Moyle 2011--ERP Proposal Application Form

For DFG use only	
Proposal No.	Region

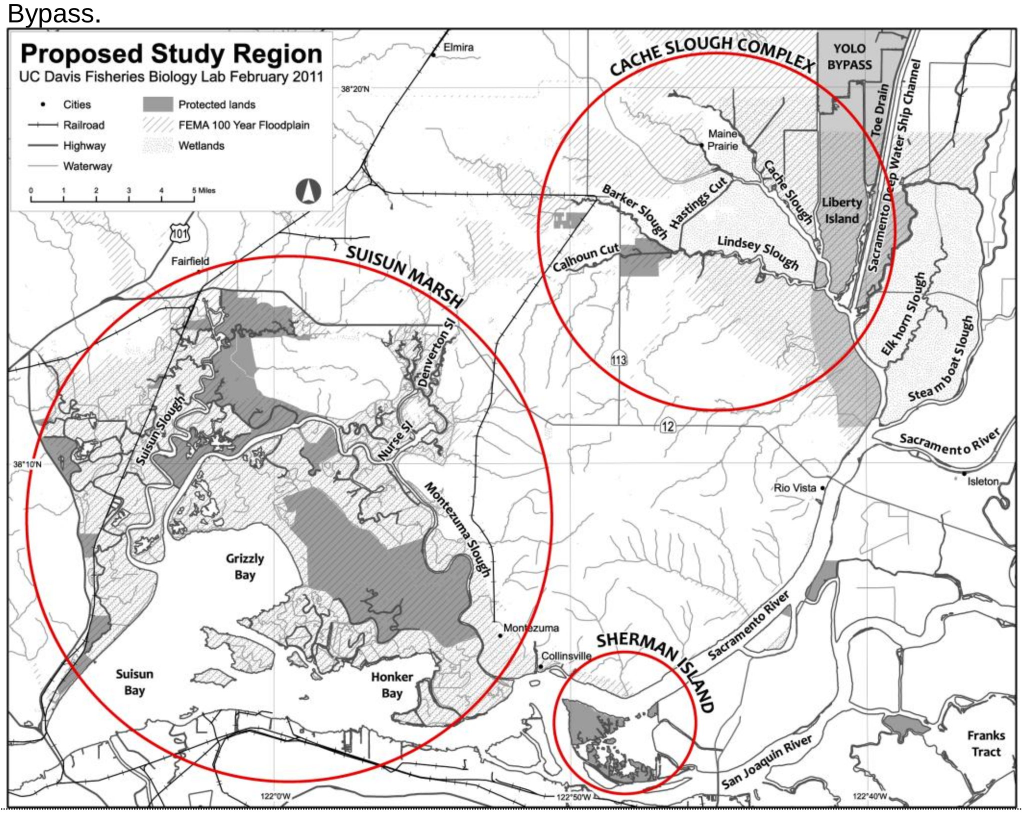
Section 1: Summary Information

1. Project title:	If we build it, will they come?: Identifying habitat characteristics that support native fish in the Delta and Suisun Marsh
2. Applicant name:	Dr. Peter Moyle
3. Contact person:	Dr. Peter Moyle
4. Address:	WFCB, One Shields Ave. University of California
5. City, State, Zip:	Davis, CA 95616
6. Telephone #:	(530) 752-6355
7. Fax #:	(530) 754-9364
8. Email address:	pbmoyle@ucdavis.edu
9. Agency Type:	Federal Agency ☐ State Agency ☐ Local Agency ☐ Nonprofit Organization ☐ University (CSU/UC) ☒ Native American Indian Tribe ☐
10. Certified nonprofit organization:	Yes ☐ No ☒
11. New grantee:	Yes ☐ No ☒
12. Amount requested:	$ 1,152,195
13. Total project cost:	$ $1,152,195
14. Topic Area(s):	(1) Shallow water habitat; (2) At-risk species assessment; estuary foodweb productivity; harvestable species assessment; hydrodynamics, sediment transport and flow regimes; non-native invasive species
15. ERP Project type:	(1) Research; (2) Monitoring
16. Ecosystem Element:	(1) Delta sloughs; (2) Bay-Delta aquatic foodweb; Bay-Delta hydrodynamics; essential fish habitat
17. Water Quality Constituent:	(1) Salinity; (2) Turbidity and sedimentation; (3) Nutrients and oxygen-depleting substances
18. At-Risk species benefited:	Delta smelt; Sacramento splittail; Sacramento River Chinook salmon
19. Project objectives:	Quantify hydrogeomorphic characteristics of sites that support native fishes at different life-history stages; identify connectivity among these sites from northern Delta to Suisun Marsh; identify restoration actions that will improve

	or augment these habitats,including improving connectivity; describe/quantify potential effects of climate change on ability of these sites to support native fishes.
20. Time frame:	August 1, 2012-July 31, 2015

Section 2: Location Information

1. Township, Range, Section: and the 7.5 USGS <u>Quad map name</u>.	Suisun Marsh: Quadrangles Fairfield South, Vine Hill, Denverton, Honker Bay Sherman Island: Quadrangles Antioch North, Jersey Island Cache Slough complex: Quadrangles Rio Vista, Liberty Island, and Dozier
2. Latitude, Longitude (in decimal degrees, Geographic, NAD83):	Latitude 38-01.133—38-20.015 N Longitude 121-39.344—122-06.370 W
3. Location description:	Suisun Marsh is located to the south of Fairfield, along the northern fringe of Suisun Bay. Sherman Island is a flooded island located east of Suisun Marsh near the confluence of the Sacramento-San Joaquin rivers. The Cache Slough complex includes Liberty and Cache Slough, Liberty Island, and the toe drain of the Yolo Bypass.



4. County(ies):	Solano, Contra Costa, Sacramento and Yolo

5. **Directions:**	Suisun Marsh and Sherman Island can be accessed by trailered boat using Hwy 12 and Grizzly Island Rd to drive to public access boat launches in Suisun City and Belden's Landing. Sherman Island can also be accessed by trailered boat using Hwy 12 to Hwy 160, and taking Sherman Island Rd to Sherman Island County Park, where public access boat ramps are available. The Cache Slough complex and the toe drain of the Yolo Bypass can be accessed by trailered boat using Hwy 12 to Rio Vista, where Rio Vista Boat Launch offers public access to a boat ramp.
6. **Ecological Management Region:**	Delta
7. **Ecological Management Zone(s):**	Sacramento-San Joaquin Delta
8. **Ecological Management Unit(s):**	North Delta
9. **Watershed Plan(s):**	BDCP, Delta Vision Plan, CALFED Ecosystem Restoration Program
10. **Project area:**	88 miles x 100 ft
11. **Land use statement:**	Agriculture, hunting, fishing, open space land trust
12. **Project area ownership:**	% Private__70____ % State___10_____ % Federal____20___ *Enter ownership percentages by type of ownership*. All navigable waters are considered federal jurisdiction.
13. **Project area with landowners support of proposal:**	Project will be restricted to open access public waterways.

Section 3: Landowners, Access and Permits

1. **Landowners Granting Access for Project:** (Please attach provisional access agreement[s]) N/A	
2. **Owner Interest:** **N/A**	
3. **Permits:**	Department of Fish and Game Scientific Collection Permit No. 801167-03 SC-001928
4. **Lead CEQA agency:**	N/A
	Yes ☐ No ☒

Section 4: Project Objectives Outline

1. List task information:

Goal 1: Endangered and Other At-risk Species and Native Biotic Communities
Achieve recovery of at-risk native species dependent on the Delta and Suisun Bay as the first step toward establishing large, self-sustaining populations of these species; support similar recovery of at-risk native species in San Francisco Bay and the watershed above the estuary; and minimize the need for future endangered species listings by reversing downward population trends of native species that are not listed.

> **Objective 1:** ***Achieve, first, recovery and then large self-sustaining populations of the following at-risk native species dependent on the Delta, Suisun Bay, and Suisun Marsh: Central Valley winter-, spring- and fall/late fall-run Chinook salmon ESUs, Central Valley steelhead ESU, delta smelt, longfin smelt, Sacramento splittail, and green sturgeon.***
> **Objective 3:** ***Enhance and/or conserve native biotic communities in the Bay-Delta estuary and its watershed, including the abundance and distribution of the following biotic assemblages and communities: native resident estuarine and freshwater fish assemblages, anadromous lampreys, and estuarine plankton assemblages***.

A key problem in California water is that the 'fish are losing', so that water management decisions increasingly involve endangered fish species, as new species are listed and the position of listed species becomes more precarious (Hanak et al. 2011). This situation is especially true in the San Francisco Estuary where seven fish species are already listed and others have potential to become listed as populations decline, especially in the face of climate change (Moyle et al. 2010). While there is general recognition that reversing the downward slide of desirable fishes requires more flow through the Delta (e.g. , 2010 report of SWRCB), it is also increasingly evident that flow has to interact with other aspects of habitat and water quality to enhance fish populations at a reasonable water cost. Therefore, the purpose of this research is to develop a better understanding of how physical habitat, flow, and other factors interact to maintain assemblages of native and non-native species in an environmental gradient that supports populations of most of the native fishes in the upper estuary. By documenting how native and alien fishes use habitat around Suisun Marsh, Sherman Island, and the Cache Slough complex, we can gain insights and test hypotheses that will aid the recovery of at-risk native species, inform flow and habitat management decisions, and allow for better adaptation to climate change.

