.

To check a box, right click on the box and highlight "Properties." Click on the circle next to "Checked." Click "OK."

Section 1: Summary Information

1. Project title:	**Using Fin Ray Geochemistry to Assess White Sturgeon Life History Movements: Establishing reach specific markers in Sacramento-San Joaquin River Fish**
2. Applicant name:	*United States Fish and Wildlife Service;* Anadromous Fish Restoration Program
3. Contact person:	**Zac Jackson**
4. Address:	4001 N. Wilson Way
5. City, State, Zip:	Stockton, CA 95205
6. Telephone #:	*209-334-2968x408*
7. Fax #:	*Primary FAX number for contact person including area code.* *209-334-2171*
8. Email address:	*Zachary_Jackson@fws.gov*
9. Agency Type:	Federal Agency ☒ State Agency ☐ Local Agency ☐ Nonprofit Organization ☐ University (CSU/UC) ☐ Native American Indian Tribe ☐
10. Certified nonprofit Organization:	Yes ☒ No ☐ If yes, specify the nonprofit organization registration number: *See www.pd.dgs.ca.gov/smbus/nonprofit*
11. New grantee:	Yes ☒ No ☐
12. Amount requested:	*$286,257.72*
13. Total project cost:	*$354,604.62*
14. Topic Area(s):	Harvestable Species Assessment; At-Risk Species Assessment; Native Fish Biology and Ecology; Environmental Water Management;
15. ERP Project type:	*Research; Pilot/Demonstration*
16. Ecosystem Element:	*Bay-Delta Hydrodynamics*
17. Water Quality Constituent:	*Other*
18. At-Risk species benefited:	*Green sturgeon (& white sturgeon)*
19. Project objectives:	*address uncertainties in basic life history, behavior and population structure of CV sturgeon; provide critical information for the development of conceptual and quantitative models to determine flow requirements for CV sturgeon and assess potential outcomes of water management alternatives*
20. Time frame:	*36 months*

Section 2: Location Information

1. Township, Range, Section: and the 7.5 USGS Quad map name.	*Please provide exact project location, using multiple coordinates and **include the names of 7.5 USGS quad maps.***
2. Latitude, Longitude (in decimal degrees, Geographic, NAD83):	*Center of study area is roughly:* *38^0 03' 05.79" N; 121^0 47' 19.43" W*
3. Location description:	*The Sacramento San Joaquin River System; North from the confluence with Battle Creek (Sacramento River) to the Merced River confluecne with the San Joaquin to the south and west into San Pablo Bay.*
4. County(ies):	*Merced; Stanislaus; San Joaquin; Sacramento; Salono; Yolo; Sutter; Colusa; Glenn; and Butte*
5. Directions:	*N/A*
6. Ecological Management Region:	*North Sacramento; Butte Basin; Colusa Basin; Feather River; American River; Yolo; East Side; Sacramento/San Joaquin Delta; East San Joaquin; West San Joaquin*
7. Ecological Management Zone(s):	*South Delta; Central and West Delta; East and North Delta*
8. Ecological Management Unit(s):	*North Sacramento; Butte Basin; Colusa Basin; Feather River; American River; Yolo; East Side; Sacramento/San Joaquin Delta; East San Joaquin; West San Joaquin*
9. Watershed Plan(s):	*Comprehensive Conservation and Management Plan; Bay Delta Conservation Plan*
10. Project area:	*~ 240 miles of Estuary stream miles*
11. Land use statement:	*Multiple uses of the CaliforniaCentral Valley, including agriculture, urban, industrial, recreational, parks, refuges etc.*
12. Project area ownership:	Public waters of the Sacramento/San Joaquin Delta and San Francisco Estuary
13. Project area with landowners support of proposal:	*N/A*

Section 3: Landowners, Access and Permits

1. Landowners granting access for project: (Please attach landowner provisional access agreement[s]): *N/A*	
2. Owner Interest: *N/A*	
3. Permits:	*Wild fish specimens will be obtained from creel surveys; No permits anticipated*
4. Lead CEQA Agency:	*Lead CEQA agency for project, (PSP Part III I. Environmental Compliance).*
5. Required Mitigation:	Yes ☐ No X *Is the work in the proposed project required as mitigation pursuant to CEQA or other authority? (See PSP Part III I. Environmental Compliance) Check and explain if yes.*

Section 4: Project Objectives

1. List task information: *Goal 1: Endangered and Other At-risk Species and Native Biotic Communities; Goal 2: Ecological Processes; Goal 3: Harvested Species*	
2. Additional objectives: *Goal 4: Habitats*	
3. Source(s) of above information: *APPENDIX D: Ecosystem Restoration Strategic Goals and Objectives*	

Section 5: Conflict of Interest

To assist ERP staff in managing potential conflicts of interest as part of the review and selection process, we are requesting applicants to provide information on who will directly benefit if your proposal is funded. Please provide the names of individuals who fall in the following categories:

- Persons listed in the proposal, who wrote the proposal, will be performing the tasks listed in the proposal, or who will benefit financially if the proposal is funded; and/or
- Subcontractors listed in the proposal, who will perform tasks listed in the proposal, or will benefit financially if the proposal is funded.

Primary Contact for Proposal: Zac Jackson
Primary Investigator: Zac Jackson
Co-Primary Investigator: Joseph Merz and James Hobbs
Supporting Staff:
Subcontractor:

Provide the list of names and organizations of all individuals not listed in the proposal who helped with proposal development along with any comments.

Last Name	First Name	Organization	Role
Jackson	Zac	USFWS	Biologist
Merz	Joseph	Cramer Fish Sciences	Biologist
Hobbs	James	University of California Davis	Biologist

Section 6: Project Tasks and Results Outline

1. Detailed Project Description
Please see attached

2. Background and Conceptual Models
Please see attached

3. Approach and Scope of Work
Please see attached

4. Deliverables.
Please see attached

5. Feasibility
Please see attached

6. Relevance to the CALFED ERP
Please see attached

7. *Expected quantitative result (project summary):*

Please see attached

8. Other products and results:
Please see attached

9. Qualifications
Please see attached

10. Literature Cited
Please see attached

Using Fin Ray Geochemistry to Assess White Sturgeon Life History Movements: Establishing Reach Specific Markers in Sacramento-San Joaquin River Fish

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Proposal to CALFED ERP PSP 2010

Introduction

Sturgeon are a critical conservation concern in California, and throughout the world (e.g., Birstein 1993; Boreman 1997; Secor et al. 2000). Once widely distributed and highly abundant, sturgeon species today exist as fragmented populations occupying limited geographic areas and containing relatively few individuals (Beamesderfer and Farr 1997; Bemis and Kynard 1997; Gross et al. 2002). Many species require immediate conservation action to increase their population size (de Meulenaer and Raymakers 2000), but an incomplete understanding of biology and population demography is hindering progress in the development of conservation strategies (Gross et al. 2002).

Since Euro-American settlement of California in the mid-1800's, white sturgeon (*Acipenser transmontanus*), have seen dramatic declines in California (AFRP 2001). Recent population surveys of white sturgeon within the Sacramento and San Joaquin river systems indicate their numbers are further declining (Fig 1. CDFG Marty Gingras, personal communication). Historical information also suggests a long-term trend of reduced growth rates (Kohlhorst 1980). While little is known about population dynamics of this species, factors influencing these trends appear to be river discharge, sport harvest, food supply and environmental contaminants (Greenfield et al 2005; Moyle 2002; Kohlhorst et al. 1980; Kogut 2008; Linville et al 2002). Freshwater flows are important for prompting spawning migrations and supporting successful recruitment (Moyle 2002). The recreational sport fishery harvests 100-900 fish per year (Figure1; Commercial Passenger Fishing Vessel data; CDFG-Marty Gingras unpublished data). Additional harvest by non-CPFV anglers likely increases annual harvest numbers substantially. Current sport fishing regulations include a slot limit (46-66 inches) to minimize impacts to sexually premature fish and large individuals that generally produce the most eggs. However, key uncertainties for informed management of this fishery include: the impact of recreational harvest on sexually immature fish, the interaction of inter-annual variability in freshwater flows on spawning cues and habitat quality of key nursery areas. Information regarding the extent of critical habitats where sturgeon spawn, rear and feed throughout the Sacramento and San Joaquin river systems is still relatively unknown. Understanding how these factors influence white sturgeon life history is extremely important if fisheries managers are to determine appropriate flow regulations and harvest quotas or implement strategies to improve habitat quality for the species' protection.

