Physical Processes Influencing Spawning Migrations of Delta Smelt
YEAR 2 – Water Year 2012

Principal Investigator: Jon Burau[1]
Co-Investigator: Bill Bennett[2]

[1]Supervisory Hydrologist
California Water Science Center, U.S. Geological Survey
Placer Hall, 6000 J Street, Sacramento, CA 95819-6129
(916) 278-3127 <jrburau@usgs.gov>

[2]Associate Research Ecologist
Center for Watershed Sciences & Bodega Marine Laboratory
University of California, Davis
Watershed Sciences Building, One Shields Ave., Davis, CA 95616
P.O Box 247, Bodega Bay, CA 94923
(707) 875-1979 <wabennett@ucdavis.edu>

Project Duration: 4 Years
Year 2, WY2012, Proposal and Work-Plan
Year 2, WY2012, Budget Total: TBD

July 1, 2011

Acknowledgments: The principal investigators wish to thank the Turbidity and Fish Migration Project Work Team (PWT) for numerous discussions and comments that greatly improved this proposal. Team members included co-chairs Dave Schoellhamer (USGS) and Larry Brown (USGS), Anke Mueller-Solger, IEP Lead Scientist, and our field team collaborators Randy Baxter (DFG) and John Netto (USFWS).

I. Project Purpose

The delta smelt (*Hypomesus transpacificus*) is a small pelagic fish endemic to the San Francisco Estuary (SFE). Although it was once abundant, the numbers of delta smelt have declined dramatically over the last two decades such that it is now protected under the California State and Federal Endangered Species Acts. As a result, delta smelt have become a major focus of environmental and water management. However, even with accelerated efforts to understand the ecology of this species, several key gaps remain in the knowledge of delta smelt life history, habitat preferences, and the factors limiting abundance (Bennett 2005, Feyrer et al. 2007, Nobriga et al. 2008, Kimmerer et al. 2010). In particular, little is known about its spawning ecology, including annual spawning migration from the brackish Suisun Bay region into the freshwater Delta (Bennett 2005, Grimaldo et al. 2009). Also urgently needed are innovative management strategies that can effectively reduce entrainment of delta smelt in the major state and federal water export facilities located in the south Delta (Kimmerer 2008). Although the role of such mortality in the decline of the species is highly controversial (Service 2007), entrainment of delta smelt often restricts export operations and interferes with allocations of fresh water throughout California.

The goal of our 4-year study is to provide information on the extent to which changes in salinity and turbidity trigger the spawning migration of delta smelt. This information is critically needed for devising management strategies that would manipulate water clarity at key locations and times to reduce entrainment mortality, as well as improve habitat to promote the persistence of this endangered species. Delta smelt appear to undergo a sudden shift in distribution, i.e. migrate, from Suisun Bay into the Delta after they encounter pulses of turbid water from the first major land-runoff produced by a winter rainstorm, the so-called "First-Flush" (Bergamaschi, et al. 1999, Grimaldo et al. 2009). Here we define First-Flush as the day following a winter storm when fluvial derived suspended sediments from the Sacramento River elevate turbidity levels down-estuary to areas in Suisun Bay including Mallard Island. We propose to sample every two weeks during the period before First-Flush occurs, or the Pre-Flush period, beginning in mid-November, and then daily immediately before and after the First-Flush markedly increases turbidity throughout the Delta. Depending on our initial study results during the First-Flush period, we anticipate reducing sampling effort from daily to every other day. Decisions to change sampling frequency will be made in consultation with our adaptive management (STEAM) team (see section VII). As in Year 1, field sampling will integrate monitoring of hydrodynamics, water turbidity, salinity, temperature, fish, and their zooplankton prey (Appendix A). This year, however, sampling will occur primarily at a two locations in the lower Sacramento River (Station SAC, and at station CCH in Cache Slough, Figure 1).

This proposed study is a major component of the work plan currently being assembled by the Interagency Ecological Program (IEP) Turbidity and Fish Migration Project Work Team (PWT). It will specifically address the primary charge to the PWT: "*Under what circumstances and to what extent can turbidity be used to predict the migration, post-migration movements, and distribution of delta smelt, as well as other species of concern, including longfin smelt, Chinook salmon, and steelhead*." Our proposal for Year 2 capitalizes on information learned from sampling in Year 1 to investigate remaining questions on the role of salinity and turbid water in triggering the spawning migration of delta smelt, as well as the extent to which it is a significant habitat feature for a variety of other desirable species. Moreover, this study will further contribute essential information on the interactions between basic physical and ecological processes that appear to play key roles in the life history of this endangered species at the onset of the spawning season.

This proposed work-plan covers **Year 2 of at least three years of field sampling** that will be required to address the overarching goal of this study. Thus, **we proposed a four year investigation** with the last year devoted to completing sample and data analysis, integration of results with hydrodynamic and population modeling efforts, as well as preparation of manuscripts for publication. This is the minimum duration required to address the primary goals, given that replication of the system is not possible, and the primary phenomenon under study occurs only once annually; i.e. there is only one estuary, one delta smelt population, first-flush of turbidity, as well as onset of the spawning migration each year. Significant inter-annual variability in hydrology alone warrants a multi-year investigation. Accordingly, the role of turbidity will be evaluated relative to the time scales at which several processes operate that may also influence migration using a semi-tiered approach (see Figure 2).