Each of our three regions is distinguished by different conditions that maintain distinct fish assemblages and food webs but all have habitats that are favored by native fishes and others that are favored by alien species. By measuring conditions at different sites, we will determine the relationships among water quality, slough morphology and hydrodynamics, and their effect on food web dynamics and fish communities using hierarchical statistical models (Gelman and Hill 2007, Zuur et al. 2007). In addition, spatial models of connnectivity will be developed from experiments using fish tag-and-recapture methods and otolith microchemistry (Barnett-Johnson et al. 2005), in order to understand how fish use and move among shallow-water and slough habitats and among the study areas. These understandings will be used to identify areas in the region that have a high potential for management and restoration of native fish populations, including declining species not currently of high concern (e.g., Sacramento hitch, tule perch). By identifying conditions in which native fishes thrive, the study will also allow for predictions as to what areas are likely to support native fishes as climate changes and sea level rises, including areas currently of low suitability (which may improve with sea level rise).

Goal 2: Ecological Processes
Rehabilitate natural processes in the Bay-Delta estuary and its watershed to fully support, with minimal ongoing human intervention, natural aquatic and associated terrestrial biotic communities and habitats, in ways that favor native members of those communities.

> **Objective 1:** ***Establish and maintain hydrologic and hydrodynamic regimes for the Bay and Delta that support the recovery and restoration of native species and biotic communities, support the restoration and maintenance of functional natural***

habitats, and maintain harvested species.
<u>Objective 2</u>: ***Increase estuarine productivity and rehabilitate estuarine food web processes to support the recovery and restoration of native estuarine species and biotic communities.***
<u>Objective 3:</u> ***Rehabilitate natural processes to create and maintain complex channel morphology, in-channel islands, and shallow water habitat in the Delta and Suisun Marsh.***

We will determine shallow water and subtidal habitat conditions in three key areas in our habitat gradient that support native fishes and the food webs upon which they depend. These results will serve two goals: the protection of regions that support natural processes, and the identification and restoration of regions that have high potential to support these processes, including connectivity among diverse habitats to support different life history stages of the fishes. We propose to integrate hydrodynamics by using the finite element models developed by Resource Management Associates, RMA-2 and RMA-11 (King 1988, 1997) to relate geomorphology and hydrodynamics of sloughs (including residence time, export of production, and connectivity) to food web production that supports native fish abundance.

<u>Goal 3: Harvested Species</u>
Maintain and/or enhance populations of selected species for sustainable commercial and recreational harvest, consistent with the other ERP strategic goals.
<u>Objective 1:</u> ***Enhance fisheries for salmonids, white sturgeon, and native cyprinid fishes.***
<u>Objective 2:</u> ***Maintain, to the extent consistent with ERP goals, fisheries for striped bass and American shad.***

The project will determine how juvenile estuarine fishes, including both native and desirable non-native species, use different parts of our habitat gradient. This will be accomplished through monthly monitoring, tagging, and modeling. Our basic assumption is improved rearing habitat will improve juvenile survival and subsequent recruitment into fisheries. We also assume that with changes in flows and sea level rise as the result of climate change, the optimal habitat for each species will be changing in position along the estuarine gradient we will study.

<u>Goal 4: Habitats</u>
Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics.
<u>Objective 1:</u> ***Restore large expanses of all major habitat types, and sufficient connectivity among habitats, in the Delta, Suisun Bay, Suisun Marsh, and San Francisco Bay to support recovery and restoration of native species and biotic communities and rehabilitation of ecological processes. These habitat types include tidal marsh (fresh, brackish, and saline), tidal perennial aquatic (including shallow water and tide flats), nontidal perennial aquatic, tidal sloughs, midchannel island and shoal, seasonal wetlands, riparian and shaded riverine aquatic, inland dune scrub, upland scrub, and perennial grasslands.***
<u>Objective 3:</u> ***Protect tracts of existing high quality major aquatic, wetland, and riparian habitat types, and sufficient connectivity among habitats, in the Bay-Delta estuary and its watershed to support recovery and restoration of native species and biotic communities, rehabilitation of ecological processes, and public value functions.***

One of our project goals is to determine habitat characteristics of tidal marshes and sloughs that support a productive food webs and desirable fishes (Blue Ribbon Task Force 2008, Healey et al. 2008, Lund et al. 2010), using sampling and hierarchical modeling to produce trends in fish utilization. In addition, tagging and recapture and otolith studies (Barnett-Johnson et al. 2005, Hobbs et al. 2005, Feyrer et al. 2007) of fish species will allow us to track the movements of important fish among key habitats along the Sacramento River. This information will be useful in suggesting ways of increasing connectivity to benefit native species and to understand changes in habitat and fish distribution in relation to climate change.

Goal 5: Nonnative Invasive Species
Prevent the establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-native species in the Bay-Delta estuary and its watershed.

Objective 7: ***Limit the spread or, when possible and appropriate, eradicate populations of non-native invasive species through focused management efforts.***

We will identify and quantify conditions in slough and shallow water habitat that discourage alien fishes as well as plants and invertebrates such as *Egeria densa*, *Corbula amurensis*, and *Corbicula fluminea* (Schroeter 2011, Grimaldo et al. 2003). Understanding of these conditions will be used inform habitat improvement projects, including changes favoring (or discouraging) alien species that might occur from sea level rise and other impacts of climate change.

2. Additional objectives:

Our objectives also include developing information that will help determine (1) best areas for restoration projects and (2) conditions that restoration actions should be designed to create or sustain. In general, our study will encompass the dynamic nature of habitats along the 88 mile-long gradient, in order to understand the likely effects of climate change including sea level rise, increased temperatures and changed hydrologic conditions. Any chance for amelioration of these conditions can only come from better understanding of habitat dynamics, including potential shifts of conditions among the main study areas.

3. Source(s) of above information:

Barnett-Johnson, R., F. C. Ramos, C. B. Grimes, and R. B. MacFarlane. 2005. Validation of Sr isotopes in otoliths by laser ablation multicollector inductively coupled plasma mass spectrometry (LA-MC-ICPMS): opening avenues in fisheries science applications. Canadian Journal of Fisheries and Aquatic Sciences 62:2425–2430.

Blue Ribbon Task Force. 2008. Delta Vision Strategic Plan. Final Report, Delta Vision, Sacramento.

Feyrer, F., J. Hobbs, M. Baerwald, T. Sommer, Q. Yin, K. Clark, B. May, and W. Bennett. 2007. Otolith microchemistry provides information complementary to microsatellite DNA for a migratory fish. Transactions of the American Fisheries Society 136:469–476.

Gelman, A., and J. Hill. 2007. Data analysis using regression and multilevel/hierarchical models. Cambridge University Press Cambridge.

Grimaldo, L. F., R. E. Miller, C. M. Peregrin, and Z. P. Hymanson. 2003. Spatial and temporal distribution of native and alien ichthyoplankton in three habitat types of the Sacramento-San Joaquin Delta. Pages 81–96 *in* American Fisheries Society Symposium.

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Healey, M. C., M. D. Deainger, and R. B. Norgaard. 2008. The State of Bay-Delta Science, 2008. CALFED Science Program, Sacramento.

Hobbs, J. A., Q. Yin, J. Burton, and W. A. Bennett. 2005. Retrospective determination of natal habitats for an estuarine fish with otolith strontium isotope ratios. Marine and Freshwater Research 56:655–660.

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King, I. P. 1997. RMA-11—A three-dimensional finite element model for water quality in estuaries and streams–documentation Version 2.5. Department of Civil and Environmental Engineering, University of California, Davis.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, and R. Howitt. 2010. Comparing futures for the Sacramento-San Joaquin delta. University of California Press

Matern, S. A., P. B. Moyle, and L. C. Pierce. 2002. Native and Alien Fishes in a California Estuarine Marsh: Twenty-One Years of Changing Assemblages. Transactions of the American Fisheries Society 131:797-816.

Moyle, P. B., W. A. Bennett, W. E. Fleenor, and Jay R. Lund. 2010. Habitat variability and complexity in

the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 8(3): 1-24. *http://repositories.cdlib.org/jmie/sfews/vol8/iss3/*
O'Rear, T., and P. B. Moyle. 2009. Trends in Fish Populations of Suisun Marsh January 2008 - December 2008. Page 54. Department of Wildlife, Fish, and Conservation Biology, University of California, Davis.
Schroeter, R. 2011. The Temporal and Spatial Trends, Biological Constraints, and Impacts of an invasive clam, Corbula amurensis, in Suisun Marsh, San Francisco Estuary. Ph.D. dissertation, U.C. Davis.
Zuur, A. F., E. N. Ieno, and G. M. Smith. 2007. Analysing ecological data. Springer Verlag.