Overall Project Description

Project Purpose

Scientists can employ several approaches to study the life history of fish species, including basic sampling of multiple life stages with sampling gears that target different size classes. More advanced techniques include tracking individual fish movements with external physical tags in mark and recapture studies, radio and acoustic tags, or examining hard parts for geochemical fingerprints of movement history. Laser ablation ICP-MS of pectoral fin rays for geochemical signatures is a technique that provides the opportunity to take a retrospective look at the life history of an individual fish by tracing migration movements throughout its life by comparing unique chemical signatures found in fin rays to those found throughout the watershed (Allen et al. 2009; Veinoit et al. 1999). Therefore, the application of fin ray geochemistry to understand white sturgeon life history patterns can provide new insights into habitat requirements of juveniles and adult spawners that could not be discovered with other methods (Allen et al. 2009). More specifically, the analysis of strontium isotope ratios is useful because the habitats that sturgeon use for spawning, rearing and feeding in the San Francisco Bay-Delta have unique strontium isotope signatures that can be incorporated into the annuli of the hard structures (Barnett-Johnson 2008; Hobbs et al. 2010). Counting annuli in transverse sections of pectoral fin rays has also been validated for the precise aging of sturgeon less than 70-yrs of age (Rossiter et al. 1995). Our proposed research will use pectoral fin clips collected from anglers, as well as fin rays collected by state and federal researchers when available. In this study we will age each fish by counting annuli and analyzing strontium isotope ratios (^{87}Sr:^{86}Sr), and trace and minor element ratios deposited in pectoral fin rays. The primary goal of this project is to provide fisheries managers with important information regarding life history movements of San Francisco Estuary white sturgeon, including:

- juvenile rearing locations;
- frequency and location of spawning migrations;

- insights into the influence of inter-annual variability of freshwater flows on spawning migrations; and
- population age structure.

Specifically, we will:

1. Use fin ray microchemistry (87Sr:86Sr and trace element/Ca ratios) to identify movement patterns in white sturgeon during their life history.
2. Refine chemical mapping using a field mesocosm experiment of caging hatchery sturgeon along stream gradients of the Sacramento and San Joaquin rivers; moving fish at set times and locations to identify how time and stream location are archived in pectoral fin ray microchemistry.
3. Collaborate with individuals engaged in sport harvest to access samples from a wide range of source fish; further, access archived material from various sources (i.e., Cal-Academy of Sciences, CDFG Stockton).

Background

White sturgeon are the largest freshwater fish found in North American, making them a unique resource and attracting recreational anglers from around the world. Sturgeon scutes and skull plates have been found in Native American middens in the San Francisco Bay, Sacramento-San Joaquin Delta, and Elkhorn Slough areas, indicating that these large fish were important sources of tribal nutrition (Gobalet 1994; Gobalet et al. 2004). An early commercial fishery developed for white sturgeon between the 1860s and 1901, stimulated by a growing acceptance of smoked sturgeon and caviar on the East Coast of North America (Kohlhorst and Cech 2001). Harvest in California was concentrated in the San Francisco Bay and Sacramento-San Joaquin Delta (Bay-Delta). Commercial catch peaked at ~1.7 million pounds in the late-1880's, but declined to 0.2 million pounds in 1901, when the commercial fishery was closed (Kohlhorst and Cech 2001; Moyle 2002). Small commercial catches in a reopened fishery from 1909 to 1917 indicated that white sturgeon populations were still low, and commercial fishing ceased in 1917. Sport fishing for white sturgeon was legalized in 1954, with a 40-inch total length minimum size limit and a one fish per day per person limit. In 1956, snagging for sturgeon was outlawed and the minimum size limit was raised to 50 inches through 1963. The small sport fishing harvest increased dramatically in 1964 when the minimum size reverted to 40 inches and bay shrimp were discovered to be effective as bait. By 1967, 2,258 sturgeon were landed by party boat anglers. Although exact sport catch data are not available, the California Department of Fish and Game (CDFG) estimates that the harvest rates during the 1980s were 40 percent greater than during the previous two decades (Kohlhorst and Cech 2001). In 1990, a 72-inch maximum size limit became law and the minimum size limit was increased by two inches per year until a new minimum size of 46 inches was reached in 1992. Illegal harvest of sturgeon is known to occur in the Sacramento River, particularly in areas where sturgeon have been stranded (e.g., Fremont Weir; M. Marshall, pers. comm.), as well as throughout the Bay-Delta. The presumably small population of white sturgeon inhabiting the San Joaquin River experience heavy fishing pressure, particularly from illegal fishing (USFWS 1995).

Sturgeon biology is characterized by long life, late maturation, slow growth, high fecundity, flexible feeding patterns and anadromous migration patterns. During most of the year, white sturgeon inhabit the brackish waters of Suisun and San Pablo Bays; presumably, they spend a portion of the year migrating upstream into the Sacramento River to spawn. Tag returns from 1974 to 1988 suggest that most white sturgeon remain year-round in the estuary and tributary rivers. Fish concentrate in the brackish water of Suisun and San Pablo bays and appear to move up or downstream in response to salinity changes. Reproductive adults, a small fraction of the population, move upstream in the Sacramento River and, to a lesser extent, the San Joaquin River in late winter and spring to spawn (Kohlhorst et al. 1991). White sturgeon life-histories are adapted to the naturally fluctuating flow regimes in the San Francisco Bay-Delta; they rely on periodic events of high freshwater outflows, which drive productivity levels in the estuaries. Recruitment is positively associated with the volume of freshwater flow through the estuary (Kohlhorst et al. 1991). Years of high flow regimes tend to match strong year classes because white sturgeon benefit from high productivity and habitat availability, which consequently increases spawning success, juvenile recruitment and overall survivorship. While white sturgeon display iteroparity, the frequency with which they migrate upstream to spawn is currently unknown and the potential for skipped or delayed spawning to influence the population dynamics is great. It is suspected that once mature, females spawn every 2-4 years and that males spawn every 1-2 years, but longer intervals or later maturation may occur if there are poor environmental conditions (Moyle 2002). White sturgeon historically ranged into upper portions of the Sacramento River system, including the Pit River, and a substantial number were trapped in and above Lake Shasta when Shasta Dam was closed in 1944 and successfully reproduced until the early 1960s (Beamesderfer et al. 2004). Sturgeon remains (unidentified species) in deposits at Tulare Lake illustrate that anadromous species were historically capable of reaching the south San Joaquin Valley (Gobalet et al. 2004), but no green or white sturgeon appear to have been trapped behind Friant Dam when it was constructed in the 1940s (CDFG 2002). White sturgeon are regularly observed in the San Joaquin River upstream from the Delta (Beamesderfer et al. 2004) and spawning is suspected to occur primarily in wet years (Shaffter CDFG retired, 2004 personal communication). Small fisheries for sturgeon occur in late winter and spring between Mossdale and the Merced River (Kohlhorst 1976; Kohlhorst et al. 1991; Scott 1993; Lewis 1995; Palomares 1995; Keo 1996; Beamesderfer et al. 2007).

Recent data collected by the CDFG during their seasonal sturgeon surveys indicate a decline in the white sturgeon population (CDFG unpublished). It is likely that the incidence of numerous consecutive dry years in the Bay-Delta system is having deleterious effects on the viability of the population. A common life history trait among iteroparous fishes, skipped spawning, could be the mechanism that explains less frequent spawning migrations and recruitment failure. In the past, reproductive white sturgeon would have found skipped spawning to be evolutionarily advantageous by foregoing bio-energetically expensive migrations during unfavorable conditions (Rideout 2005). However, if unfavorable conditions are occurring at longer intervals due to heavily modified river outflows, they may be skipping spawning more frequently or delaying the age at maturation. Moreover, overharvest of white sturgeon may be influencing and synergistically interacting with poor environmental conditions to decrease the number of individuals spawning or delay the age of maturity. The implications of skipped spawning or delayed maturation for white sturgeon in the Bay-Delta are grim; the fish that remain in Suisun and San Pablo Bays are susceptible to overharvesting by PFVs that target reproductively viable adults.

If environmental and fishing pressures continue to affect spawning success and habitat conditions, white sturgeon may become threatened with extinction. In order for fisheries managers to determine appropriate harvest levels, it is imperative to more thoroughly understand their life history, habitat use and migration patterns. We propose to use pectoral fin ray geochemistry to reconstruct white sturgeon life history patterns in concert with determining age, migration events and environmental conditions throughout an individual fish's life; this insight will provide fisheries managers with information to accurately identify key nursery habitats, estimate migratory movements and determine recruitment rates that are influenced by variable environmental conditions.

Previous studies employing pectoral fin ray geochemistry utilized variations in trace level concentrations of strontium and barium in ratio to calcium, (the primary constituent of fin rays) to infer life history and movement patterns in both white and green sturgeon (Vinoitt 1999, Allen et al . 2009). The use of strontium/calcium and barium/calcium are particularly useful in reconstructing life history patterns of anadromous species because the concentration of strontium (~9ppm) in the ocean is much great than in freshwaters (2-4ppm), while the opposite trend is true for barium (~21ppb in ocean, and ~50ppm in freshwater). However these elements may not be useful for proximity studies in freshwaters due to the lack of temporally stable differences in element/calcium ratios. Recent studies have shown that the ratio of two isotopes of strontium (^{87}Sr and ^{86}Sr) can vary spatially even when the concentration of strontium does not vary due to long-term geological processes. The ^{86}Sr isotope is a geologically stable isotope, meaning once initially formed, does not decay over time. However the ^{87}Sr isotope undergoes radiogenic decay from rubidium ^{87}Rb to ^{87}Sr over approximately 4.5 billion years. Watersheds or tributaries containing varying geological compositions (age, rock type) can produce different strontium isotope ratios ^{87}Sr/ ^{86}Sr, that are temporally stable over ecological timescales. Moreover, contrary to bulk strontium to calcium ratios, the ratios of ^{87}Sr to ^{86}Sr cannot be modified by the biological processes of the fish, thus values measured in waters will reflect the true values deposited in hard structures, thus making strontium isotope ratios the method of choice for reconstructing movement patterns in freshwater systems.