Although turbid water appears to be a key feature of delta smelt habitat (Feyrer et al. 2007, Nobriga et al. 2008, Grimaldo et al. 2009, also described in Appendix A of the main proposal), the observed patterns may manifest from a wide range of other co-occurring and interactive physical cues and environmental processes. Migration is also likely to be influenced by maturity level, seasonal tidal currents, lunar phase, and food abundance. Thus, we will need to sample under sufficiently diverse environmental conditions (particularly, varying hydrology) to provide information on the extent to which turbidity may act alone, or in concert with other processes to initiate migration. The inherent complexities and logistical challenges associated with these questions justify our **proposal for a four-year study with intensive field sampling to occur over approximately 3 weeks during each of three years.** As described below, the unusual hydrological setting experienced in Year 1 further supports this concern.

Overall, our study is designed to address several key questions:

(1) Does an increase in turbidity (> 10-12 NTU) in the western delta associated with winter runoff initiate a sudden shift in delta smelt distribution from Suisun Bay into the western Delta?

(a) To what extent is the migratory response affected by inter-annual variability in hydrology? For example, droughts, where runoff is insufficient to raise turbidity levels above 12 NTU, versus floods, where extreme river inflows can overwhelm other environmental cues.

(b) How quickly do delta smelt respond to a migratory trigger (variations in salinity and turbidity)? Does an increase in turbidity or decrease in salinity produce an immediate response, or is there some lag period before the onset of the spawning migration?

(c) Do other environmental variables such as lunar and tidal phase, time of day (i.e. ambient light), or changes in food abundance that may be associated with increased turbidity influence the migratory response, including the influence of increased turbidities?

(2) Is there a maturity threshold that must be reached before delta smelt respond to turbidity or other associated environmental variables that may influence migration?

(3) How do delta smelt migrate upriver, given the strong tidal currents and outflows typically associated with the winter season and rainstorms?

Our proposed study can also provide opportunities for collaborative work and scoping of several secondary goals, including (i) the extent to which pulses of turbid water vary in organic versus inorganic particulate matter; (ii) how to adapt our sampling design to serve as an "early warning system" for signaling when delta smelt may be approaching the water export facilities in the south Delta; and, (iii) developing methods for improving interpretations of spatial structure, i.e. the nature and extent of patchiness, accounting for (a) the influence of tidal current phase on the IEP fish survey data sets, and (b) lateral position within the water column at a given location.

Here, we provide a detailed description of work proposed for Year 2. This study design is largely influenced by the findings from a pilot-study in water year (WY) 2010 and the WY 2011 field season (Year 1). Thus, we first briefly summarize our preliminary findings from the WY 2011study relevant for this proposal; a detailed description of the findings in WY 2011 is provided in Appendix A.

II Project Background & Conceptual Model

WY 2011 Findings – The field study occurred from 12/21/2010 to 1/1/2011, and consisted of ten sampling days at the locations shown in Figure 3. Overall, despite careful hydrologic and meteorological forecasts, the environmental conditions and turbidity distributions of turbidity at our sampling locations were highly unusual (see Figures 4, 5). Most striking during the WY 2011study period, were the unexpectedly low turbidity levels (< 50 NTU) despite substantial freshwater outflow (~ 75K cfs) from a December storm. While turbidity levels in the Sacramento River were modestly elevated, water clarity did not change in western Suisun Bay (i.e. Mallard Island) during December-January. Moreover, turbidity from the upper watershed did not arrive in Suisun Bay (Mallard Island) until late March (Figure 4). This unusual scenario resulted from releases of relatively clear water (10-20 NTU vs. 100-200 NTU in runoff) from reservoirs in the upper watershed just prior to, and, during the December storm. For example, turbidity levels exceeded 100 NTU on several occasions during January-February 2010, even though freshwater flows were less than 55K cfs in the Sacramento River. The reservoir releases were substantial, constituting 50-100% of the flow at Freeport (Sacramento River) during December-January, whereas they typically only make-up about 10% of the flow at Freeport. The uniqueness of this event emphasizes the difficulties associated with designing field investigations to quantify biological responses to hydrological events and further justifies the need for multiple years of field sampling.

Given that these unusual conditions provided only a modest turbidity signal, we were unable to directly address Question #1, especially since high turbidity never extended to the San Joaquin River or Suisun Bay where the majority of delta smelt occur at this time of year. Moreover, the elevated turbidities at our Decker Island sampling locations were likely due to pulses produced by wind re-suspension extending up into the Sacramento River from Suisun Bay on flood tides (Figure 5) rather than from First-Flush. Thus, the delta smelt sampled at these locations in WY 2011 were likely following the eastern margin of turbid water from Suisun Bay (Figure 5). However, the extent to which these fish were maintaining position at this location, or migrating up-river is unclear; evidence for up-river migration in the catch data is weak (Appendix A). Therefore, since delta smelt may have been occurring near Decker Island prior to the December storm, we could not clearly determine potential responses to turbidity mobilized by the high Sacramento River inflows.

Overall, the results from our WY 2011 sampling compliment and provide insight into questions developed in the pilot study in January 2010. In both years, delta smelt were caught at the shoal-channel interface almost exclusively on flood-tides, whereas they

were caught primarily on ebb-tides in sampling near the shoreline (beach seines) in WY 2011. These results clearly indicate that delta smelt respond to changes in tidal-current direction by adjusting their lateral position in the river. This finding also implies that delta smelt may have adapted specific strategies for reducing the energetic costs of migration (Bernatchez and Dodson 1987). Employing such a behavior would facilitate either maintaining position at this location or migration up-river. As discussed above, however, without a larger turbidity signal, or clearer temporal lag in the catch between along-channel sampling locations we are currently unable to determine if these fish were migrating in response to higher turbidity.