Section 5: Conflict of Interest

Primary Contact for Proposal:	Dr. Peter Moyle
Primary Investigator:	Dr. Peter Moyle
Co-Primary Investigator:	Dr. James Hobbs Dr. William Fleenor
Supporting Staff:	Patrick Crain Teejay O'Rear John Durand
Subcontractor:	N/A

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
Katz	Jacob	UC Davis	Advisor

Section 6: Project Tasks and Results Outline

1. <u>DETAILED PROJECT DESCRIPTION</u>

PROBLEM STATEMENT

Perhaps the biggest single problem facing managers of the upper San Francisco Estuary is how to manage the environment, especially flows, in ways that do not further endanger listed fish species and that will keep other species from becoming listed under state and federal endangered species acts (Lund et al. 2010, Hanak et al. 2011). Much of the information needed by managers to make tough choices currently derives mainly from regular monitoring programs or from habitat studies at fairly small scales. In addition, most programs surveying fish and invertebrates in the San Francisco Estuary were designed for monitoring striped bass abundance trends and sample only open-water channel habitats (e.g., DFG's Summer Tow-net Survey, DFG's Fall Midwater Trawl), even though most native fishes live primarily in near-shore or in shallow water (Moyle 2002, Nobriga et al. 2005b). These programs have been successful at documenting long-term trends in abundance and have allowed us to observe the decline in pelagic organisms such as mysids, native copepods, and fishes such as delta smelt, longfin smelt, and striped bass (Sommer et al. 2007, Mac Nally et al. 2009).

However, recent evidence suggests some peripheral habitats have been less affected by this collapse and merit comparison with adjacent areas that show severe declines [e.g., delta smelt “First Flush Study,” unpublished data, striped bass and threadfin shad in Suisun Marsh (Schroeter 2008, O'Rear and Moyle 2010), delta smelt in Cache-Lindsey Slough (Nobriga et al. 2005, Sommer et al., unpublished data) and in Sherman Lake (Feyrer et al., unpublished data)]. Among the many suspected causes of this decline in open-water biota, termed "Pelagic Organism Decline" (POD), is reduction and elimination of peripheral habitats such as floodplains and marshes through reclamation and diking for agricultural and urban development (Sommer et al. 2007, Mac Nally et al. 2009). These peripheral habitats are thought to have once provided major spawning and foraging areas for desirable species, as well as a source of nutrients to support pelagic food webs, and thus their restoration has been a goal of several planning efforts (e.g., BDCP). Additionally, it appears that energy flow through the food web to many fishes may have shifted from a primarily pelagic pathway to a benthic or littoral pathway, due in part to the overbite clam (*Corbula amurensis*) (Nichols et al. 1990, Kimmerer and Orsi. 1996, Feyrer et al. 2003, Grimaldo et al. 2009, O'Rear and Moyle 2010), increasing the importance of shallow, near-shore habitats. However, little documentation exists that verifies the importance of peripheral habitats to desirable and native species, except in Suisun Marsh (Matern et al. 2002, O'Rear and Moyle 2010) and Liberty Island (Nobriga et al. 2005). Few studies have attempted to look at these habitats over a broad enough scale, including examining biotic connectivity among habitats, to accommodate the effects of large-scale changes in flow management or climate. There is little understanding as to how native fishes can respond, and adapt, to rapid, large-scale change.

PROJECT GOALS AND OBJECTIVES

Goal 1: Quantify attributes of habitat that support native fish.

Objective 1. Compare abiotic and biotic characteristics of habitat across a broad environmental gradient in areas deemed vital to native biota and targeted for restoration actions: The Cache Slough complex, Sherman Lake, and Suisun Marsh.

Our study focuses on Cache Slough and Sherman Lake in order to compare them with Suisun Marsh, which is the subject of ongoing study by UC Davis. These three areas today seem to support higher numbers and diversity of native fishes than most other parts of the upper San Francisco Estuary (SFE) and represent a gradient of tidal conditions from fresh to brackish. All three areas have complex physical habitat and variable conditions of water quality. Thus they should allow for comparative analysis of potential effects of increases in outflow (more fresh water) and potential effects of sea level rise (more salt water).

Objective 2. Compare the composition of fish and invertebrate assemblages in relation to physical habitat features, water quality, and flows and to study the connectivity of native fish populations among these habitats and across sites.

Sampling methods used in Sherman Lake and Lindsey Slough will be akin to those used by the 30+ yr UC Davis Suisun Marsh Fish Study, thus allowing comparisons along a gradient of environmental variables. In addition, tag-and-recapture will be used to identify movement of fish from one habitat to another, and otolith microchemistry will be examined to determine large-scale patterns of habitat use in relation to life history.

Goal 2: Quantify connectivity of different habitats that support native fish life histories.

We will examine connectivity of tidal freshwater habitats used for spawning and early rearing to juvenile and adult brackish habitats via retrospective life history studies of Sacramento Splittail. To do so we will use otolith microchemistry to reconstruct temporal patterns of habitat usage in relation to life history strategies.

Objective 1. Identify the natal origin of adult Sacramento Splittail using the strontium isotope ratio $^{87}Sr{:}^{86}Sr$ found in the core region of the otolith.

Objective 2. Identify juvenile nursery areas by measuring strontium isotope ratios outside the core region (up to day 90).

Previous studies using otolith strontium isotope ratio ^{87}Sr:^{86}Sr have successfully identified the natal origins and juvenile rearing areas for Sacramento Splittail (Feyrer et al. 2007, 2010). Ongoing studies have also successfully distinguished between Sacramento splittail that reared in the Yolo Bypass and those that reared in the mainstem Sacramento River (Figure 3). Thus the methods and ground-truthing for using otolith strontium isotope ratios for life history studies have already been established (Hobbs et al. 2005, Feyrer et al. 2007, 2010, Hobbs 2010).

PROJECT DESCRIPTION AND LOCATION

Cache Slough Complex

The Cache Slough complex refers to the network of sloughs and flooded islands located to the northwest of the confluence of Cache Slough and the Sacramento Deep Water Shipping Channel. The sloughs of the complex are physically very different. Cache Slough is a broad, heavily leveed channel that is simple both in terms of geomorphology and structural complexity. Lindsay Slough has retained some of its natural channel morphology and is characterized by variable bathymetry, large woody debris, and heavily vegetated mid-channel bars. There are no significant streams that flow into the Lindsay Slough system; however, the pumps of the North Bay Aqueduct are located at the terminal end of Barker Slough, a tributary to Lindsay Slough. The lack of local inflows and the tidal nature of the system combine to suggest that the residence time in Lindsay Slough is high. This, coupled with dense riparian vegetation and organic debris, implies that the Lindsay Slough region is highly productive. Liberty Island, a large tract of recently flooded agricultural land bordered by Cache and Prospect sloughs, is the southernmost extent of the Yolo Bypass. During periods of high Sacramento River flow, the Yolo Bypass floods, connecting Liberty Island with the Sacramento River. Liberty Island is subject to high winds, which constantly stir up the sediment and maintain high turbidity (Nobriga et al. 2005a, Lehman et al. 2010). The Toe Drain of the Yolo Bypass, a large agricultural ditch that parallels the bypass's east levee, basically serves as a conduit between the floodplain of the bypass and the Cache Slough complex. A tidal marsh in Lindsay Slough was used as a reference site in the BREACH studies (C. Simenstad et al. 2000) which examined the relationship among age of marsh, aquatic vegetation and invertebrate and vertebrate abundance.

Sherman Lake

Sherman Lake is an unreclaimed flooded ‘island’ located at the confluence of the Sacramento and San Joaquin rivers. It is bordered by the Sacramento River to the north, Mayberry Slough to the east, and the San Joaquin River to the south and west. Due to its location, Sherman Lake, in reality a wide tidal slough, is heavily influenced by flow from both the Sacramento and San Joaquin rivers and is subject to salinities that range from brackish to fresh water. It is a prime example of natural marsh restoration that has been ongoing for decades. The eastern two-thirds of the lake is shallow (1-3m), open water dominated by submersed aquatic vegetation (*Egeria densa* and *Stuckenia pectinata*). The western third consists of a network of interconnected tidal channels bordered by cattails (*Typha* spp.) and tules (*Schoenoplectus* spp.). This network of channels strongly resembles the undisturbed marsh habitat found rarely in other parts of the estuary (Suisun Marsh). Unpublished data from the California Department of Fish and Game show that the lake is used by delta smelt, Sacramento splittail, Chinook salmon, steelhead and other native fishes such as hitch (*Lavinia exilicauda*), tule perch (*Hysterocarpus traskii*), and Sacramento blackfish (*Orthodon microlepidus*).

Suisun Marsh

Suisun Marsh is a brackish-water marsh bordering the northern edge of Suisun Bay in the San Francisco Estuary; it is the largest, uninterrupted expanse of estuarine marsh remaining on the western coast of the contiguous United States (Moyle et al. 1986). Most of the marsh area is diked wetlands managed for waterfowl, with the rest of the acreage consisting of tidal sloughs (California Department of Water Resources and California Department of Fish and Game 2007). The marsh's central location in the

San Francisco Estuary makes it an important rearing area for euryhaline freshwater, estuarine, and marine fishes. For this study, data used will be collected as part of the on-going UC Davis Suisun Marsh fish monitoring study, funded by DWR.

HYPOTHESES

Hypothesis 1: Residence time of water and pelagic organisms will be positively correlated with shoreline-development index and network complexity (e.g., Shreve magnitude); residence time will also be negatively correlated with Sacramento River flow and Delta outflow.

Hypothesis 2: Phytoplankton, zooplankton, and benthos abundance will be highest in areas of high water residence time, hence areas of high shoreline development and high network complexity.

Hypothesis 3: Native fishes will be more abundant in areas with high zooplankton and benthos abundances and low abundances of most alien fishes.