Approach and Scope of Work

The primary objectives of this study are to (1) identify juvenile rearing areas in the Sacramento and San Joaquin rivers, (2) determine the frequency of spawning migrations in the white sturgeon population, (3) establish age at first spawning migration and (4) and examine the role of inter-annual variability of freshwater flow on the life-history of fish harvested in the CPFV fishery. By examining the ratios of strontium isotopes (^{87}Sr:^{86}Sr) in pectoral fin rays via laser ablation— inductively coupled plasma–mass spectrometry (LA- MC-ICP- MS) and trace element ratios with LA-ICP-MS, the movement of fish from the brackish waters of bay habitats back to freshwater spawning habitats can be retraced (Figure 3). Moreover, the unique strontium isotopes deposited on the pectoral fin rays in conjunction with a previously developed geochemistry map (Figure 2) can allow us to retrospectively determine key life history migrations.

Fin-ray geochemistry techniques have numerous advantages over traditional radio-tracking and mark-recapture studies. White sturgeon are a long-lived species (>100 years old) and short-term tracking studies can only examine a small portion of their lives. In addition, telemetry and mark-recapture projects can be costly and there is often a low recapture rate (Veinott et al. 1999). Inserting transmitters into a fish can potentially alter the behavior or physiology, and even cause mortality (Bridger et al. 2003; Rein et al. 1994). In contrast, fin ray geochemistry is non-lethal and provides us with an entire life-history for every fish caught and it has already proven to be extremely useful in studying white sturgeon in the Fraser River and Klamath River (Veinott et al 1999; Allen et al 2009).

We propose a 3-year study to examine life history patterns of white sturgeon by using laser ablation methods established by Allen et al. (2009) for Klamath River green sturgeon and by Veinott et al. (1999) for Fraser River white sturgeon. Our study is comprised of three tasks:

1) We will refine the use of strontium isotope and trace element ratios to map key habitats along the main stem Sacramento River where known spawning occurs and at locations of potential juvenile rearing habitats, and along the San Joaquin River of known occurrences of white sturgeon by collecting waters samples and caging juvenile fish in mesocosms for up to 3 months.

2) Starting in 2011, one hundred fin clips will be obtained from our technician and student supplementing the CDFG seasonal CPFV sturgeon surveys for 3 seasons, totaling 300 fin clips. We will further supplement fin ray samples with any archived samples by the various federal and state resource agencies.

3) We will section fin rays collected in task 2 and age fin rays by enumerating annuli and measure the strontium isotope and trace element ratios deposited in fin rays using laser ablation MC-ICP-MS and Quadrapole ICP-MS technology. Analysis will occur intermittently, and report writing will be finished by 2014.

Objectives and Hypotheses

We propose to use laser ablation multi-collector ICP-MS and Quadrapole ICP-MS to determine migration patterns in adults, juvenile nursery areas and population structure of white sturgeon in the Bay-Delta. Assuming that each migration upstream is a spawning event, we will ask the following questions:

1. **Do white sturgeon use a variety of habitats within the Sacramento San Joaquin River system to complete their life history?**

   H_1: Microchemistry signatures from discrete locations throughout the Sacramento-San Joaquin river system are recorded in sturgeon fin rays from a variety of sturgeon sampled.

   H_0: No differences in microchemistry signatures were observed throughout the sampled population.

2. **Is spawning migration frequency in the white sturgeon population associated with freshwater outflow?**

H_1: High freshwater outflow increases the proportion of spawning migration events in the sampled population.

H_0: There is no relation between flow and incidence of spawning migration.

3. **Are CPFV are harvesting fish that have not spawned?**
4. **Does population age structure vary in association with interannual variability in freshwater outflow?**

H_1: High freshwater outflow produces stronger year classes.

H_0: There is no relation between flow and population structure.

Methodology

Task 1. Stratified exposure of young sturgeon to river reaches

Field mesocosm sites (Figure4) include (1) the mainstem Sacramento River near (a) Hwy 162; (b) Feather River; (c) American River; (d) Walnut Grove; (e) Liberty Island; (f) Sherman/Decker Island; and (g) Sherman Lake; and (2) the mainstem San Joaquin River near (a) Hills Ferry Barrier (RM 118.5); (b) Laird Park (RM89); (c) Durham Ferry Recreational Area (RM71.5); (d) Mossdale (RM54); (e) Rough and Ready Island (RM38); and (f) Twitchell Island (RM15).

We will obtain seventy-eight (78) white sturgeon juveniles from a local hatchery for use in this study. During field caging experiments, three replicate (3) cages (2 fish per cage) will be deployed at each site. Six fish will be Passive Integrated Transponder (PIT) tagged, photographed, measured and weighed and placed in cages. Water temperature will be recorded at each cage using an hourly logger attached to each cage.
The cages will be retrieved every 2 weeks and fish will be measured, weighed and scanned for PIT tags. After 6 weeks, 3 of 6 individuals will be relocated to the next station downstream with fish at the lowest station moved to the furthest upstream location on each river. At the end of 12 weeks, fish will be dispatched and fin ray samples removed for analysis (see sections B and C below). To support healthy test subjects, we will deliver a food supplement to each cage. Because michrochemistry in fish boney structures is primarily delivered by water and not food (Walther and Thorrold 2006), we

will provide a food source (ball of ghost or grass shrimp or hatchery food tethered to inside of cage) at initial cage setting and at each subsequent relocation for each cage group throughout the study. In supplement to mesocosm rearing, we will collect an extensive array of water samples from the Sacramento and San Joaquin rivers and tributaries during the spawning and juvenile rearing periods to construct a detailed map of strontium isotope and trace element ratio distributions.
A group of six (6) individuals will be kept at the source hatchery as reference fish to make comparative assessments for microchemistry analyses.

Contingency
If field mesocosm experiments experience high mortality we will supplement these efforts by rearing juveniles in laboratory mesocosms using source waters collected from field locations at the Center for Aquatic Biology and Aquaculture (CABA) at UC, Davis. CABA has a long history of aquaculture rearing of white sturgeon and adequate facilities to conduct lab studies.

Task 2. Collection of fin rays from wild sturgeon

CDFG conducts periodic creel surveys census of CPFV at numerous ports around the bay. We will utilize these opportunities, in coordination with our own sampling, to collect pectoral fin ray samples from harvested fish from fisherman on a voluntary basis. This approach insures the best overlap of fin ray data with that collected by CDFG and used for management purposes. This approach will serve to minimize any unnecessary additional mortality to the population. To generate interest and garner support for this endeavor, we will create a web site where anglers that volunteer fin rays and other catch information could find out the age and migratory history of their fish.

Task 3.1 Fin ray growth calculations

The back-calculation of fish length-at-age will be conducted using standard methods (LeBreton and Beamish 2000; Veinott et al. 1999). Calcified layers, or growth zones, are incrementally deposited on fin rays and vary in association with season. During summer periods of rapid metabolism, wide regions of calcium carbonate are deposited on the fin ray; during winter periods characterized by slower metabolic rates, thinner bands are deposited. Based on previous research, we will assume that each thin band deposited in the winter season accounts for one year of life (Figure 3). We will use digital imaging analysis to distinguish these demarcations and accurately quantify the annuli to age individual fish. For our cage experiments, we will validate ring deposition at each station with the use of fin ray marks. According to Geffen (1992), the only direct method available for validating the deposition rate of an individual is by counting the rings laid down by individuals whose boney structures have been marked at the beginning of an experimental period, and perhaps again at intervals during the time period. We will mark fin ray structures of caged sturgeon with oxytetracycline (OTC) immediately before deployment and at each station re-deployment following the methods of Rien and Beamesderfer (1994).

Once the fin rays are aged, year-class designation will be back-calculated from sample year to create a histogram in order to see if there are strong year classes. We will then examine the environmental conditions that occurred during the years of successful spawning, and retrace the migration patterns of fish during that year through geochemistry analysis. The synthesis of age, migration patterns and spawning success in the past will inform fisheries managers of specific conditions that benefit or negatively impact white sturgeon.

Task 3.2 Fin ray geochemistry

The laser ablation of calcified hard structures for trace element and strontium isotope ratios using quadrapole and multi-collector mass spectrometry approach is a new tool that allows fisheries managers to reconstruct the life history of individual sturgeon by analyzing archived isotopes deposited in pectoral fin rays and comparing them to the isotopes of water samples collected throughout the watershed (Allen et al. 2009; Veinott et al. 1999). Because the geochemistry of waters in a watershed is dependent on the age and geological composition of the bedrock, streams occurring in different geologies have a unique isotopic signature (Figure 2). We will use a previously developed model of ^{87}Sr:^{86}Sr ratios and Sr/Ca ratios in the Central Valley and refine this information with more detailed surveys to identify nursery habitats and a model of salinity as a mixture of freshwater strontium isotope ratios with the globally stable marine isotope ratio to determine estuarine residence (Hobbs et al. 2010).