Most delta smelt also were caught during daylight hours. While the flood-ebb tide asymmetry in fish position was also apparent during nighttime, the overall catch was much lower. This is consistent with the notion that smelt are more dispersed throughout the water column at night as opposed to being more surface-oriented during daylight; a pattern also observed for larval smelt in Suisun Bay (Bennett et al. 2002, Hobbs et al. 1998).

Finally, the majority delta smelt were caught in the Sacramento River (n=654), rather than the San Joaquin River (n=4). Apparently low numbers of delta smelt in the San Joaquin River provides support for our working conceptual model; we would not expect many delta smelt to occur there unless turbidity levels increased following the first-flush, which did not happen (Figure 5). Thus, the lack of a large turbidity signal suggests that our sampling locations in the San Joaquin River were upriver from the majority of fish whereas our Sacramento River locations were likely within the eastern margin of the delta smelt habitat extending up from Suisun Bay.

In WY 2012, we propose to address the role of turbidity relative to other environmental variables in initiating the spawning migration (Question #1). Our study design relies heavily on our preliminary results from WY 2011 which effectively addressed *how* delta smelt migrate (Question #3), but also indicate the need to determine the extent to which the eastern margin of delta smelt habitat moves upriver on flood tides from Suisun Bay during the Pre-Flush period.

Conceptual Model- Our study design is based on the following conceptual model of delta smelt spatial dynamics and responses to turbidity (Question #1). Our rational is based on current knowledge of delta smelt, our previous hydrodynamic and fish sampling studies, as well as contemporary life history theory for fish migration.

Delta smelt exhibit a patchy distribution at both regional (population) and local scales. During the fall, or Pre-Flush period, delta smelt occur in areas with suitable habitat conditions, defined roughly as relatively cool, low salinity water that is highly turbid

(Feyrer et al. 2007). Within such areas delta smelt occur in relatively small aggregations, or patches (Bennett 2005, Newman 2010) that tend to associate with prominent hydrodynamic features, such as frontal zones, where zooplankton food resources also accumulate. In the northern San Francisco Estuary during fall such habitat is typically available along the northern shore of Suisun Bay-Suisun Marsh, as well as in the north Delta, including the Cache Slough-Liberty Island complex. Although most of the population tends to be located in northern Suisun Bay-Suisun Marsh at this time of year, delta smelt also traditionally occur in the north Delta area, year-round (Bennett 1993, Bennett 2005, Nobriga et al. 2005)

The stretch of the Sacramento River connecting these areas, however, typically has much lower turbidity and presumably fish abundance during fall. Some fish, however, are likely to move between these disparate areas, occurring in a thin ribbon along the northern shore of the Sacramento River, but overall in much lower abundance. During this Pre-Flush period, the extent of relatively unfavorable habitat with lower fish abundance in this stretch of the Sacramento River can vary considerably among years depending on freshwater outflow, as well as over lunar cycles (i.e. 14 day, spring-neap cycle). Spring tides produce the maximum tidal dispersive mixing, and thus determine the extent of tidal timescale intrusion of Suisun Bay water up into the Sacramento River during flood tides, as well as downriver transport of favorable habitat from the north Delta during ebb-tides.

The First-Flush effectively connects these areas by increasing turbidity throughout the Sacramento River and Delta at the time when many individuals are maturing. This sudden and dramatic increase in turbidity has been thought to serve as a cue, triggering a pronounced shift in adult distribution upriver (i.e., a spawning migration, Grimaldo et al. 2010). However, migration may also be prompted by other co-occurring and potentially interacting processes, such as lunar phase, or density and composition of zooplankton food in the turbid water.

The apparent effect of turbid water in triggering the spawning migration may also arise from a unique sequence of fish responses to changes in tidal direction as well as turbidity that occur at several spatiotemporal scales. Our previous sampling results suggest strongly that delta smelt respond to changes in tidal current direction by quickly adjusting their lateral position in the river (Appendix A, Figure 6B in main proposal). However, because near-shore tidal currents are typically relatively slow (weaker) due to friction with the shoreline, they also change direction earlier (e.g. as much as hour) relative to those in the main channel, where water moves faster and with higher momentum (Figure 14). This lateral gradient in timing and shear that results can also promote a lateral turbidity gradient as the tides change direction. Interestingly, this suggests that lateral

movements facilitating position maintenance (or migration) are also likely to maintain fish with the more turbid region of the lateral gradient (Figure 14). Thus, lateral migrations apparently in response to tidal direction, may also be prompted by a simultaneous change in the turbidity gradient. Moreover, given that turbid water is generally considered a refuge from predation, it is reasonable to speculate the tidal and turbidity signals serve to reinforce the lateral migration behavioral response which has clear adaptive significance for this species.

The spawning migration may then result from the interaction of this relatively instantaneous process occurring as the tides change direction, with the regional turbidity field as it changes over the winter season. During the Pre-Flush period, the longitudinal turbidity gradient is effectively flat; water in the Delta remains relatively clear with higher turbidity water from Suisun Bay intruding upriver during flood tides. While lateral tidal migrations would facilitate maintaining position at a particular location, an affinity for turbid water would preclude most movements into the relatively clear Delta water. After the First-Flush, however, the longitudinal turbidity gradient reverses and reaches an annual maximum (Figure 5). Turbidity levels are now higher throughout the north Delta, forming a continuous gradient that extends downriver to Suisun Bay. Lateral migrations at the tidal time scale still result in fish moving to the higher turbidity end of the lateral gradient, even though the overall longitudinal gradient has reversed (Figure 14). This change in the longitudinal gradient may also promote a shift in fish distribution upriver, or the spawning migration.