Hypothesis 4: Native fishes will be more abundant in areas with more variable salinities, cooler summer temperatures, and lower submersed aquatic vegetation (SAV) density.

Hypothesis 5: Connectivity among Sacramento splittail populations and life stages will be greater among habitats with high residence time, greater zooplankton abundance and cooler, more variable conditions.

BACKGROUND INFORMATION AND PREVIOUS WORK

The University of California, Davis, Suisun Marsh Fish Study, which anchors this study, was initiated in 1979 to monitor the abundance and distribution of fishes in relation to each other, to environmental variables, and to water management activities (e.g., water exports). The study has used two primary methods for sampling fishes: beach seines and otter trawls. Juveniles and adults of all species have been surveyed monthly at multiple stations since the beginning of the study; between 1994 and 2002, larval fishes were also surveyed to better understand their ecology in the marsh.

Moyle et al. (1986) evaluated the first five years of data collected by the study and found three groups of species that exhibited seasonal trends in abundance, primarily due to recruitment. The structure of the fish community was relatively constant through time; however, total fish abundance declined over the five years. The decline was partly due to strong year-classes early in the study period, which was followed by both extremely high river discharges and drought that resulted in poor recruitment. Native fishes were found to be more prevalent in small, shallow sloughs, while introduced species were more prominent in large sloughs.

Meng et al. (1994) incorporated eight more years into their study, which revealed that the fish assemblage structure was less constant over the longer time period than the earlier study indicated. Additionally, introduced fishes had become more common in small, shallow sloughs, possibly as a result of drought and high exports allowing increased salinities in the marsh and depressing reproductive success of native fishes. Like Moyle et al. (1986), Meng et al. (1994) found a general decline in total fish abundance (particularly in the native fishes) through time. Matern et al. (2002) found results similar to Meng et al. (1994): fish diversity was highest in small sloughs, and native fish abundances continued to decrease.

Recent reports on the marsh have added to the growing body of evidence supporting the POD and the importance of peripheral habitat. For example, Schroeter (2011) found a strong negative correlation between overbite clam abundance and chlorophyll a concentration, which was largely driven by the magnitude and variability of salinity. However, the decline in Suisun Marsh is less dramatic than in other regions of the San Francisco Estuary, suggesting that some component of near-shore subtidal and tidal habitat has a positive effect on key fish species. O'Rear and Moyle (2009, 2010) have documented what appears to be low abundance of phytoplankton and zooplankton in late summer and early fall concomitant with greater use of inshore habitats by fishes.

Suisun Marsh is currently the subject of many planning, restoration, and research activities. The Suisun Marsh Plan looks to maintain and promote good habitat in the marsh for waterfowl. The Rush Ranch Plan seeks to conserve native biodiversity on the public open-space lands while providing recreational and educational opportunities for the public. Data garnered by the on-going UC Davis fish study are currently be used for, among other things, (1) modeling Delta and longfin smelt population dynamics, (2) evaluating the effect of the Morrow Island Distribution System intake on fish entrainment, (3) time-series analyses of inshore fish assemblages throughout the San Francisco Estuary, and (4) background for a study on the effects of sea level rise and altered Sacramento River flows on the marsh.

The other areas selected for study have been subject to much less study, usually as part of larger studies of the Delta. For example, the University of Washington BREACH study sampled Lindsay Slough in the 1990's (Simenstad 2000). The recently flooded Liberty Island has received some attention because of its presumed potential to support delta smelt and other native fishes (Nobriga et al.2005, Lehman et al.2010). The Cache Slough complex is subject to some studies and monitoring efforts evaluating physical and biological water quality parameters. Many long-term monitoring efforts have stations within the complex, including the 20-mm and Spring Kodiak Trawl surveys conducted by the California Department of Fish and Game and periodic beach seines in Liberty Island conducted by the Fish and Wildlife Service. However, the spatial scope of these surveys is very limited, and little attention is paid to other near-shore habitats within the complex. These surveys have collected at-risk native species such as delta smelt, suggesting that more intensive and comprehensive sampling could reveal populations of these fishes in different areas of the complex, as well as populations of native species in decline but not yet regarded as 'at risk' (e.g., Nobriga et al. 2005). Sherman Lake (in reality, more a tidal slough) has been sampled sporadically by various agencies and U.C. Davis, but there is limited understanding of why it appears to support so many native fishes.

Currently, we are collaborating on a parallel project with Fred Feyrer of the US. Bureau of Reclamation entitled "Life History and Biology of Splittail" and a newly funded project by the Delta Science Program entitled "Understanding the Scale and Mechanisms of Connectivity between Splittail Populations and the Implications for Management" to examine the life history and connectivity of Central Valley and Napa-Petaluma populations of splittail. This study focuses primarily on how adult splittail found in Suisun Bay migrate back to natal rivers to establish genetic connectivity. Our study will focus on adult splittail found in Suisun Marsh and Sherman Lake and is intended to be complimentary to these ongoing studies.

2. CONCEPTUAL MODELS

RESTORATION OF HABITATS FOR NATIVE FISH.

Our conceptual model of important drivers of slough function and productivity is found in Figure 1. Here, drivers influence outcomes through a system of filters that scale the effect. The model includes both abiotic and biotic factors that affect slough function and the aggregation of zooplankton and native fish.

Residence time, connectivity, and water quality have an important effect on native fish abundance. Among sloughs and regions, these conditions vary enormously. Wetland connectivity optimizes food production and affects water quality. High residence times can maximize food production and accumulation. Water quality is the final filter in that low oxygen conditions can eliminate most species, high temperatures can favor non-native fishes, while fluctuating salinities can select for fishes with different salinity tolerances. Many native estuarine species, including Sacramento splittail and tule perch, tolerate changing salinities better than some introduced fish and invertebrates.

Restoration activities should center on the modification of these functions, in the context of climate change. If it is clearly understood how filters interact with each other and with the biotic components of the system, sloughs and adjoining marshes can be managed or even redesigned as highly productive components of the SFE, even as drivers shift and apply new pressures.

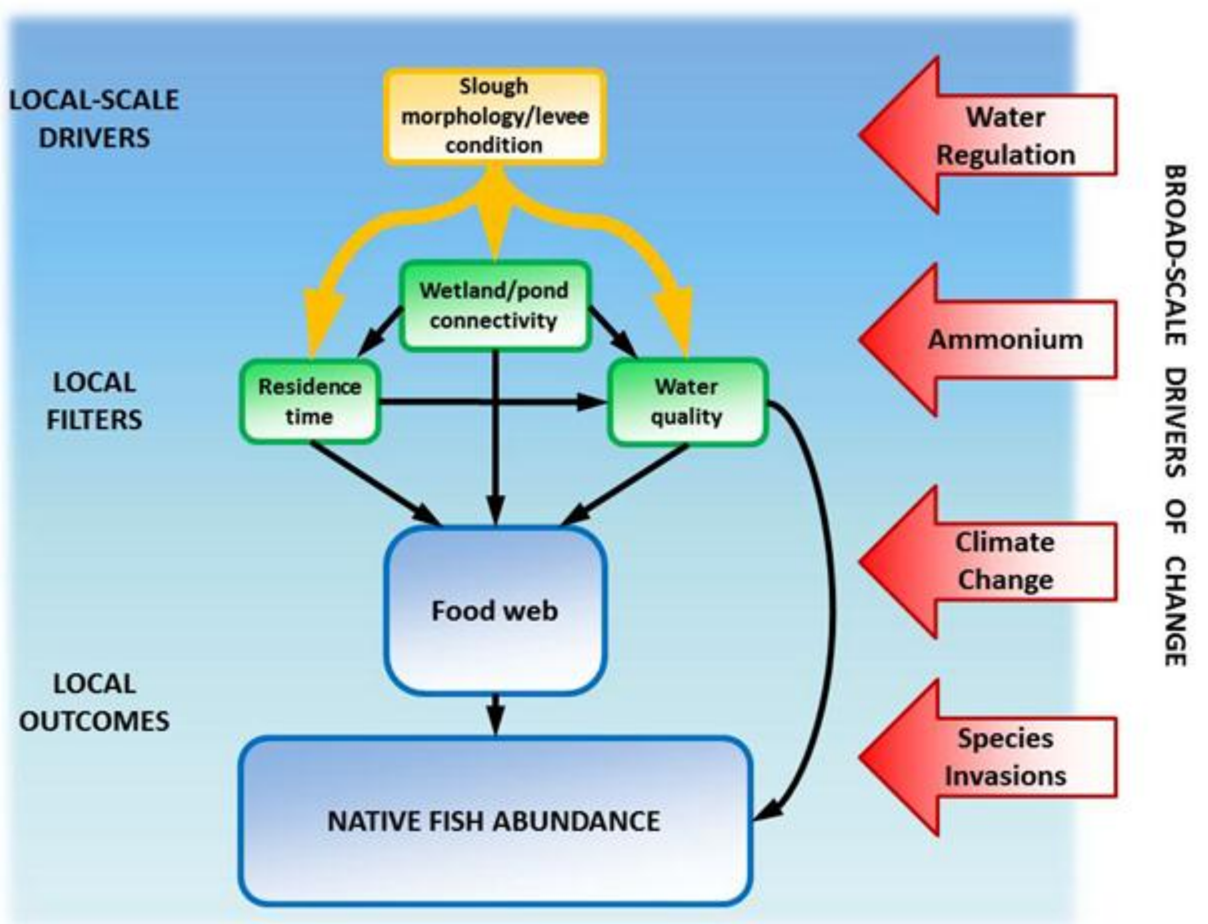


Figure 1. Conceptual model of factors influencing food web structure and native fish abundance in Suisun Marsh. Broad-scale drivers (in red) are influences that occur at any scale larger than an individual slough, such as the scale of the marsh, the SFE, or beyond. Local drivers (in yellow) occur at the scale of a slough and are largely a function of slough morphology and hydrology. Filters (in green) are links between drivers that can either exacerbate or mitigate the destabilizing effect of drivers at the local scale. The effects of the broad-scale drivers are largely manifested through these filters to the outcomes, here identified as food web structure and native fish abundance. Note that the filters consist of hydrodynamic and other abiotic factors of direct ecological relevance to life histories of local organisms. They are the ecological factors that can be most easily manipulated during restoration actions.