For each fish, we will laser ablate each annulus at a resolution of 40 microns, from the base of the fin ray (age zero) until the final annulus (age of collection). The strontium isotope ratios and Sr/Ca ratios for each annulus will be analyzed by a multi-collector ICP-MS and quadrapole ICP-MS respectively. This technique allows us to trace the migration pattern of the fish throughout its entire life by comparing Sr/Ca concentrations and isotope ratios ^{87}Sr:^{86}Sr of each annulus along the transect to known unique Sr signatures in the Central Valley (Figure 2).

Task 4. Data Interpretation

Population age structure

We will define recruitment in its evolutionary sense: when a juvenile becomes sexually reproductive. Recruitment is important because it is the rate at which the adults replace themselves with offspring and it indicates the likelihood that a white sturgeon population will persist. In order to calculate recruitment rate, we will use data from CPFV landings submitted to CDFG (Figure 1). Due to the elusiveness of juveniles in sturgeon surveys, fishery landings are the only reliable source to obtain fin clips and catch data of juveniles. Currently, the CDFG-enforced minimum allowable catch size is 46 inches total length. Based on known size-class data, we will assume that white sturgeons around 50 inches are new recruits to the fishery.

We will age and laser ablate the fin rays and then compare the data to timing of spawning events of adults in order to predict how many juveniles are surviving to adulthood.
The patterns of ^{87}Sr:^{86}Sr in fin rays will determine migration movement patterns and habitat use starting from age-0 to time of collection. Data collected by long-term monitoring stations will be used to reference levels of freshwater outflow. The map of signatures of isotope ratios will allow us to analyze habitats that are utilized by white sturgeon over their life span, including their juvenile stage, which scientists currently

know little about. Results from caged fish experiments will verify increment deposition rate, incorporation of unique strontium isotope and Sr/Ca ratios, and movement patterns collected in the wild sturgeon fishery.

Task 5. Data Analysis

Trace elements and Sr isotope ratios - Measures of trace element concentrations and strontium isotope ratios ^{87}Sr:^{86}Sr will be statistically analyzed using parametric multivariate techniques. All concentrations of trace elements will be standardized to Ca, and data presented as the ratio of trace element to Ca. We will use multivariate ANOVA (MANOVA) to test the null hypothesis of no significant differences in trace element ratios among locations with Bonferroni corrections to test differences among natal origins. First, we will log transformed the data (log[x þ 1]). The assumption of multivariate normality and the equality of the variance–covariance matrices will then be assessed by examining each of the univariate variables for normal distribution of errors and homogeneity of variance using residual analysis (Winer et al. 1991). All variables will be assessed as to whether they meet the assumptions of normality and homogeneity of variances after log transformation. Linear discriminant function analysis (LDFA) will be used to determine whether trace element ratios to calcium in fin rays of caged sturgeon reflect differences in hypothesized natal origins (reflected in cage stations). Using the jackknife procedure of general linear model discriminant function, each sample will be removed sequentially from the data set and the discriminant function will be calculated from the remaining data. Cross validation analysis will also be used to determine the percent of fish accurately classified to natal origin. The caged juvenile data set will be used as a reference data set in LDFA to identify the adults sampled from the fishery of unknown natal origin. In addition, the classification of adults back to their natal origins will be further assessed using a maximum likelihood mixed-stock analysis approach (integrated stock mixture analysis [ISMA]) as described by Campana et al. (2000). The ISMA model has distinct advantages over the LDFA model: prior probabilities of group membership are known, and the ISMA model is relatively distribution insensitive. However, the ISMA model can be sensitive to small sample sizes. The ANOVA and MANOVA will be conducted using SYSTAT 10.0 (SPSS 2000) and or JMP-IN. The

LDFA will be conducted with MATLAB, and the ISMA will be conducted with Sþ statistical software.

Flow effects - We will use a binary logistic regression to examine the role of river flow in determining years of spawning/recruitment for sturgeon. Binary logistic regression is particularly appropriate for this analysis because our goal is to classify spawning/recruitment occurrences into two categories, years in which spawning/recruitment did or did not occur (see Feyrer et al. 2006). The response variable in the analysis will be coded as either 1 or 0, based upon the incidence of spawning/recruitment. Independent variables included in the model will be river source, mean daily values of flow (m^3/s), peak annual outflow (acre-feet for drainage), and period of peak discharge associated with lifestage (immigration, emigration, spawning).

Deliverables

Expected Results and Possible Implications

We expect to find that the population of white sturgeon is heavily influenced by Sacramento and San Joaquin river flow regimes. If this is the case, then water resources in both systems will need to be managed according to white sturgeon habitat requirements to positively affect future success of this population. These findings will allow us to predict future recruitment rates and tailor fisheries management practices accordingly.

1. **Is frequency of spawning migration associated with freshwater outflow?**

If the proportion of the population spawning in wet years is higher than in dry years, then freshwater outflows are a driving factor for spawning success. If dry years are characterized by infrequent spawning migrations, it is likely that white sturgeon skip spawning because of lower productivity and lower growth rates in San Pablo and Suisun bays.

However, if the proportion of adult spawners does not vary with freshwater outflow, then we will assume that either: 1) a random proportion of adults spawn every year despite environmental conditions, or 2) all adults spawn at the same time intervals and even during dry years.

2. **Do juvenile sturgeon rely on upper river habitats for rearing?**

Currently, very little is known about the juvenile rearing habitats of white sturgeon. Very few individuals are observed during extensive IEP monitoring surveys and thus understanding how juveniles use different areas of the river-delta-bay continuum is paramount for effective management of this native species. Since few individuals are captured along the mainstem Sacramento River, where spawning is known to occur, and along the San Joaquin River of where white sturgeon are encountered during IEP surveys, it is likely that juveniles are rearing for a considerable time (1-3 years) in mainstem Sacramento River. However, very little sampling occurs along the mainstem Sacramento and San Joaquin rivers, thus this supposition cannot be supported at this time. Caging fish in key locations along the Sacramento and San Joaquin rivers will allow us to create a roadmap of potential rearing habitats and test the hypothesis that juveniles rear in upper river habitats.

3. **Does population age structure vary in association with freshwater outflow?**

If juvenile recruitment rates vary in association with freshwater outflow, then production and survival of larvae benefit from higher flows. The recruits survive due to increased productivity, habitat availability and predation avoidance.

In contrast, if juvenile recruitment rates do not vary in association with freshwater outflow, then we assume that juveniles are recruited during dry years despite low productivity, depressed growth rates and less available habitat.

4. **Does population structure vary in association with freshwater outflow?**

If stronger year classes are produced during wet years, then the population relies on freshwater outflow for spawning success and juvenile recruitment. Therefore, because white sturgeon are long-lived, it is probable that the dynamics of the population is a reflection of previous and current flow regimes and management practices.

Conversely, if population structure does not vary in association with freshwater outflow, then it is likely that other unknown factors are affecting population abundance (e.g., poaching, environmental contamination, diet shift).

Feasibility

Our team has in depth experience sampling fish, performing large-scale field experiments and performing detailed microchemistry analysis on a variety of fish species including white sturgeon. We also have an excellent working relationship with CDFG, who is directly responsible for the creel sampling we propose to use in this project; members of our team have direct experience working with and collecting samples from sturgeon anglers. We have extensive experience analyzing microchemistry and migratory data and have written and published data assessing fish growth, movement and survival using a variety of monitoring techniques proposed in this study. Our team has had experience caging fish in the wild and handling wild sturgeon for diet analysis. We fabricate and repair much of the largescale sampling and trapping equipment we have employed throughout the Central Valley for the past 18 years.

Fin ray chemical and structural analyses will occur at the University of California Davis. As method development has occurred over the past several years and peer-reviewed manuscripts using these techniques are currently in press, we consider the feasibility and likelihood of success very high.

Relevance to the Ecosystem Restoration Program

Our proposal addresses several of the main goals of the Ecosystem Restoration Program, including: Achieving recovery of at risk species, and maintaining or enhancing populations for harvest. This research would provide vital information for assessing the impact of recreational harvest on white sturgeon populations and information regarding the life history and population dynamics. This study also meets several priority criteria as outlined in the PSP including, being and interdisciplinary based study, using existing data and being a collaborative project between the University, USFWS and Cramer Fish

Sciences. We also provide information that can be used to test hypotheses identified in the DRERIP evaluation of BDCP by providing recruitment data in relation to water flow regimes.

Relevance to the Delta Science Program

Our proposal is uniquely tied to Delta Science Program, emphasizing water management and habitat effects on a charismatic mega-fauna species that has received relatively little scientific study within the California region. The package calls for research proposals focused on Native Fish Biology and Ecology and the development of systems that support Water and Ecosystem Management Decisions. Primary questions asked within the PSP include:

- How do native migratory fishes navigate through the San Francisco estuary?
- What factors affect migratory behavior?
- What are the management implications?
- What is the spawning behavior of native fish species, and where do they spawn?
- How might climate change and management actions affect spawning?
- What are annual flow requirements for sufficient habitat configuration of native fishes?
- How are habitat requirements for aquatic organisms distributed spatially under different river flow regimes, alternative water storage and conveyance scenarios, and climate change scenarios?

Our proposal is a new and unique investigation addressing each of these questions as they pertain to one of the key species of special interest, white sturgeon, specifically within the Bay-Delta ecosystem.