A shift in fish distribution in response to increasing turbidity can be detected at either the scale of the population, or the aggregation (or patch). Given the logistical challenges associated with sampling in the western Delta, however, we are more likely to observe the migration process at the population scale. As the First-Flush occurs and turbidity spreads across the Delta and downriver to Suisun Bay, delta smelt are likely to encounter pulses of turbid water at different times throughout their distribution. Thus the population scale response is likely to occur over several weeks (justifying 3 weeks of sampling). At the scale of a patch, or individual fish, movement up into the Delta may occur very quickly, roughly over a day or two. Assuming that delta smelt migrate upriver by synchronizing their movements with tidal direction (i.e. on flood tides), the rate of travel is likely to be related to the relative strength of flood tides versus freshwater outflow, which can be weak, or overridden, when outflows are high in the Sacramento River (Figure 13). Although spawning has never been observed directly, it likely occurs on sandy to gravel substrates along the shoreline in the northern Delta, Sacramento Ship channel, and perhaps also along the northern shoreline of the Sacramento River near Rio Vista (Bennett 2005).

We are unlikely to distinguish the relative importance of all of these processes since several occur simultaneously at different scales. From a management perspective, however, it will be sufficient and challenging to determine if turbid water, in itself, or some other factor, such a food density, is the primary reason underlying the association between delta smelt. In addition, we will conduct lateral transects to measure various water quality variables (e.g. temperature, electrical conductivity, turbidity, etc.) to quantify the nature of lateral gradients which may provide additional cues for delta smelt. Moreover, we will also explore the possibility of including measurements of organic carbon concentrations as we develop the study logistics with the other participating agencies.

III. Estimated "Take" of Endangered Species

Management of threatened and endangered fishes is truly a conundrum: by definition, listed species deserve protection, yet learning how to restore them can require sampling and killing fish that may be at critically low abundance. Determining how our proposed study may impact the populations of ESA-listed species is difficult due to the highly stochastic nature of fish catch among net tows, as well as survival of individuals through spawning. Nevertheless, estimates of the likely numbers of ESA listed species to be caught need to be projected.

Catch, or "take", estimates, for four species including four runs of Chinook salmon, were developed using data from our WY 2011 sampling. Daily potential catch was estimated using the mean catch per net tow for flood versus ebb tides at Stations T(sac)D and T(sac)U to reflect Stations SAC and CCH, respectively (Table X). Daily catch was estimated based on 8 flood tide and 2 ebb tide net tows each day. Potential catch during the Pre-Flush period was estimated using the mean catch from Station T(sac)U and assuming the First-Flush occurs on January 10, 2012. Thus, overall "take" is estimated over 5 Pre-Flush sampling days, and 21 First-Flush sampling days.

Table 1- Estimates of total potential catch, or "take" for four species of concern, including four runs of Chinook salmon, using data from the WY 2011 sampling. Numbers are mean catch on flood versus ebb tides in Kodiak trawls at station T(sac)D (SAC), and T(sac)U (CCH) for delta smelt, longfin smelt, and Chinook salmon. Numbers for salmon runs are proportion of catch from Kodiak trawls in Sacramento River. Estimate for Central Valley steelhead is based on a total catch of 3 fish in the WY 2011 sampling.

Species	Flood		Ebb		Estimate
	SAC	CCH	SAC	CCH	
Delta smelt	7.2	1.2	0.7	0.32	1,800
Chinook salmon	2.0	1.5	1.5	1	825
Fall	0.77	-	-	-	625
Late Fall	0.05	-	-	-	40
Spring	0.03	-	-	-	30
Winter	0.15	-	-	-	130
Longfin smelt	0.7	0.06	0.11	0.1	180
Steelhead trout	-	-	-	-	10

Catch of ESA species will be assessed daily during the proposed sampling, as in our WY 2011 study. If the daily catch rate, cumulative catch, appears excessive relative to our "take" limit for a given species an ordered sequence of measures will be implemented, in consultation with the STEAM team. Measures to reduce take as well as maintain the integrity of the sampling design in order of priority include: (1) reduce tow durations, (2) extend the intervals between samples, and (3) consider dropping sampling location(s).

To effectively address the Year 2 study questions, our key objective is to obtain a consistent time series of fish occurrence in net samples as logistically feasible over the study period. Thus, we are more concerned with reliably assessing fish presence vs. absence rather than estimating overall fish abundance. To avoid frequent samples with large numbers of ESA species, we will be modifying tow durations (for example) in real-time, based on discussions with the STEAM team. Essentially, we need to ensure that tow durations are sufficient to detect delta smelt when they are present (i.e. so we don't miss them) but also avoid catching large numbers of these fish. From our previous sampling experience, this is likely to be a concern only when sampling occurs during the day on flood tides.

To further reduce the likelihood of lethal take, or mortality, associated with sampling, the USFWS required that appropriate measures be considered to subsample, or return unharmed, as many ESA listed fish as possible. Options for reducing mortality will differ greatly among species and the types of net gears used in the study. Overall, hardier species, such as salmon smolts, are less harmed than the very fragile delta smelt or longfin smelt by the Kodiak trawl.

In general, all fish sampled are immediately placed into a water-filled trough. Then, all salmon smolts are identified, measured, and released back into the river, and all delta smelt and longfin smelt will be identified. Typically, the majority of smelt caught are either already dead or appear to be severely harmed by the net, and will be sacrificed. However, in our Year 1 sampling it was clear that lower tow durations also greatly reduced net trauma to delta smelt and longfin smelt, increasing the proportions of these fish that appeared unhurt and potentially released. For our Year 2 sampling, we will develop standard procedures (i.e. a SOP) that will describe under what circumstances apparently unharmed delta smelt and longfin smelt may be released without compromising the sampling design. Typically, only a few individual longfin smelt are retained for analysis by DFG. The SOP will also describe protocols used for fish release; field crews will also be trained to implement the release protocols prior to the sampling season.