CONNECTIVITY AMONG HABITATS

Biological connectivity within and among habitats along an 80 mile gradient is difficult to demonstrate, despite the obvious connection via Sacramento River flows and tidal action. However, an understanding of connectivity for recovering fish species that utilize different regions during their life history is of key importance in guiding the restoration of physical habitats at the micro- and meso-scale. To characterize this attribute we will focus on potential movements of a species that is known to move readily among our three study areas, at different life history stages, and remains abundant enough to collect sufficient specimens for scientific analysis. Sacramento splittail is a native fish species of concern in the San Francisco Estuary and its watershed and can be considered a model species whose behavior and life history connects floodplain, riverine, and marsh habitats in the tidal freshwater regions of the upper estuary with brackish open bay and marsh habitats downstream (Moyle et al. 2004). Once listed as a threatened species under the Federal Endangered Species Act, it is now considered a species of special concern by the U.S. Fish and Wildlife Service, the California Department of Fish and Game, and the CALFED Bay-Delta Program (Sommer et al. 2007). Historically, abundance of splittail has varied in response to freshwater flow and the corresponding availability of spawning and nursery habitat (Meng and Moyle 1995, Sommer and Herbold 1997, Moyle et al. 2004, Feyrer et al. 2006). Wet years typically produce strong year-classes of splittail because of improved growth and feeding conditions on inundated floodplains, which presumably improve the survival of young fish prior to estuarine entry (Ribeiro et al. 2004, Feyrer et al. 2006, 2007). However, during years encompassing the POD (2002-present), splittail abundance indices have been lower than expected based upon the historical relationship with flow. Moyle et al. (2004) developed a generalized conceptual model of the splittail life cycle (Figure 2), that exemplifies the connectivity of multiple habitats in the upper estuary and which has been supplemented in recent years with empirical data from new studies. Adult splittail are primarily distributed in inshore shallow brackish and freshwater habitats of Suisun Bay, the Napa River, and Suisun Marsh during the fall months (Feyrer et al. unpublished data). During winter and early spring, adults migrate upstream to inundated floodplains and river margins for spawning. Gravid adult splittail typically migrate upstream and enter Yolo Bypass, the primary floodplain of the Sacramento River, starting in January following flow pulses (Harrell and Sommer 2002). Based upon studies of adults and larvae, spawning is thought to occur on flooded annual terrestrial vegetation (Caywood 1974, Sommer and Harrell 2002, Crain et al. 2003, Sommer et al. 2007). Wet years that provide a large area of floodplain inundation for a suitable time period typically produce the largest year-classes of splittail (Jassby et al. 1995, Meng and Moyle 1995, Sommer and Herbold 1997, Feyrer et al. 2006, 2007). The presence of larvae in Suisun Marsh in very wet years (Meng and Matern 2001) suggests that either spawning may occur downstream (e.g., Suisun Marsh) or that larvae can be washed downstream at a young age by extreme flow events. Larvae and juveniles remain upstream in inundated habitats until those habitats begin to dry and then move downstream to tidal freshwater and brackish portions of the estuary during early summer (Feyrer et al. 2005). Peak emigration of age-0 splittail from Yolo Bypass varies temporally among years but typically occurs when fish are 30-40 mm in length, suggesting an ontogenetic influence on downstream emigration. Local floodplain production in Yolo Bypass may be important to, or at least an indicator of, system-wide production (Feyrer et al. 2006). Juveniles will rear in the estuary 1-2 years until they become sexually mature and then initiate their spawning migrations (Daniels and Moyle 1983).

New empirical data demonstrating two genetically distinct splittail populations (Baerwald et al. 2007), which are largely distributed in different regions of the estuary (Feyrer et al. 2005, Baerwald et al. 2008), indicate that the generalized conceptual model (Moyle et al. 2004) of the splittail life cycle needs to be reevaluated. The original conceptual model presented by Moyle et al. (2004) suggests a single rearing location for adult fish, centered in Suisun Bay and Marsh, from which adults opportunistically spawn at various locations. The new information on splittail population genetics and distribution (Feyrer et al. 2005, Baerwald et al. 2007, Baerwald et al. 2008) indicate that the Moyle et al. (2004) conceptual model may only apply to the splittail population which spawns in the Central Valley and did not consider the population which spawns in the Petaluma and Napa rivers.

Our study will provide the framework for evaluating the role of connectivity of different habitats, (e.g., North Delta, Yolo Bypass, and Suisun Marsh), many of which are currently undergoing or are slated for major intertidal marsh habitat restoration. By comprehensively examining the life-history movement patterns of Sacramento splittail, prior to major restoration actions in the North Delta and changes in the timing of freshwater flow and managed inundation of the Yolo Bypass, we will be able to more effectively evaluate the benefit of restoration actions in any one given region of the estuary to the population dynamics of splittail. We also expect insights into how migratory patterns might change as climate changes and how nutrients and other organisms might move among habitats.

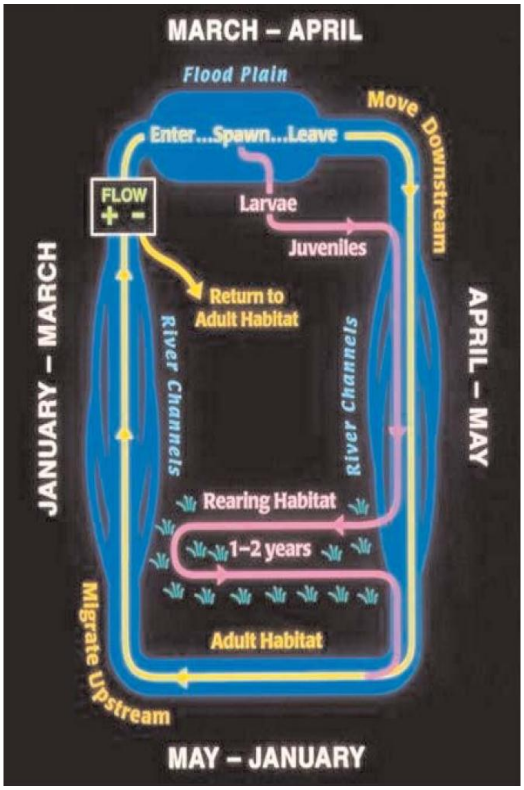


Figure 2. Generalized conceptual model of the Sacramento splittail life cycle (Moyle et al. 2004).

3. APPROACH AND SCOPE OF WORK

Our approach to understanding the nature of native fish habitats and how these habitats are connected takes an inter-disciplinary, multi-investigator approach, relying on our considerable experience with conducting long-term monitoring of fish and invertebrates in Suisun Marsh (30+yrs) and restoration ponds in South San Francisco Bay, applying similar investigative approaches in the North Delta and Sherman Lake (i.e., the middle point between the North Delta and Suisun Marsh), and coupling new state-of-the-art technology for tracking the migration history of fish using laser ablation multi-collector ICP-MS on fish otoliths, effectively linking the sites in this study using migrations of Sacramento splittail.

Ecological modeling techniques that are capable of dealing with complex, nested data such as these have become readily available only in the past several years (Clark 2004, Zuur et al. 2007, 2010, Bolker et al. 2009). Generalized linear mixed models (GLMM) are useful for constructing correlative statistical models that involve spatial and temporal autocorrelation from repeated sampling at sites (Cressie et al. 2009). Generalized additive models (GAM) are capable of separating sampling and process from signals to allow more accurate predictions of population abundance across multiple sites and conditions (Clark and Bjornstad 2004). Both program R (http://www.r-project.org/) and Stata (http://www.stata.com/) provide highly flexible platforms for the construction of hierarchical models. Bayesian inference using the open source OpenBugs (http://mathstat.helsinki.fi/openbugs/Home.html) allows the use of multiple overlapping data sets and prior knowledge to inform and refine model building (McCarthy 2007). We are currently using these platforms to model fish and invertebrate abundance with environmental variables using data from the U.C. Davis Suisun Marsh fish project. The proposed study would extend the general patterns obtained from Suisun Marsh to a larger regional scale to inform estuary-wide decision-making regarding habitat restoration.

These ecological analyses can be combined with the hydrodynamic modeling capabilities of RMA, a finite element model that has been calibrated for the SFE and which can be tailored to our needs in the each of the sampling regions (King 1988, 1997). The resulting ecological models are able to incorporate geomorphic and hydrodynamic variability in addition to water quality conditions.