Specifically, our study aims to:

- provide critical information needed to improve ecosystem quality and reduce the mismatch between ecology and management
- address uncertainties in basic life history, behavior and population structure

- provide critical information for the development of conceptual and quantitative models to determine flow requirements for aquatic species and assess potential outcomes of water management alternatives
- provide critical information to model white sturgeon population responses to water management and habitat restoration
- address key species of interest (i.e., white sturgeon) with results that are likely to apply to other species (e.g., green sturgeon)
- address questions about migratory histories and behavior, responses to environmental variation, importance of various habitat types, and associated management implications

This project will also provide critical information regarding the freshwater outflow requirements to cue white sturgeon to migrate up river and for successful recruitment. Currently the State Water Resources Control Board is imposing strict outflow requirements for threatened and endangered estuarine species of which the white sturgeon is a species of special concern, a species of focus for this process, and a sport fishery with which considerable financial support by the public.

White sturgeon is a charismatic megafauna and an important recreational sport species that has received relatively little study as to its ecological role in the Bay Delta Region (Moyle 2002). The white sturgeon once supported a significant commercial fishery within the San Francisco Estuary, but it is hypothesized that the population declined because of a combination of overfishing, significant water quality and habitat degradation, and damming of rivers. The species' slow rate of maturation and its use of estuaries, coastal bays, and upstream areas of rivers make the Central Valley sturgeon stock(s) vulnerable to habitat alterations.
The continued exploitation of mature females to produce caviar and the more recent increase in poaching activity to meet this demand may add pressure on this resource. One of the main Delta Science Program goals is to protect and recover, through ecosystem management and restoration, native fish populations that depend on the San Francisco Estuary.

In spite of considerable scientific progress, many uncertainties remain about basic life history, behavior, and population structure characteristics of white sturgeon within the San Francisco Estuary. Gaining a better understanding of these elements of sturgeon ecology would support successful recovery and estuary management in several ways. For instance, within San Joaquin River restoration planning activities, there is potential to provide access to historic habitat for sturgeon. A clearer understanding of habitat and timing requirements for sturgeon could help facilitate this. It has also been postulated that water operations determine migration and spawning success for white sturgeon (Kohlhorst 1991). The relationship between water operations and recruitment success is illustrated by the fact that all years of good recruitment have occurred during either wet or above-normal years (USFWS 1995). Balancing water requirements of sturgeon with agriculture, metropolitan water supply, power production and flood protection needs continues to exert a fundamental environmental challenge for California. Predicted future climate changes may further alter flow magnitude, temperature and timing, exacerbating this balancing act. How sturgeon will respond to flow and temperature changes over the course of their life will determine their ability to adapt to climate change (Lindley 2008) and our management response to that change. Information gathered from this study will help clarify these issues and provide clearer understanding of potential management actions.

By addressing key uncertainties in basic life history, migratory behavior and population structure, the study we outline here would improve our ability to better match management of current and future water supply scenarios and ecology of the Bay Delta System. Establishing the frequency of spawning migrations of adult sturgeon, and identifying juvenile rearing habitats and factors contributing to year-class success of white sturgeon life histories will support the management of these populations by identifying environmental conditions necessary to support population viability.
Lastly since we utilize fish that are already being harvested by sport fisherman, the additional impact to the population will be minimal. The minimal cost of this project in relation to the vital information it will provide coupled with the high probability of

project success, as supported by the publication record of the P.I.s, makes this project a strategic choice for inclusion in the Delta Science Program.

Our project addresses the following specific goals of the Delta Science Program 2010 PSP:

Interdisciplinary Project— This proposal incorporates multiple research disciplines, including new field and lab studies, migration-flow relation modeling, finray micro-chemistry, genetics, and integration of available information (e.g., historical data and archived tissue samples).

Synthesis of Existing Information — The state of California has collected a wealth of monitoring information on white sturgeon in the Bay Delta System, including seasonal adult sturgeon populations studies that have been ongoing intermittently since 1967. However, much of this information remains only partially analyzed, including information assessing absolute and relative abundance, recruitment, movement and migration, harvest rate, and survival. One of our primary goals is to work with various agencies to analyze, integrate, and synthesize existing information across these data-sets in new ways to better understand the various aspects of sturgeon ecology that remain unknown.

Collaborative Proposals — We have developed a collaborative team of federal, state, private and educational facility scientists. Our group has a variety of strengths from ecology, micro-chemistry, field and laboratory sciences, modeling and statistical backgrounds with extensive experience in estuary and riverine environments.

Relevance to other Delta Science and Management

Recognition of serious issues within the Delta has led to a number of different management strategies which relate to water supply, facility infrastructure and ecosystem management. For successful Delta ecosystem management to occur, a clear understanding is needed for the ecosystem processes and biological resources that support a healthy Delta. This includes important life history requirements and population responses to management decisions.

AFRP- CVPIA

According to the U.S. Fish and Wildlife Service (2001), research needs for successful management of white sturgeon include: estimates of abundance, distribution, mortality rates, and movement patterns. Information necessary to determine the success of restoration actions include: Mapping and surveys of available broodstocks and spawning grounds, including physical and chemical parameters, number of brood fish, “spawnability", and embryo survival; Estimate juvenile sturgeon abundance and year-class strength; Identification of environmental parameters related to year-class strengths. Information we gather within this study will help provide AFRP with important information needed to successfully manage Central Valley sturgeon for the CVPIA.

Bay Delta Conservation Plan (BDCP)

The purpose of the BDCP is to provide for the recovery of endangered and sensitive Delta species and their habitats in a way that also will provide for the protection and restoration of water supplies. Key components of the BDCP are to identify and implement conservation strategies to improve the overall ecological health of the Delta and ecologically friendly ways to move fresh water through and/or around the Delta; Address toxic pollutants, invasive species, and impairments to water quality; and provide a framework to implement the plan over time. Both green and white sturgeon are identified as “Covered Species” in the BDCP. Information we gather within this study will help the BDCP provide conservation and management strategies for sturgeon.

Delta Operations for Salmonids and Sturgeon (DOSS) Group

The purpose of the DOSS is to provide advice to the Water Operations Management Team (WOMT) and National Marine Fisheries Service (NMFS) on measures to reduce adverse effects from Delta operations of the Central Valley Project and the State Water Project to important fisheries resources such as sturgeon. Information we gather within this study will support the DOSS by providing important information about juvenile rearing locations, frequency and location of spawning migrations and insights into the influence of inter-annual variability of freshwater flows on spawning migrations.

Conservation Strategy, DRERIP and ERP Conservation Strategy

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP) is one of four regional plans intended to guide the implementation of the CALFED Ecosystem Restoration Program (ERP) element. The DRERIP is meant to refine the planning foundation for the Delta, develop and refine specific restoration actions and provide project implementation guidance, program tracking, performance evaluation and adaptive management feedback specific to the Delta. The DRERIP Fish Habitat Linkage Model (FHL model) provides a roadmap for how the various conceptual models designed for the DRERIP process intertwine to define fish habitat and ultimately produce fish. The model identifies the key linkages between hydrology and numerous other components of fish habitat. Information we gather within this study will help populate and refine these models as they relate to white sturgeon so that they appropriately articulate the current scientific understanding of important aspects of the Sacramento-San Joaquin River Delta ecosystem, including white sturgeon and aid in the identification and evaluation of ecosystem restoration actions that help support wise sturgeon management.

Matching Funds —

The USFWS Anadromous Fish Restoration Program (AFRP) has budgeted $200,000 for FY2011 for a project to assess: the effects of environmental contamination on white sturgeon, the effects of fin ray removal on growth and survival of white sturgeon, and age and growth of the current white sturgeon population compared to historical evaluations of the population. Funding for these studies from AFRP in future years is expected to total at least $210,000. Other studies that complement the proposed microchemistry work and the previously mentioned projects that AFRP is funding include acoustic telemetry of adult sturgeon in the San Joaquin River (FY2010 - $23,000, FY2011 - $95,000) and a study to determine sturgeon spawning locations in the San Joaquin River (FY2011 - $70,000). The acoustic telemetry project is also supported by CDFG staff at a cost of approximately $30,000 per year.

Relevance to Delta Science Program issues outside this PSP — The Central Valley Project Improvement Act (CVPIA) requires the Secretary of the Department of the Interior to develop and implement a program which makes all reasonable efforts to ensure that natural production of anadromous fish, including sturgeon, in the Central Valley will be sustainable, on a long-term basis, at levels not less than twice the average levels attained during the period of 1967 - 1991.

One of the goals of the Sacramento-San Joaquin Delta Reform Act of 2009 is to provide for sustainable management of the Delta ecosystem. A key element of a healthy ecosystem is protection and recovery of populations of native fishes that depend on the San Francisco Estuary. Efforts to clarify uncertainties about basic sturgeon life history, behavior, and population structure characteristics, and the present and potential future factors that affect their distribution and abundance are paramount to successful implementation of various restoration and conservation plans associated with the Sacramento San Joaquin Delta and San Francisco Estuary.