IV. Project Description – Study Design & Tasks

Study Design

For WY 2012 we propose to focus sampling to address whether a sudden increase in turbidity associated with the first-flush winter storm initiates the delta smelt spawning migration (Question #1). Thus, our study design will differ somewhat from WY 2011, in which we configured sampling to detect a response to a turbidity signal, as well as to understand *how* delta smelt migrate upriver. Overall, we propose deploying two Kodiak trawls at an upriver and a downriver location with sampling to occur during a Pre-Flush and a First-Flush phase differing primarily in sample frequency. We also propose to capitalize on our previous finding that delta smelt were caught primarily during flood tides during the daytime. This will reduce sampling effort, requiring a single crew per trawl for 8-10 hours each day and largely eliminate sampling throughout the night and entire ebb-tides. Also, since we are primarily interested in documenting a distributional shift this year and not on *how* smelt migrate, we propose to drop seining from this year's design. Overall, this will reduce wear and tear on our people and equipment as well as facilitate overall safety, although some night sampling will occur in the early morning and extend into the evening on some dates.

Pre-Flush Phase- We propose an extended period of sampling before the First-Flush winter storm to provide baseline information on delta smelt spatial dynamics and relative abundance. Specifically, the Pre-Flush sampling is designed to (1) locate the eastern extent of salinity and turbidity intrusion from Suisun Bay that occurs during spring flood tides; and, (2) the margin of favorable habitat from the north Delta that is transported downriver during spring ebb-tides; as well as (3) verify that delta smelt actually occur in lower abundance between those locations. Essentially, we need to determine where adult delta smelt are during the Pre-Flush phase before we can conclude they have changed their spatial distributions in response to turbidity or any of the other variables we are measuring. We will also monitor the patterns of delta smelt catch in the other IEP surveys that occur during the fall, particularly the Chipps Island Salmon Smolt Survey, Fall Mid-Water Trawl Survey, and the Bay Study Survey.

Sampling locations will be established just upriver of the position of maximum intrusion of Suisun Bay water during flood-tides (SAC(1), and just downriver of the influence of north Delta water on ebb-tides (CCH). Intrusion of turbidity from Suisun Bay usually extends to somewhere between Mallard Island and Rio Vista; a more detailed analysis will estimate this location this summer, which we expect to be down-estuary this year given the "wet" winter we had last year. The upriver sampling will occur in Cache Slough somewhere between Steamboat and Miner Sloughs, and near a USGS flow station (CCH, Figure 1). The specific locations for each station will determined during the pre-flush sampling period, to insure they avoid turbidity intruding from either upriver or down estuary. Pre-Flush sampling will occur every 14 days on spring tides which are periods of maximum intrusion of bay waters into the delta due to tidal dispersive mixing: spring sampling will occur on November 10; 23, December 9, 23; January 9, 23; February 7, 21. Sampling would end after February 21st if the first-flush storm hasn't arrived, providing a maximum of 8 Pre-Flush sampling days.

On each day of Pre-Flush sampling 2 Kodiak trawls will sample hourly for a ten hours, centered on the flood tide with a single ebb-tide sample at each location before and after each flood (Figure 11). At the downriver location, sampling will alternate hourly between stations SAC(1) and SAC(2) and concurrently at the upriver location between stations SAC(3) and CCH (Figure 10). This will ensure at least 3 samples are taken during the flood tide at each site and a single sample during the ebb before and after the flood tide at each site. Given we expect the flood tides to be relatively unaffected by increased river flows during the Pre-Flush period, this strategy allows us to sample almost the complete reach between station SAC(1) and CCH because these stations are roughly a full tidal excursion away from each other. We anticipate that this level of

sampling effort will be sufficient to document the occurrence of delta smelt in this stretch of the river during Pre-Flush conditions. Ten hours of sampling, centered on the flood tide is similar to the strategy adopted during the First-Flush sampling, which will generate Pre- and First-flush time series that are comparable.

Pre-Flush sampling is required to primarily verify that delta smelt abundance is very low in this stretch of the river (pink regions shown in Figures 8 and 9). Given that delta smelt probably always occur along the north shore, we need to document at what level before the First-Flush occurs. Overall, we anticipate catching few smelt during the Pre-Flush period except perhaps at the margins of suitable habitat in Suisun Bay and north Delta (e.g. at the end of the flood-tide at station SAC(1) and at the end of the ebb-tide at station CCH (Figure 6). We also need to detect if fish begin to migrate before the First-Flush increases turbidities, using some other cue such as changes in the local salinity field, or maturity level if the First-flush is delayed. Pre-Flush sampling also provides an effective means of getting our marine resources up to speed and crews fully trained, so they can be rapidly deployed once the First Flush begins. Finally, Pre-Flush sampling reduces the importance of sampling during the "clear-water" period that occurs between the initiation of rainfall and arrival of fluvial suspended sediments in the western delta, because we will document the Pre-Flush spatial distributions every two weeks using this sampling strategy. This is important since predicting when and if fluvial-derived turbidities will reach Suisun Bay is extremely difficult.