TASK 1—PROJECT MANAGEMENT AND REPORTING

This research program will be directed by Dr. Peter Moyle, Professor of Wildlife, Fisheries and Conservation Biology at the University of California, Davis, who will serve as the lead PI for all tasks. Dr. Cathryn Lawrence of the Watershed Science Center, U.C. Davis, will provide management and logistical support throughout the project. Patrick Crain and Teejay O'Rear will be responsible for field work under the supervision of Dr. Moyle. Dr. William Fleenor, Research Engineer in Department of Civil & Environmental Engineering, U.C. Davis, will provide support for hydrodynamic modeling for Task 2. Dr. James Hobbs will lead the otolith studies that are described in Task 3. Weekly meetings will be held among Dr. Moyle, Dr. Lawrence, Dr. Fleenor, Dr. Hobbs and all personnel in order to review progress and make management decisions. All the analyses will be performed at the University of California, Davis. Deliverables will be produced as outlined in Table 1 (see below).

TASK 2—SAMPLING AND ANALYSIS

2.1 Fish sampling

In order to effectively sample both near-shore and channel habitats, we will use a combination of boat electrofishing and trawling. Electrofishing will be conducted using a Smithroot 5.0 GPP boat-mounted electro-fisher at a constant pulse width of 60 pulses per second and a variable power so as to maintain a constant electrical current of 8±1 amps. Approximately 300 m of shoreline will be sampled in the down-current direction, with effort being measured in both distance of shoreline and time spent electrofishing. Stunned fish will be collected using long-handled dipnets and placed in an aerated live-well prior to identification. Trawling will be conducted using a four-seam otter trawl with a 1.5 m X 4.3 m opening, a length of 5.3 m, and mesh sizes of 35 mm stretch in the body and 6 mm stretch in the cod end. The otter trawl will be towed at 4 km/hr for 5 minutes in smaller channels (i.e., those with a depth of 1-4 m and a width of 10-20 m) and, to compensate for small catches, 10 minutes in larger channels (i.e., those with a depth greater than 4 m and a width more than 20 m; Moyle 1986, Meng et al. 1994, Matern et al. 2002). Contents of each trawl will be placed into large containers of water. Fishes will be identified using (Wang 1986) and Moyle (2002); the first 30 individuals of a species will be measured to the nearest millimeter standard length (mm SL), weighed to the nearest 0.1 g, and will be returned to the water. Sensitive native species will be processed first and immediately released. Numbers of Siberian prawn (*Exopalaemon modestus*), red swamp crayfish (*Procambarus clarkii*), signal crayfish (*Pacifasticus leniusculus*), overbite clam (*Corbula amurensis*), Asian clam (*Corbicula fluminea*) and other macroinvertebrates (e.g. hydrozoans) will also be recorded. Crustaceans from Mysida will be pooled into one category, "mysids," and given an abundance ranking: 1 = 1-3 shrimp, 2 = 3-50 shrimp, 3 = 51-200 shrimp, 4 = 201-500 shrimp, and 5 = >500 shrimp. The index will be necessary because most mysids pass through the trawl, and those that remain in the net are difficult to accurately identify and count.

2.2 Water Quality and Zooplankton sampling

Chlorophyll a fluorescence and other water quality parameters (including temperature, dissolved oxygen, electroconductivity, and turbidity) will be measured with a Hydrolab Sonde 5a and georeferenced to site. Chlorophyll a fluorescence and turbidity will be calibrated to actual measurements using water taken by subsurface collection, filtered on a GG/G filter, and frozen for laboratory analysis. These same samples will be used to characterize nutrients, including NH_4 and NO_3. Zooplankton will be collected using a 200-µ mesh 0.5 x 2 m plankton net, deployed in an oblique tow, allowing an integrated sample of the water column. Collections will be obtained at key sites, corresponding with fish trawls, collected monthly. Samples will be stained with rose Bengal dye and preserved in 5% formaldehyde for counting at a later date. These samples will be processed in the lab by subsampling to obtain between 100 – 200 individuals of each of the dominant species.

2.3 Hydrodynamic modeling and data analysis

Hydrodynamic characteristics of the sites, including connectivity, vectors, peak flow, and residence time, will be modeled using RMA, a finite element model that has undergone extensive calibration for the San Francisco Estuary and Sacramento-San Joaquin Delta (King 1988, 1997). The relationship among water quality characteristics, plankton, and fish species abundance will be modeled using PCA to produce a variance-covariance matrix. From this, parameters of interest will be chosen to build a hierarchical GLMM using Bayesian inference (McCarthy 2007). A hierarchical model is necessary in order to control error effects of repeated sampling across months and years and the nested sample design of sites within sloughs within regions (Zuur et al. 2010). The resulting models will be compared with AIC, using an information theoretic approach (Bolker 2008). The power of this analysis is that error and autocorrelation can be partitioned out of the correlation, providing a powerful tool for understanding the relationship between organism abundance and multiple, complex physical variables.

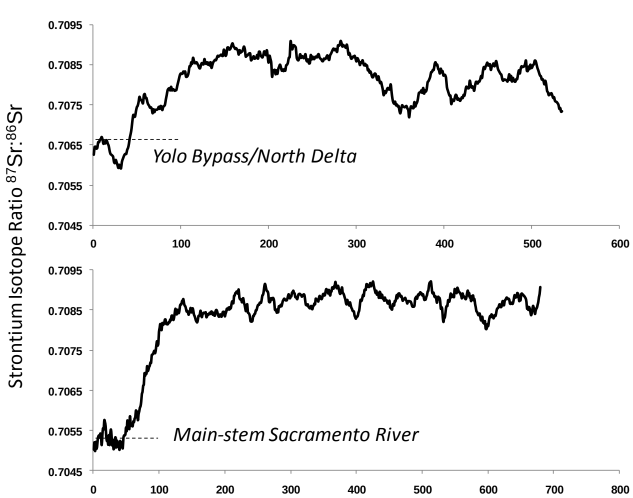
The broad gradient of sampling across sites, sloughs, and regions will result in flexible models with the capability of describing zooplankton and fish species abundance. This in turn will allow evaluation of sites that most lend themselves to restoration.

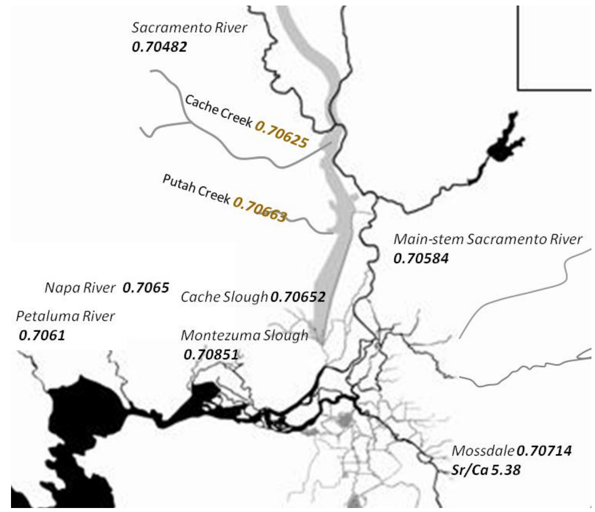
TASK 3—CONNECTIVITY OF HABITATS VIA SPLITTAIL

3.1 Otolith Chemistry

The otolith ^{87}Sr:^{86}Sr approach to determine habitat use is a relatively new tool for fishery managers and has considerable application in the San Francisco Estuary and Central Valley watersheds (Barnett-Johnson et al. 2005, Hobbs et al. 2005, Feyrer et al. 2007, 2010, Hobbs 2010). Freshwater ^{87}Sr:^{86}Sr ratios vary due to the geological composition and age of a water shed, resulting in spatially discrete signatures of watersheds (Barnett-Johnson 2008). Our previous research on splittail otolith chemistry has established unique chemical fingerprints for the Sacramento River, San Joaquin River, and San Pablo Bay (Napa-Petaluma) spawning populations (Feyrer et al. 2007, 2010). Further research has established that unique signatures exist for splittail spawning on the Yolo Bypass, which receives water from the west-side creeks (Cache and Putah) versus the main-stem Sacramento River (Figures 3 &4). Thus adult splittail found in Suisun Marsh and Sherman Lake can be retraced to their natal habitats in the Yolo Bypass, Sacramento River, San Joaquin River,,, or the Napa and Petaluma rivers. This work should demonstrate the potential connectivity (or lack thereof) among the diverse habitats, suggesting directions for future research in this area.

We will examine ~200 adult Sacramento splittail collected in Suisun Marsh and Sherman Lake during the fall, prior to spawning migrations for otolith chemistry and growth measurements. In addition we will collect water samples from each site quarterly to encompass any seasonal variations due to freshwater flow. Methods are described in Hobbs et al. (2005) and Feyrer et al. (2007).





Figures 3 and 4. Strontium isotope ratios at different locations in the San Francisco Estuary. SE of strontium ratios= ±0.0001 based on over 1000 measurements of laboratory standards.

3.2 Age and Growth

In addition to reconstructing the migration history for splittail, otoliths will be used to determine age and growth rates of splittail by using microstructural analysis. Paxio et al. (2004) had difficulty determining ages from otoliths of adult splittail, but we feel confident we can apply techniques similar to those we developed for juveniles (Feyrer et al. 2007) on adults. For example, Paxio et al. (2004) worked with sagittae otoliths, which are commonly used in age and growth studies of teleost fishes. However, due to the Weberian apparatus, the inner ear structure and thus the function and form of each otolith pair in ostariophysan fishes such as splittail differ from that of other bony fishes. The result for splittail is a unique otolith morphology in which the sagittae and asterisci otoliths are reduced in size. Consistent with other researchers, we have found that lapilli otoliths are the most suitable for ageing splittail (Figure 5).