Qualifications

Zac Jackson- Zac is a fish biologist with the USFWS Anadromous Fish Restoration Program. He received B.S. degrees in Zoology-Fish and Wildlife Management and Natural Resources Management from North Dakota State University and a M.S. degree in Fisheries Biology from Iowa State University. Zac's research background is in answering questions related to the management and conservation of aquatic species and systems. His research questions are framed and approached in a manner that has relevance to the general scientific community and natural resource managers. Specifically, Zac's past research has included assessing ecological thresholds in agriculturally eutrophic lakes and numerous age and growth studies on a variety of native and non-native fish species. Zac will coordinate with state and federal agencies, anglers, and fishing guides and will be involved with sample collection and analysis and grant management.

Dr. James Hobbs- Dr. Hobbs is a professional research scientist with the Interdisciplinary Center for Inductively Coupled Plasma Mass Spectrometry and the Department of

Wildlife, Fish and Conservation Biology at UC Davis. He received his B.S. degree in Marine Biology from Sonoma State University, completed his PhD. in Ecology from the University of California, Davis and was a Post-Doctoral Scholar with the Pacific Estuarine Ecosystem Indicators Research at the Bodega Marine Laboratory and a Sea Grant-CALFED Post-Doctoral Fellow at the University of California, Berkeley. Dr. Hobbs's research focuses on understanding the population biology and ecology of commercially important and threatened species development with the use of otolith microstructure and microchemistry techniques. Dr. Hobbs has published many articles in peer review literature and is regarded as the leading expert in the application of laser ablation inductively coupled plasma mass spectrometry in California. He has received many grants from state and federal agencies to investigate the biology and ecology of threatened and endangered species throughout the West. (U.S. Forest Service to determine natal stream origins and migration history of Chinook and Coho salmon in the Klamath River; Army Corp of Engineers-Bonneville Power District to determine migration history and estuarine residency of spring Chinook salmon; Sonoma County Water Agency to determine estuarine residency in Steelhead trout; Department of Water Resources to determine outbreeding depression rates in Chinook Salmon in the Feather Riverl; Interagency Ecological Program to determine ocean residency in the threatened longfin smelt and natal origin of the endangered delta smelt, to name a few).

Dr. Joseph Merz will lead the team on field components of experiments using hatchery juveniles in the Sacramento and San Joaquin rivers. His team will also collect tissue samples from party boats. Joe is an authority on Central Valley aquatic ecology, with extensive knowledge of Sacramento-San Joaquin aquatic ecosystems and has published several papers on fish ecology, movement and habitat restoration. Joe has a long-standing relationship with many Central Valley stakeholders. He also has extensive experience in handling fish and designing field experiments including trap and collection of fish, fish tagging, tissue sampling and artificial propagation of fish in the river environment as well as fish pen operations. He is part of the Central Valley Fish Tracking Consortium and has contributed to a recent CALFED study of steelhead life history decisions and has been the community mentor for two CALFED Doctoral Sea Grant Fellowships.

Figures

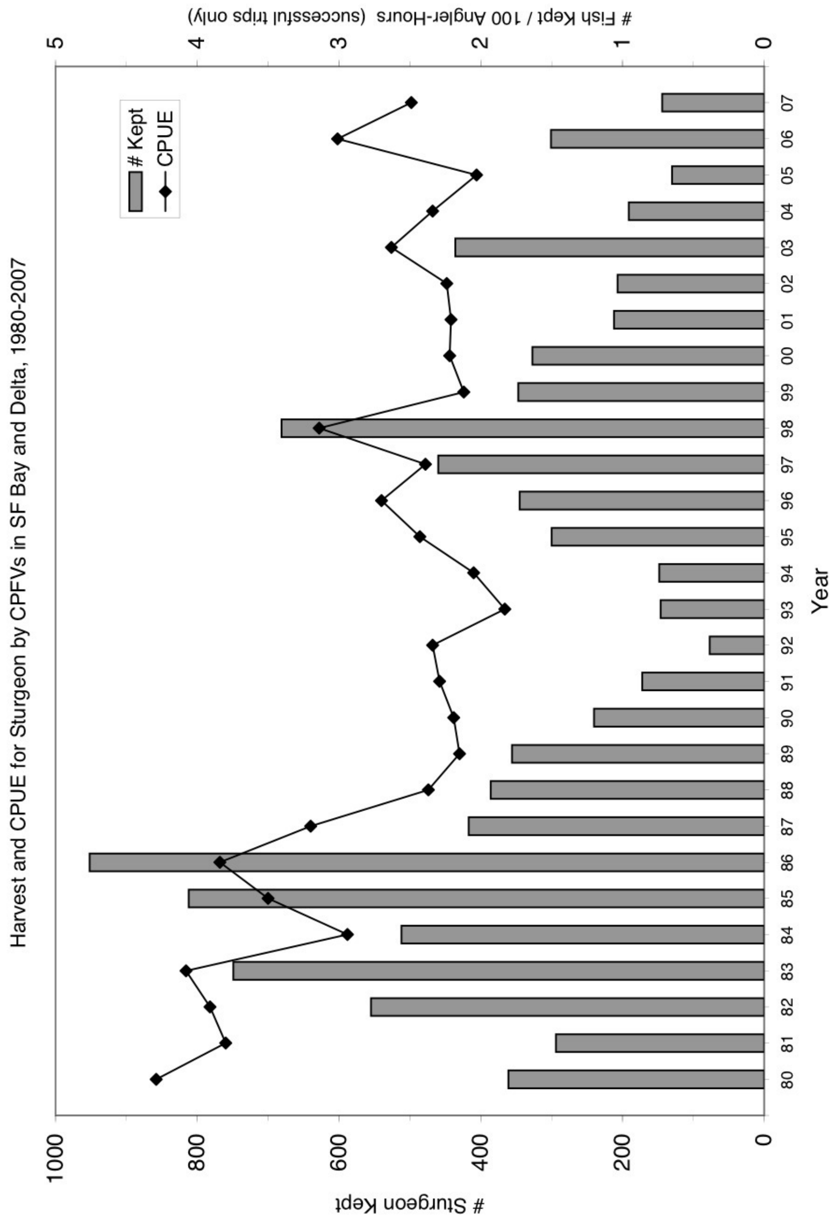


Figure 1. Sturgeon harvest and Catch Per Unit Effort in SF Bay-Delta for Commercial Passenger Fishing Vessels, 1980-2007 (CDFG Marty Gingras, pers. comm.).

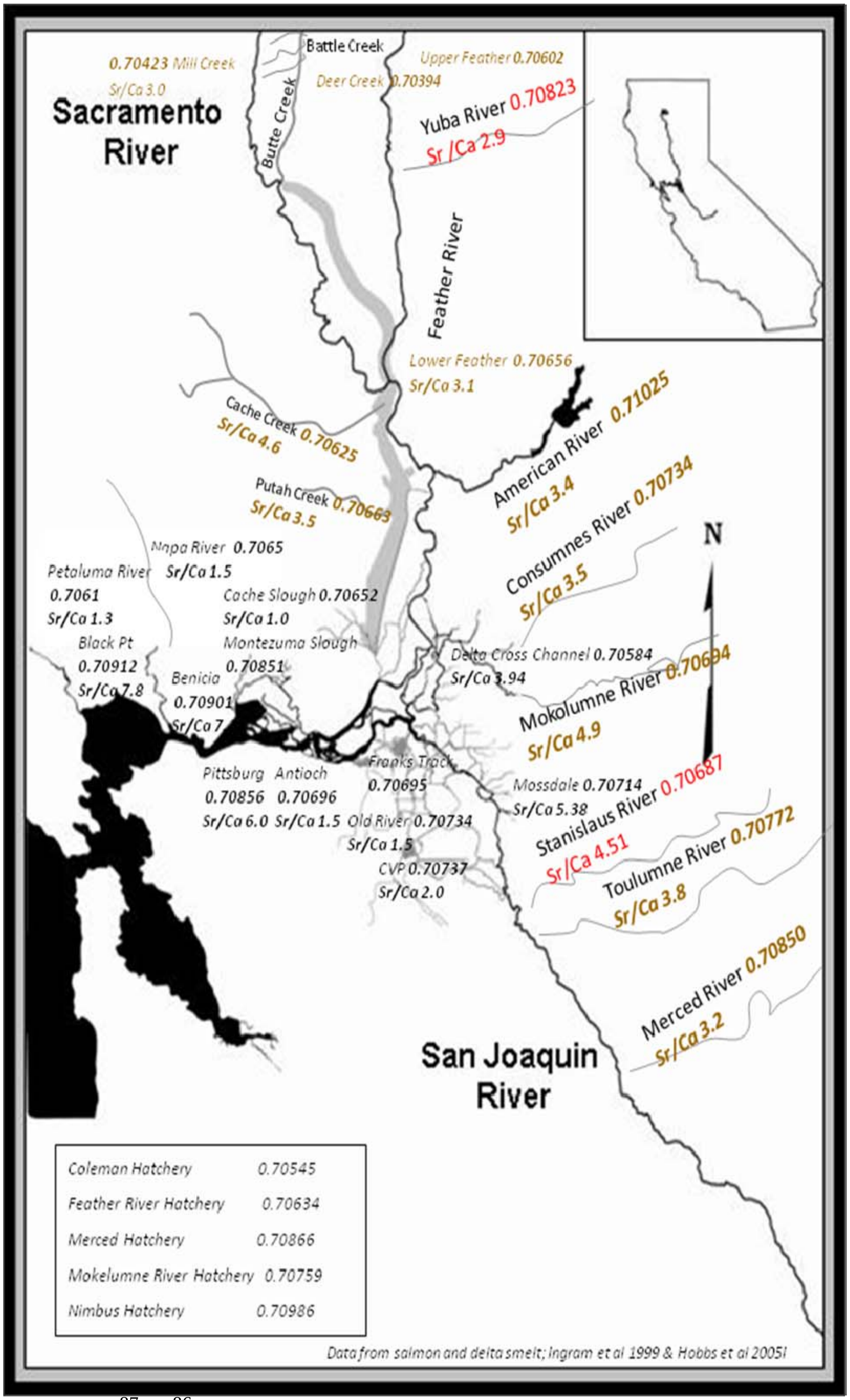


Figure 2. ^{87}Sr:^{86}Sr isotope and Sr/Ca ratio values from water samples in SF Bay-Delta (Ingram et al 1999; Webber 2002, Hobbs et al. 2005, Barnett-Johnson 2008, Miller et al 2010 and C.E. Zimmerman unpublished data).