First-Flush Period- The primary difference in sampling strategy during the First-Flush period will be to initially sample daily over a three week period, and primarily at a single downriver (SAC) and upriver (CCH) location (Figure 1). Sampling frequency may be reduced to every other day if we observe minimal variability in daily catch. Sampling will be centered on the flood-tide as before, but as Sacramento River flow increases during the First-Flush period, the duration of flood tides will decrease (Figure 13). Thus, we expect the number of samples taken during high flow periods to be reduced to as few as 5 tows at each site per sampling day. If outflow eventually overwhelms the flood-tides, we propose to take 5 hourly samples centered on the weakest daytime ebb tide. If during this period we get zero catches for a couple of days, we propose to quite sampling, as determined by the adaptive management team. Tow durations during the First-Flush period will initially be 15 minutes, but will be reduced to either 10 or 5 minutes if catch becomes excessive in consultation with the adaptive management team (see Section IX).

To detect a migratory response to increasing turbidity we anticipate higher catches of delta smelt initially at station SAC, then some time later, at station CCH as they travel to the north Delta area where most spawning likely occurs (Figure 1). Ideally, we'd prefer

stations SAC and CCH to be located as far apart as possible because it would reduce the chances of delta smelt catch increasing simultaneously at both stations. Our primary objective is to detect a migratory response at the population level, i.e. on a scale of weeks, however, we also may be able to detect responses from different groups (patches) as these fish move past an individual sampling locations during flood tides (e.g. individuals move out in the water column during flood tides and remain there throughout the flood tide, Figure 6) and by large distinct groups passing the SAC site first, then arriving at the CCH site at some appropriate time later.

The fact that individual fish, or groups of fish, can theoretically move to the north Delta rapidly (in a few days) if they efficiently use the tidal currents, is the primary justification for sampling on a daily basis, which may change in consultation with the adaptive management team. Additionally, however, sampling every day will, hopefully, allow us to better deduce the migratory response of the population given our catch time series may include high frequency variability due to a sequence of small groups migrating past our sampling locations (e.g. sampling daily may make it easier to detect a shift in the population by allowing us to "average" out the high frequency variations associated with individual groups passing our sampling locations).

For several reasons our sampling is unlikely to cause a depletion-effect that would bias our study results, even if it is highly effective for delta smelt. That is, we do not believe that the catch (i.e., removal) of delta smelt at station SAC will reduce, or will otherwise adversely affect interpretations of fish occurrence at station CCH. First, the spatial and temporal extent of our sampling is extremely minor relative to the size of the study area. For example, the cross sectional area of the Kodiak trawl is on the order of 14 m^2, whereas the lower Sacramento River is approximately 10,000 m^2 (10 m deep x 1000 m wide), such that our net samples constitute only about 14/10000, or 0.14% of the total area. Moreover, we are proposing to sample only about 10 out of 60 minutes (or 16% of each hour) and over only 8 out of 24 hours (or 30% of each day), such that our total sampling effort reflects only about 5% of each day using a 10 minute net tow, and 2.5% with a 5 minute net tow. Although we have been successful in identifying a specific habitat type and when we might anticipate higher concentrations of smelt (i.e. near the bathymetric interface, and on flood tides during the day), delta smelt are distributed in relatively small aggregations (patches). This means that, at best, our sampling is able to detect the occurrence of fish aggregations, since the typical catch of delta smelt in surveys resembles something similar to a negative binomial or Poisson distribution (see section ESA Considerations of main proposal). Thus, our sampling strategy and the questions we are addressing are scaled to the level of *detecting* whether a group of delta smelt are in the vicinity rather than estimating *how many* fish occur in the area. Moreover, given that we also will be actively monitoring catch rates and adjusting net

tow durations, it is unlikely that we will reduce local abundance sufficiently to bias our results.

Study Tasks

Overall, field sampling would occur bi-weekly during the Pre-Flush period and then for approximately three weeks during the First-Flush period (Figure 1). We will measure river discharge and velocity (laterally averaged), as well as electrical conductivity, temperature, salinity, turbidity of the water continuously in each river. Fish sampling will use Kodiak trawl nets. The Kodiak trawl is highly effective for delta smelt but requires specialized deployment, using two boats running in parallel to tow the net stretched between them. We will also conduct additional sampling for zooplankton each hour using a pump system. Sampling would be done through a collaborative effort involving the USGS, UC Davis, and the IEP (specifically, DFG & USFWS). Details about sampling design and logistics are given in Appendix B, and preliminary findings from sampling in WY 2011 are provided in Appendix A.

Fish Sampling & Analysis (Bennett & Swee Teh, UCD)- All delta smelt that do not survive the trauma caused by the Kodak trawls will be preserved to optimize the information that can be extracted from their tissues. A proportion of delta smelt that do survive the trawls will be released however, how many and when this is done can only be determined near or during the time of sampling. A variety of techniques can be applied to assess somatic and reproductive stage and overall condition, as well as growth and genetic composition. We will implement several techniques that are most relevant to addressing our study questions, but will insure that all specimens are archived for additional analysis by our group or other researchers in the future. All fish in the samples will first be identified and measured by personnel onboard. Ideally, we would then weigh each fish or obtain its volume using a graduated cylinder. Then each fish will be wrapped in aluminum foil, and frozen in liquid nitrogen contained in portable “dewars”. Such flash-freezing allows for a variety of analyses to be conducted on each fish sample. For this study we will examine fish gut contents for comparison with estimates of zooplankton densities, and use several histological and histo-chemical techniques to provide a detailed assessment of the overall health and reproductive potential of the spawning stock.