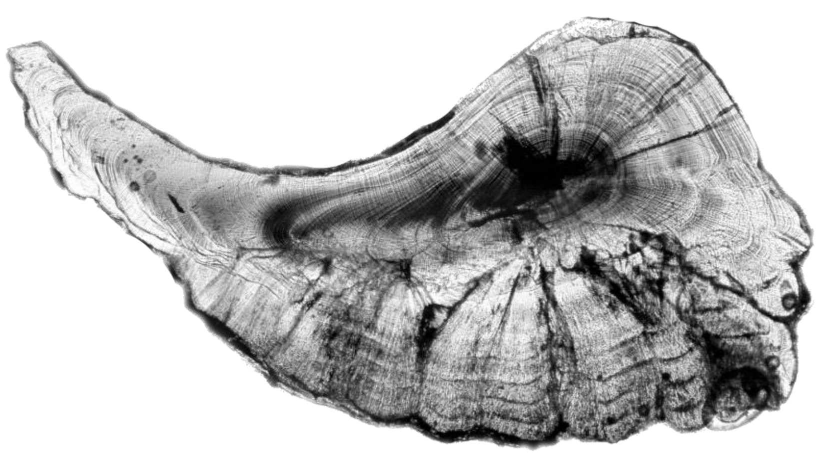


Figure 5. Photo micrograph of the left lapillar otolith from an adult splittail 5+ years old.

4. <u>DELIVERABLES</u>

Research findings and progress from these tasks will be distributed in quarterly reports, our final report, at presentations during national and local meetings, and in articles submitted to both the IEP Newsletter and peer-reviewed publications. Our team has a good record of publishing results of our studies (see CVs of PIs) and of getting them incorporated into more policy-oriented venues (e.g. Lund et al. 2007, 2010, Hanak et al. 2011). In order to achieve the publication timeline (See Table 1), additional personnel resources (Durand) will be added in the final year to support analysis. In addition, Mr. Durand will assist with curation of data and initial model building while the field component is in progress. Data collected after model construction may be useful for model validation (Gelman and Hill 2007), other late data (i.e., data collected in summer 2015) can be added to the model with little effort, allowing sufficient time for writing and submission to peer-reviewed journals.

Finally, the workshop that we propose (which will be hosted by U.C. Davis) will be an essential component of a critical desired outcome. The model that we are proposing will allow managers to make informed, justifiable decisions about where to direct scarce resources for restoration of tidal and subtidal marsh function to support native fishes. This workshop will help us to disseminate these ideas, and place them in a format that is useful for regional stakeholders.

Table 1. Estimated schedule of deliverables.

	2012	2013	2014	2015
Action/ Products	**Summer:** Begin field work	**Summer:** Evaluate 1st year **Fall:** Issue report of preliminary trends	**Summer:** Analyze 1st and 2nd years **Winter:** Draft scientific paper 1: Fish abundance in peripheral habitats of the Delta	**Summer:** Complete field work **Fall:** Submit paper 1 Draft scientific paper 2: Optimizing decisions for marsh restoration that benefits native fish in the S.F. Estuary **Winter:** Draft scientific paper 3: Connectivity among peripheral marsh habitats in the SFE **Workshop:** Using habitat predictors to develop models supporting restoration choices for native fish

5. <u>FEASIBILITY</u>

The proposed study is feasible due to the combination of (1) researcher experience, (2) the lack of contingencies for completion, and (3) the resources available for modeling. We have a crew of experienced field personnel, a good inventory of sampling equipment, a history of study completion, and considerable resources to draw on at UCD to assure the most recent techniques in data analysis and modeling are used. Otolith chemistry techniques are now well established for the San Francisco Estuary and Watershed and Dr. Hobbs and his Interdisciplinary Center for ICP-MS has become one of the top otolith chemistry labs in the world. The modeling techniques proposed, while somewhat new to the ecological literature, have existed in the social sciences for over two decades, and they solve a number of theoretical and practical problems faced by ecologists. The inclusion of Mr. Crain to facilitate experimental design, and of Mr. Durand, to assist with high-level modeling was done so as to maximize the benefit of these modeling strategies.

6. RELEVANCE TO THE CALFED ECOSYSTEM RESTORATION PROGRAM

Recognition of serious issues within the Delta has led to a number of different management strategies that relate to water supply, facility infrastructure, and ecosystem management. For successful Delta ecosystem management to occur, a clear understanding is needed of ecosystem processes and biological resources that support a healthy Delta (Lund et al. 2007, 2010). This includes important life-history requirements and population responses to management decisions, as well as responses to climate change. This study directly addresses objectives 1 and 3 under goal 1 and objectives 1,2, and 5 of goal 4, of Appendix D in the ERP PSP. We also directly address the first priority of the ERP PSP by assessing fish response to restoration and splittail spawning functions, as well as the second priority to continue to study the delta and Suisun Marsh.

Most importantly, our study will describe the physical habitats that support native fish and inform conservation actions in the BDCP, DRERIP, the ERP Conservation Strategy, and other conservation planning and implementation efforts in the Delta.

Bay Delta Conservation Plan (BDCP) The purpose of the BDCP is to provide for 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 to find ecologically friendly ways to move fresh water through and/or around the Delta. Implementing conservation strategies in an effective and adaptive manner is extraordinarily difficult because it requires knowledge of effects of toxic pollutants, invasive species, and impairments to water quality, as well as basic ecological processes.

DRERIP and ERP Conservation Strategies 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 among 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 native fishes so that they appropriately articulate with current understanding of important aspects of the San Francisco Estuary ecosystem, and aid in identification and evaluation of habitat restoration actions that will help support native fishes.

7. EXPECTED QUANTITATIVE RESULTS (PROJECT SUMMARY):

This project seeks to answer the questions: How do physical (water quality, connectivity, geomorphology, hypsometry) conditions affect food webs and fish species assemblages? What characteristics are consistent with promoting native fish species and discouraging alien nuisance species? How do these characteristics vary across the estuarine gradient? How do fish use corridors between habitats? By evaluating the physical and biotic conditions across a large gradient of the northern SFE, we expect to answer these questions using a predictive model of habitat function and fish response. Such a model will have the capability to distill a large number of environmental variables and evaluate the likelihood of key parameters. We will be able to quantify, at least for the length of the project, fish-habitat relationships, and compare them with the long-term relationships we are developing for Suisun Marsh. Because the model is designed to be predictive, it will be useful for two-fold purposes: (1) To determine and prioritize areas for restoration projects; and (2) To determine the most important physical attributes that should be considered in restoration, including those that are responding to sea level rise and climate change.

8. OTHER PRODUCTS AND RESULTS:

At least three papers will be produced for the scientific peer reviewed literature, one describing conditions and differences among sloughs, another predicting ideal fish habitat, and a third discussing the how climate change will likely effect conservation strategies for native fishes in the study region. The latter will be based in part on analyses of how native and alien fish species statewide will respond to climate change currently underway for the California Energy Commission. We also envision a review paper that discusses developing and applying criteria for creating optimal habitat for desirable fishes (while discouraging non-native fishes) that can be used in evaluating restoration sites throughout the north and western Delta, following up on the analysis of Moyle et al. (2010).

9. QUALIFICATIONS

PERSONNEL

All personnel involved in the project are part of the informal Delta Solutions Team at the Center for Watershed Sciences, UC Davis. The team focuses on providing interdisciplinary study and analysis of Delta problems and issues, most noticeably as expressed in Lund et al.(2007,2010).

Dr. Peter Moyle, the lead PI for this proposal, has been working on the ecology and conservation of California's freshwater and sea-run fishes since 1969, resulting in the book, *Inland Fishes of California* (2002) and many other publications. He is author or co-author of seven other books as well. He has been involved in the study of fishes of the San Francisco Estuary since the 1970s, including a 30 yr study of Suisun Marsh and its fishes. He has been part of an interdisciplinary team that has created two influential reports on the future of the Delta, published by the Public Policy Institute of California in 2007 and 2010. In 2010 he received the Brown-Nichols Award in recognition of his work on SFE fishes. He is a professor in the Department of Wildlife, Fish, and Conservation Biology and associate director of the Center for Watershed Sciences, UC Davis.

Dr. William Fleenor supervises the Environmental Dynamics Laboratory in Civil Engineering at U.C. Davis, where he is a professional research engineer. His principal research interest is quantifying interactions between fluid transport and mixing processes to better understand water quality in natural and engineered systems through field experimentation, tracer studies, detailed laboratory studies, and numerical modeling. His work with the U.C. Davis Watershed Science Center has included hydraulic modeling of North Delta flood flows, investigation of the hydrologic constraints on restoration of the McCormack-Williamson Tract, advising on installation of a remote sensing network on the Cosumnes floodplain and supervision of data collection and analysis for the study of depleted oxygen and fluvial dynamics in the Stockton Deep Water Ship Channel.