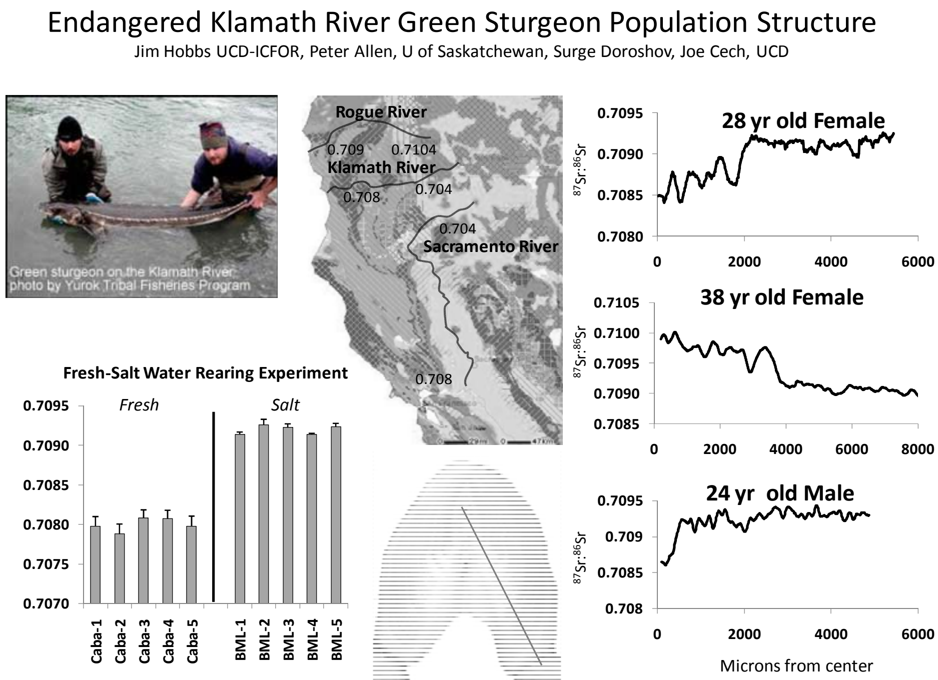
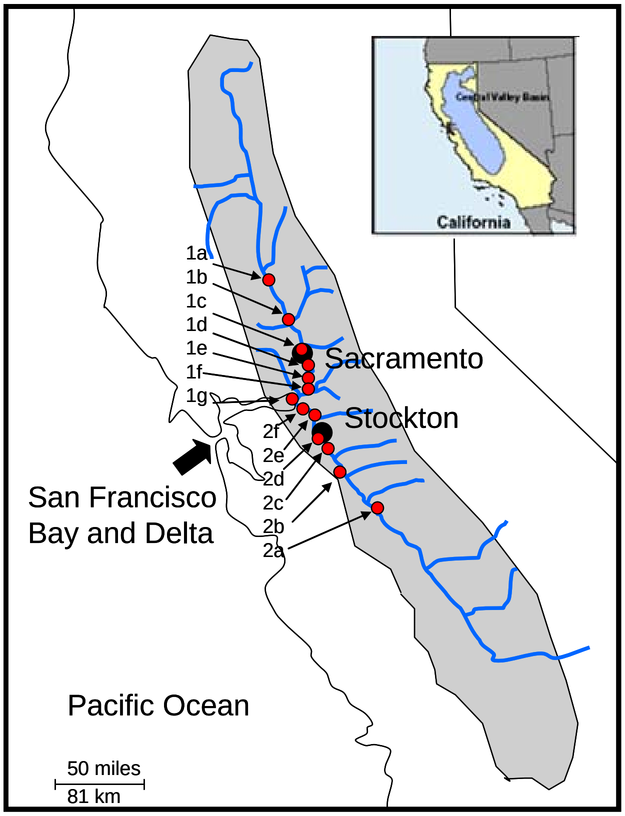


Figure 3. Strontium isotope ratios of Green Sturgeon from hatchery reared fish at Bodega Marine Lab and the Center for Aquatic Biology and Aquaculture at UC Davis, and wild fish collected by the Yurok Tribe on the Klamath River.



River locations for stratified exposure of juvenile sturgeon

(1) Sacramento River
- (a) Hwy 162
- (b) Feather River
- (c) American River
- (d) Walnut Grove
- (e) Liberty Island
- (f) Sherman/Decker Island
- (g) Sherman Lake

(2) San Joaquin River
- (a) Hills Ferry Barrier
- (b) Laird Park
- (c) Durham Ferry Recreational Area
- (d) Mossdale
- (e) Rough and Ready Island
- (f) Twitchell Island

Figure 4. The Sacramento-San Joaquin River System and major tributaries below non-passable reservoirs (blue). Gray area indicates greater Central Valley.

LITERATURE CITED

Allen PJ, JA Hobbs, JJ Cech, JP Van Eengennaam, and SI Doroshov (2009). Using trace elements in pectoral fin rays to assess life history movements in sturgeon: estimating age at initial seawater entry in Klamath River green sturgeon. Transactions of the American Fisheries Society, 138:240-250.

Anadromous Fish Restoration Program (AFRP). 2001. FINAL RESTORATION PLAN FOR THE ANADROMOUS FISH RESTORATION PROGRAM http://www.fws.gov/stockton/afrp/restplan_final.cfm

Barnett-Johnson, R., T. E. Pearson, F. C. Ramos, C. B. Grimes, and R. B. MacFarlane. 2008. Tracking natal origins of salmon using isotopes, otoliths, and landscape geology. Limnol. and Oceanogr. 53:1633-1642.

Beamesderfer, R. C. P., M.L. Simpson, and G.J. Kopp. 2007. Use of life history information in a population model for Sacramento green sturgeon. Environmental Biology of Fish. 79:315-337.

Beamesderfer, R. C. P., and R. A. Farr. 1997. Alternatives for the protection and restoration of sturgeons and their habitat. Environmental Biology of Fishes 48:407–417.

Bemis, W. E., and B. Kynard. 1997. Sturgeon rivers: an introduction to acipenseriform biogeography and life history. Environmental Biology of Fishes 48:167–183.

Birstein, V. J. 1993. Sturgeons and paddlefishes: threatened fishes in need of conservation. Conservation Biology 7(4):773–787.

Bridger CK and RK Booth (2003). The Effects of Biotelemetry Transmitter Presence and Attachment Procedures on Fish Physiology and Behavior. Reviews in Fisheries Science, 11(1): 13–34.

Boreman, J. 1997. Sensitivity of North American sturgeons and paddlefish to fishing mortality. Environmental Biology of Fishes 48:399–405.

Campana, S. E., G. A. Chouinard, J. M. Hanson, A. Frechet, and J. Brattey. 2000. Otolith elemental fingerprints as biological tracers of fish stocks. Fisheries Research (Amsterdam) 46:343–357.

de Meulenaer, T., and C. Raymakers. 2000. Report to animals committee on review of significant trade of Acipenseriformes. Submitted for Convention on International Trade in Endangered Species of Wild Fauna and Flora at 16th Meeting, Shepherdstown, West Virginia. TRAFFIC International.

Gobalet, K.W., 1994. A prehistoric sturgeon fishery in San Pablo, Contra Costa County, California: An addendu. Calif. Fish and Game (80)3: 125-127.

Gobalet, K.W., P.D. Schulz, T.A. Wake, and N. Siefkin. 2004. Archaeological perspectives on native American fisheries of California, with emphasis on steelhead and salmon. 2004. Transactions of the American Fisheries Society 133:801–833.

Greenfield, B.K., J.A. Davis, R. Fairey, C. Roberts, D. Crane, and Gary Ichikawa. 2005. Seasonal, interannual and long-term variation in sport fish contamination, San Francisco Bay. Science of the Total Environment. 336(1-3): 25-43.

Hobbs, J. A., Q.-z. Yin, J. Burton, and W. A. Bennett. (2005). Retrospective determination of natal habitats for an estuarine fish with otolith Sr isotope ratios. Mar. and Freshw. Res. **56**:655-660.