Histology and histo-chemistry will measure levels of glycogen, fatty acids, and reproductive hormones on about 100 fish each sampling year. Such analyses are essential for accurately assessing overall variability in the condition of the spawning stock, including maturity level, feeding success, and potential exposure to toxic chemicals (e.g. Bennett et al. 2008). Currently, reproductive maturity is first assessed using IEP protocols which include opening the body cavity of each fish to determine sex and estimate maturity using a rank scale (0-6). Although this will provide valuable real-time

information for addressing study question 5, we will provide a more highly detailed assessment of maturity in the laboratory. For example, although 53% of the female delta smelt caught in the Pilot Study were judged to be at stage 3 pre-spawning condition, individuals tend to remain at this stage for a relatively long time before reaching stage 4, or ripe condition (Joan Lindberg, UCD, personal communications). Analysis of fatty acid and reproductive hormone levels will more precisely pin-point the time remaining before these fish become ripe and then spawn. Methods for these analyses will generally follow those described in Juaneda and Rocquelin (1985), Teh and Hinton (1993), Teh et al. (1997), and Person-Le Ruyet et al. (2004). This information obtained from these analyses will not only be useful for distinguishing among different groups of fish that occur over time at our sampling locations, but will also provide a comprehensive assessment of reproductive potential (i.e., likely reproductive output and success). Thus, these analyses will address the question of whether delta smelt must reach a certain level of maturity before migrating (Question 5).

We may also preserve some fish using our standard methods (Bennett et al. 2008) that are currently implemented in addition to IEP protocols during their regular monitoring surveys. Following the grading of maturity, individuals are preserved to allow assessments of growth and histological condition. With this procedure, individuals are first decapitated and the head is placed in 70-90% ethanol (ETOH) for later examination of otoliths, then the remaining body is fixed in a buffered formaldehyde solution for histological assessment of liver and gonad health (Bennett et al. 1995, Teh et al. 1997). We are also eager to analyze otoliths to measure age and growth (Bennett et al. 1998), however, this work will be contingent on our successful development of methods for reliably estimating age in delta smelt older than about 200 days post-hatching. At this age and time of the year daily growth increments in otoliths become extremely difficult to distinguish. Fish growth slows considerably, and many individuals begin to form annular, rather than daily, growth increments. Archived samples will also be available for future analysis of otolith micro-chemical composition (Hobbs et al. 2006) to assess variability in natal origin both within and among different patches of delta smelt, as well as for evaluation of genetic composition (e.g. Fisch et al. 2009).

Zooplankton Sampling & Analysis (Wim Kimmerer, SFSU)- We also propose sampling for zooplankton to assess variability in food density as a factor influencing migration (Question 4) and position within the water column. On each day, zooplankton will be sampled in conjunction with the fish sampling. This would occur at each Kodiak trawl station (SAC & CCH, Figure 1).

Specific sampling methods will need to be adjusted to closely match those used for the fish and to minimize logistical difficulties. We will probably use plankton nets similar to

those we have implemented in past studies, and which were used in WY 2011 (Bennett et al. 2002, Kimmerer, et al. 2002).
Zooplankton samples will be preserved in formaldehyde until analysis. Subsamples will be taken, if necessary, and enough organisms counted to adequately characterize variability in delta smelt prey. We will also examine gut contents of all delta smelt that are preserved to determine variability in diet during this life stage, and the extent of selectivity relative to the concurrent zooplankton samples.

***Data Analysis*:** Delta smelt response to turbidity will be assessed by comparing fish catch in samples taken before and after turbidity levels increase at our sampling locations, and by geo-referencing the water sampled from all net tows to slack-water. This involves using time series of hydrodynamic measurements collected during fish sampling to estimate the location where that sampled water (and fish) was at the previous slack water period. This will be done by (1) assuming pure advection (e.g. no dispersive mixing and no fish behavior within a tidal excursion of our sampling locations) and (2) that we can make the relatively minor corrections to the fixed velocities to account for amplitude and phase differences that occur along a tidal excursion. We will also similarly assess zooplankton densities in this way and through comparisons with the measured turbidity levels during sampling to examine the role of turbidity in affecting feeding (as gut fullness) and prey selectivity.

Geo-referencing each sample will facilitate detecting when and how quickly delta smelt migrate, based on when during a tidal cycle we detect (catch) fish. For example, if we detect fish during a flood tide but fail to detect any on the following ebb tide, it could suggest the fish either chose to remain above our sampling position, or we missed them in subsequent tows. Because the overall migration is likely to involve different groups of fish over a period of several days (or more) increases the probability that we will detect the occurrence of a distributional shift over time. The net-tow data will then be evaluated with the suite of environmental measurements, zooplankton densities, and other conditions (e.g. day vs. night) occurring at the time of sampling. First, a variety of exploratory data analysis and graphical techniques will be used to examine patterns and preliminary relationships. Based on the characteristics of the data set we will select an appropriate modeling technique and define a final model that best fits the data. The model results will provide insight into the various factors and interactions among factors associated with delta smelt migration within a sampling year and especially among years as data become more available.

***Interactions with Other Studies*-** Our proposed study is closely integrated with several of our ongoing studies on delta smelt, which are also coordinated with numerous other efforts by the IEP. Bennett is currently lead PI (with collaborators S. Teh and W.

Kimmerer) on a project to quantify individual growth, body condition, and gut contents, in relation to food availability and other environmental variables for delta smelt caught by the ongoing IEP fish surveys. The proposed methods for analyzing fish condition and zooplankton densities closely follow the protocols from that study; data obtained from this study will be integrated with our broader fish growth and condition study.

We expect to use data from the ongoing IEP conducted "Chipps Island trawl" to identify the spatial distribution of smelt in the region between Suisun Bay and the delta. Even though the Chipps Island trawl uses a midwater trawl fished near the surface, and is therefore, not directly comparable to the Kodiak trawls proposed in this study, we expect the data to be internally consistent and able to characterize a temporal shift at this site. Furthermore, we expect this study to be tightly coupled/coordinated with a possible "Fall-X2" action presently being developed by the USBR.