Dr. Cathryn Lawrence is the Project Manager for the Center for Watershed Sciences and the Department of Land, Air and Water Resources at U. C. Davis. She received her Ph.D. in Ecology at U.C. Davis in 1995 where she continued to work as an Assistant Project Ecologist until 2006. She has used statistical and simulation models to explore a variety of coastal and aquatic processes near the San Francisco Estuary, focusing on off-shore and riverine hydrodynamics, striped bass populations, and the effect of climate change on salmonids.

Dr. James Hobbs is an assistant research scientist with the Department of Wildlife, Fish and Conservation Biology at UC Davis and an associate with the Interdisciplinary Center for Inductively Coupled Plasma Mass Spectrometry. He received his PhD. in Ecology from the University of California, Davis, 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 has published many articles in peer-reviewed 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.

Patrick Crain is a researcher affiliated with the Moyle Laboratory at U.C. Davis. He received his B.S. from U.C. Davis and his M.S. from Sacramento State University (in progress). In addition to coordinating multiple projects in the Moyle lab, Mr. Crain is responsible for conducting research on a number of fresh water and estuarine California fishes, including the Sacramento perch pond study, the Delta Largemouth bass/SAV study, and the South Bay pond study. He is an expert in boat handling and study sampling, and is the author of many invited presentations and papers in the peer-reviewed literature, including *San Francisco Estuary and Watershed Science.*

Teejay O'Rear is a graduate student in the Moyle Laboratory at U.C. Davis, where he received his B.S. His M.S. is expected in 2011, after which he will continue to work in the lab as a Junior Specialist. Mr. O'Rear is an expert in California's native and introduced fishes. He currently heads the U.C. Davis Suisun Marsh fish research program, and is researching the diet of white catfish and other marsh species. Mr. O'Rear is an expert in boat handling and experimental design.

John Durand holds a B.S. in Ecology and an M.S. in Ecology and Systematics from San Francisco State University. Currently, he is a PhD candidate in the Moyle laboratory at U.C. Davis. His masters' research focused on food web dynamics of the SFE and will be published in 2011. Mr. Durand produced the Delta Food Web Conceptual Model for DRERIP, which is being expanded for publication. His current research, funded by the Delta Science Program and the U.C. Davis Center for Watershed Sciences, involves combining hydrologic models with population models of fish and zooplankton in Suisun Marsh and the Delta, using new analytical techniques suitable for large time series data. His research on connectivity of Arctic river ecosystems under climate change in Alaska will be published in Ecosphere in March 2011. At Davis, he has focused on modern analytical techniques suitable for large time-series data.

Contingencies and constraints. We are unaware of any contingencies, constraints, or requirements are likely to affect completion of the project. Investigators are part of the Interagency Ecological Program so are covered by IEP permits for take of threatened and endangered species. PI's have appropriate Scientific Collection Permits (DFG), Animal Use Protocols (UCD), and boat and electrofishing handling and safety training,

Project management. Dr. Moyle, working closely with Dr. Lawrence, will have the ultimate responsibility for project management. Key project personnel will meet weekly where possible to discuss problems and solutions with data collection and analyses and to make management decisions. All personnel are co-located in the Center for Watershed Sciences or in the neighboring Academic Surge building, so informal contact among researchers is frequent.

PREVIOUS CALFED AND DELTA SCIENCE PROGRAM FUNDED RESEARCH

1. DELTA SCIENCE PROGRAM PROPOSAL NO. 85. 2011-2014. Linking Trophic Ecology with Slough and Wetland Hydrodynamics, Food Web Production and Fish Abundance in Suisun Marsh. Recommended for funding.

2. CALFED PROJECT NO. 1036. 2007-2010. Predicting The Effects Of Invasive Hydrozoa (Jellyfish) On Pelagic Organisms Under Changing Salinity And Temperature Regimes. Completed.

3. CALFED PROJECT NO. RSF9. 2005-2008. The Spatial Ecology of Delta Smelt Revealed by Otolith Biogeochemistry: Effects on Population Dynamics and the Efficacy of the EWA Program. Completed.

4. CALFED PROJECT NO. ERP−02−P34. 2003-2006. Restoration of Sacramento perch to the San Francisco Estuary. Completed.

5. CALFED PROJECT NO. ERP−02−P32. 2003-2006. Distribution and abundance of shrimp, plankton and benthos in Suisun Marsh. Completed.

10. LITERATURE CITED

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Section 7: Project Budget

1. **<u>Detailed Project Budget</u> *(Excel spreadsheets can be used)***

PERSONNEL SERVICES	**Number of Hours**	**Hourly Rate**	**Totals**
Staff Level			
PI, Dr. Peter Moyle	600	0	$0
Co-PI, Dr. James Hobbs @ 25% of $5,450/m for 12 m/yr, Yrs1-3	1500	32.70	$49,050
Co-PI, Dr. William Fleenor @ 10% of $6676.00/m for 12 m/yr, Yrs1-3	600	40.00	$24,034
Project Manager, Dr. Cathryn Lawrence (or designee) @10% of $6148/m for 12 m/yr, Yrs1-3	600	36.88	$22,133
Laboratory Technician, TBD @ 25% of $3408/m, 12m/yr, Yrs1-3	1500	20.45	$30,672
Jr. Specialist, Patrick Crain @ 50% of 4362/m for 12 m/yr, Yrs1-3	3000	26.17	$78,516
Jr. Specialist, Teejay O'Rear @ 25% of 4362/m for 12 m/yr, Yrs1-3	1500	27.17	$39,258
Jr. Specialist, TBD @ 100% of $3068/m for 12 m/yr, Yrs1-3	6000	18.33	$110,448
Graduate Student Researcher @ 50% of $3488 for 8 m/yr, Yrs1-3	2000	20.92	$41,856
Graduate Student Researcher @ 100% of $3488 for 4 m/yr, Yrs1-3	2000	20.92	$41,856
Analyst, John Durand, 100% of 57,709/yr Yr 3	2000	28.85	$57,709
Student Assistant @ $9.25/hr, 80 hr/m in , Yrs1-3	2880	9.25	$26,640
Student Assistant @ $9.25/hr, 80 hr/m in , Yrs1-3	2880	9.25	$26,640
Student Assistant @ $9.25/hr, 80 hr/m in , Yrs1-3	2880	9.25	$26,640
Subtotal			$575,452

Staff Benefits	
Co-PI Hobbs @ 47.2%	$23,152
Co-PI Fleenor @ 47.2%	$11,344
Proj. Mngr. Lawrence @ 34%	$7,525
Laboratory Technician @ 47.2%	$14,477
Jr. Spec. Crain @ 47.2%	$37,060
Jr. Spec. O'Rear @ 47.2%	$18,530
Jr. Spec TBD @ 47.2% /yr	$52,131
GSR @ 1.3 %	$1,088
GSR Resident Tuition and Fees, 3 Qtr @ 4743.50/Qtr in Yr 1, 5% per year increase	$44,862
Analyst Durand	$27,239
SA @ 1.3%/yr	$346
SA @ 1.3%/yr	$346
SA @ 1.3%/yr	$346
TOTAL PERSONNEL SERVICES	$813,898
OPERATING EXPENSES	
Description	
UC Davis Required Employee Liability Insurance	$3,740
Boat fuel, Lab and Field Equipment maintenance and repair	$15,800
Fish tags (5000 tags @ $1/tag)	$5,000
Nutrient/chl a analysis supplies	$45,000
Zoop Analysis (for 100 samples)	$10,000
Otolith lab service fees ICPMS @ the Interdisciplinary Center for ICPMS-UCD	$4,240
Otolith supplies	$1,250
Sample jars (estimated as 1000 jars @ $1/jar)	$1,000
Chemicals (formalin, etc) and associated waste disposal	$3,500
Printing, computer and project management supplies	$1,500

Publishing and Presentation Costs	$4,500
Travel Costs (truck rental, mileage, food)	$21,300
Total Operating Expenses	$116,830
Equipment	N/A
SUBTOTAL	$930,728
OVERHEAD @ 25% of MTDC (Equipment and Student Fees not subject to overhead)	$221,467
ANNUAL TOTAL	$1,152,195

2. **Budget justification:**

Salaries

The attached budget shows the salary rate, percentage time and time period for all requested salaries. All of the requested faculty and staff are needed to accomplish the scope of work for this project.

Benefits

The requested benefit rates are the composite rates that take effect July 1, 2010 with a 7% addition to the composite rate for leave assessment for non-student appointments.

Operating Expenses

The requested supplies are needed to accomplish the project scope of work. The lab and field supply costs are based on recent costs in other projects scales to the number of samples to be taken and processed for this project. Where there are no comparable projects on which to estimate the costs, catalog costs and UCD laboratory recharge rates have been multiplied by the number of samples likely to be needed. Travel costs are estimated using current UCD Fleet Services rental rates and current UCD travel policy.

Indirect Costs

The funding for this project comes from the State of California so the negotiated rate of 25% is used to calculate project indirect costs using MTDC base.

3. **Administrative overhead:**

Please note that the University of California, Davis federally negotiated indirect cost rate agreement is currently 51.5% of Modified Total Direct Costs (MTDC). However, the University has an approved rate with State Agencies for 25% MTDC. The MTDC base excludes equipment capital expenditures in excess of $5,000, patient care costs, tuition remission, rental costs, scholarships and fellowships, as well as the portion of each subcontract in excess of $25,000. When applicable, these items have been excluded when calculating the indirect costs.