Hobbs, J.A., L.Lewis, N Ikemiyagi, T.Sommer, and R. Baxter. 2010 The use of otolith strontium isotopes (87Sr/86Sr) to identify nursery habitat for a threatened estuarine fish **DOI 10.1007/s10641-010-9672-3**

Ingram , B.L. and P.K. Weber 1999. Salmon origin in California's Sacramento-San Joaquin river system as determined by otolith Sr isotopic composition. Geol. 27, 851-854.

Kohlhorst, D.W. and J.J. Cech. White Sturgeon. *Chapter in* California Living Marine Resources: A Status Report. California Department of Fish and Game 2001.

Kohlhorst, D.W., L.W. Miller, and J.J. Orsi. 1980. Age and growth of white sturgeon collected in the Sacramento-San Joaquin Estuary, California: 1965-1970 and 1973-1976. California Fish and Game 66:83-95.

Kohlhorst, D.W., Botsford, L.W., Brennan, J.S., Cailliet, G.M. 1991. Aspects of the structure and dynamics of an exploited central California population of white sturgeon (Acipenser transmontanus)

Kohlhorst, D.W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. California Fish and Game 62:32-40.

LeBreton, G.T.O and F.W.H Beamish. Suitibility of lake sturgeon growth rings in chronology development. Transactions of the American Fisheries Society. 129(4) 1018-1030.

Linville, R.G., S.N. Luoma L. Cutter, and G.A. Cutter. 2002. Increased selenium threat as a result of invasion of the exotic bivalve Potamocorbula amurensis into the San Francisco Bay-Delta Aquatic Toxicology 57: 51–64.

Miller, J.A., A.Gray, and J.E. Merz 2010. Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon Oncorhynchus tshawytscha. Marine Ecology Progress Series. 408:227-240.

Moyle, PB 2002. *Inland Fishes of California.* University of California Press, Berkeley pp. 106-109.

Rideout RM, Rose GA and MPM Burton. 2005. Skipped spawning in female iteroparous fishes. Fish and Fisheries, 6: 50-52.

Rien, T.A., and R.C. Beamesderfer. 1994. Accuracy and precision of white sturgeon age estimates from pectoral fin rays. Transactions of the American Fisheries Society 123:255-265.

Rien. T.A., Beamesderfer, R.C., Foster P., and Craig A. Retention, recognition, and effects on survival of several tags and marks for white sturgeon. California Fish and Game 80-4:161-170.

Rossiter, A., D. L. G. Noakes, and F. W. H. Beamish. 1995. Validation of age estimation for the lake sturgeon. Transactions of the American Fisheries Society 124:777-781.

Secor, D. H., V. Arevyev, A. Nikolaev, and A. Sharov. 2000. Restoration of sturgeons: lessons from the Caspian Sea Sturgeon Ranching Program. Fish and Fisheries 1:215–230.

Geffen, A.J. 1992. Validation of otolith increment deposition rate, p. 101-113. In D.K. Stevenson and S.E. Campana [ed.] Otolith microstructure examination and analysis. Can. Spec. Publ. Fish. Aquat. Sci. 117.

Gross, M.R., J. Repka, C. T. Robertson, D.H. Secor, and W. Van Winkle. 2002. Sturgeon conservation: Insights from elasticity analysis. American Fisheries Society Symposium 00:183-200.

U.S. Fish and Wildlife Service. 2001. Final restoration plan for the Anadromous Fish Restoration Program: A plan to increase natural production of anadromous fish in the Central Valley of California. Prepared for the Secretary of the Interior by the U.S. Fish and Wildlife Services with the assistance of the Anadromous Fish Restoration Program Core Group. Stockton, CA.

U.S. Fish and Wildlife Service. 1995. Working paper: habitat restoration actions to double natural production of anadromous fish in the Central Valley of California. Volume 2. May 9, 1995. Prepared for the U.S. Fish and Wildlife Service under the direction of the Anadromous FishRestoration Program Core Group. Stockton, CA.

Veinott G, Northcote T, Rosenau M and RD Evans (1999). Concentrations of strontium in the pectoral fin rays of the white sturgeon (Acipenser transmontanus) by laser ablation sampling – inductively coupled plasma – mass spectrometry as an indicator of marine migrations. Can. J. Fish. Aquat. Sci., 56: 1981-1990.

Walther, B. D. and S. R. Thorrold. 2006. Water, not food, contributes the majority of strontium and barium deposited in the otoliths of a marine fish. Marine Ecology Progress Series 311:125-130.

Weber PK. 2002. Geochemical markers in the otoliths of Chinook salmon in the Sacramento-San Joaquin River system, California. PhD dissertation, University of California,Berkeley, CA

Winer, B. J., D. R. Brown, and K. M. Michels. 1991. Statistical principles on experimental design. McGraw-Hill, New York.

Yuan L. Wang, Frederick P. Binkowski and Sergei I. Doroshov 1985. Effect of temperature on early development of white and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Environmental Biology of Fishes 14:43-50.

Fin Ray Geochemistry Study Proposal Budget

	Projected Hours								Expenses							
	$166.00 Sr. Scientist IV	**$185.00 Fed Grant Rate**	**$100.00 Biologist III**	**$111.68 Biologist IV**	**$65.00 Biologist I**	**$54.00 Bio-Tech II**	**$46.00 Field Tech II**	**Labor**								
Objectives and Tasks	**Merz**	**Hobbs**	**Watry**	**Jackson**	**Montgomery**		**Student**	**Subtotal**	**Phone**	**Travel**	**Direct**	**Misc.**	**Totals**			
Task 1. Stratified exposure of young sturgeon to river reaches - 1 year study 2011																
Task 1.1 Cage experiment - Sacramento and San Jaoquin rivers									$20	$750	Food	$1,400	$2,170			
Activity 1.1.1 Cage construction			4		80	80		$9,920		cage material	$3,500		$13,420			
Activity 1.1.2 Collect water samples from study reaches						24	24	$2,400					$2,400			
Activity 1.1.3 Acquistion of and deployment of 39 cages and 78 sturgeon	8		8					$2,128		temp loggers	$2,000		$4,128			
Activity 1.1.4 Sturgeon tagging; photography and movement every 2 weeks					280	280	280	$46,200		Accomodations	$2,700		$48,900			
Objective 1 Subtotal	8	0	12	0	360	384	304	$60,648	$20	$750	$8,200	$1,400	$71,018	per year	$71,018	1 year
Task 2 Collection of fin ray samples 3 year study 2011-2013																
Task 2.1 Collect samples from CDFG Stockton Office			4	20				$2,634	$20	$1,267			$3,921			
Task 2.2 Collect samples from CPFV boat captains	8	8	8			96	96	$13,208	bags; ice chest; tags		$350		$13,558			
Task 2.3 Team coordination	8			20				$3,562					$3,562			
Objective 2 Subtotal	16	8	12	40	0	96	96	$19,403	$20	$1,267	$350	$0	$21,040	per year	$63,120.95	3 years
Task 3 Fin Ray Geochemistry																
Task 3.1 Fin ray preparation						100		$5,400					$5,400			
Task 3.2 Run rays from juvenile study (66 samples)		11						$2,035					$2,035			
Activity 3.2.1 SR Isotopes @44/hr								$0		UCD_ICPMS Recharge		$3,652	$3,652			
Activity 3.2.2 Trace Elements @31/hr								$0		UCD_ICPMS Recharge		$2,822	$2,822			
Task 3.3 Run anaysis on rays collected from adults 100/yr		30						$5,550					$5,550			
Task 3.4 Run Water samples (11) @165/sample								$0					$0			
Task 3.5 Staff coordination	8			20				$3,562					$3,562			
Objective 3 Subtotal	8	41	0	20	0	100	0	$16,547	$0	$0	$0	$6,474	$23,021	per year	$69,062	3 years
Task 4 Communication of study findings																
Task 4.1. Data analysis								$0					$0			
Activity 4.1.1 annual summaries (3 years)	24	24	24	34			40	$16,461					$16,461			
Task 4.2 Report writing and distribution (1 report)	20	20	40	40			40	$17,327					$17,327			
Task 4.3 Presentation of results to professional groups								$0					$0			
Activity 4.3.1 DELTA Science Program presentations (2 conferences)		16		8	8		24	$5,477					$5,477			
Activity 4.3.1 Final Report and publication	20	20	20	20			40	$13,094					$13,094			
Objective 4 Subtotal	64	80	84	102	8	0	144	$52,359	$0	$0	$0	$0	$52,359	per year	$52,359	1 year
Task 5: Management/Admin																
Task 5.1. Coordination with resource agancies				55				$6,142					$6,142			
Task 5.2 Coordinate with boat captains and anglers				55				$6,142					$6,142			
													$0			
Objective 4 Subtotal	0	0	0	110	0	0	0	$12,285	$0	$0	$0	$0	$12,285	per year	$36,853.72	3 years
Project Totals	**96**	**129**	**108**	**272**	**368**	**580**	**544**	**$161,241**	**$40**	**$2,017**	**$8,550**	**$7,874**	**$179,723**	Total budget	$292,413.50	3 years
														Cost match	$68,346.90	3 years
														Requested	$ 224,066.60	3 years