Data and information from this proposed study also will fill several key gaps in an individual-based model for the delta smelt population under development by W. Kimmerer (lead PI) and collaborators (Bennett and K. Rose, LSU). Moreover, we also will be working closely with modelers at RMA to develop a fish movement-behavior model, evaluate our field sampling results, and further refine field objectives (Resource Management Associates, 2009).

Finally, because we will be preserving and archiving all delta smelt, there will be numerous opportunities for other researchers to apply various techniques to these specimens, particularly micro-chemical analysis of fish otoliths, and assessment of genetic composition.

Feasibility- This proposed study is a major component of the work plan currently being assembled by the Interagency Ecological Program (IEP) Turbidity and Fish Migration Project Work Team (PWT). Jon Burau, USGS, will serve as project lead with Bill Bennett, UCD, as Co-investigator. Together they will share the responsibilities of project coordination, analyses of study results, and preparation of reports and manuscripts. Members of the Turbidity and Fish Migration PWT will also collaborate in various roles, including advisory, planning, and participating in the field sampling.

Feasibility of a field sampling project such as this depends on a variety of issues, including careful planning and quality of the field crews. Because the timing of the field sampling will be triggered by the first-flush winter storm, equipment and crews will have to be on standby and ready to begin sampling on relatively short notice. We expect our ability to quickly mobilize to be greatly enhanced this year because: (1) the Pre-Flush sampling will allow us to have boats and crews ready and on "stand-by", (2) the overall

effort is substantially less involved (2 trawl sites instead of 5 and sampling limited to day-time flood tides (a single crew) as opposed to full tidal cycle measurements (two crews) which included night-time sampling. It is always easier and quicker to mobilize a smaller effort.

Finally, we will be sampling during high flows (lots of debris in the water) and during winter storms, and thus under very challenging conditions. Nevertheless, we are confident that the proposed study design for WY2012 is feasible, given our collective experience working in this estuary, and the recent successful execution of the WY2010 Pilot Study and WY2011 experiment.

The key issue that may limit the feasibility of this project, however, is the highly uncertain nature of settling on allowable "take" of species protected under the California State and Federal Endangered Species Acts. Even with careful estimation of potential "take" levels, the largely stochastic nature of fish sampling increases the likelihood that negotiated take levels may be exceeded early-on in the study.

Deliverables- Anticipated products from this study will initially include an annual report. These reports will summarize the results from the previous year's field studies and analysis, including descriptions and justifications of modifications to the sampling design and emphasis for the upcoming year. Preliminary results in these reports are likely to be useful to resource managers of the estuary. We will also present results at IEP workshops, as well as various local and national conferences of professional societies. Most importantly, we anticipate producing at least 3 peer-reviewed publications from this work. Possible titles for such papers include:

Burau et al. - Using velocity data to infer spatial distributions and to deduce behavior of aquatic organisms in the Sacramento\San Joaquin Delta.

Burau et.al. Differences in the hydrodynamics of the Sacramento and San Joaquin Rivers in the western delta and their implications for delta smelt migration.

Bennett et al. – Factors influencing the spawning migration of the endangered delta smelt in the San Francisco Estuary.

Bennett et al. – Interaction physical factors and fish movement behavior in developing management tools for the endangered delta smelt in the San Francisco Estuary.

Kimmerer et al. – Role of zooplankton density and feeding success in the spawning migration of delta smelt in the San Francisco Estuary.

V. Task Timeline & Sampling Schedule

We present here the task timeline for the entire study while giving the sampling schedule for the proposed YEAR 2 field exercise.

Given the inherent uncertainties of field sampling during the winter storm season, and the need to adaptively set specific logistics for subsequent investigations, the following timeline is necessarily fluid. Nonetheless, we anticipate field investigations will occur in conjunction with the first-flush winter storm in each of the next three years (Dec-Jan, Table 1). Although not reflected in the timeline (Table 1), analysis of data and specimens, as well as the preparation of annual reports and publications will continue, but with lower emphasis, throughout the field study period. Many folks involved with the field work will not be responsible for data and specimen analysis or the preparation annual reports and publications. Thus, we anticipate that during the field investigations each year everyone associated with the project will devote higher emphasis to either conducting the field sampling, or in analyzing data in real-time to facilitate an adaptive approach to new information as it is obtained.

Sampling Schedule – During the pre-flush sampling period and one week prior to an approaching winter storm that is likely to produce the first-flush, predictions of the approximate sampling periods for each day will be made by the USGS based on harmonic analysis of velocity data at Rio Vista and at station CCH (Cache Slough). These velocity predictions will be similar to those shown in Figure 12 but with sampling start and end times explicitly identified. The Pre-flush sampling (Figure 10) will begin November 10, 2011, as discussed previously, and the First-Flush sampling will begin in conjunction with the arrival of the first-flush.

Pre-flush sampling will start on the hour, 2 hours prior to the predicted time of slack water before the maximum daytime flood tide. Sampling will continue through the flood tide and will include at least two ebb tide samples after slack water as is shown conceptually on figure 10). Pre-Flush sampling will be conducted hourly. The Pre-flush sampling will occur every two weeks (during spring tides) until the First-Flush sampling begins or until the study window is past (last day to sample, February 21, 2012). For both the Pre-Flush and First-Flush sampling, crews are expected to be on site roughly 30 minutes prior to the estimated start times and will use real-time data obtained

from the California Data Exchange Center (CDEC) to determine when “slack water” actually occurs.

First-flush sampling will include only a single ebb before flood and after flood sample (Figure 11). Hydrodynamic data obtained at each sampling location 2 days prior to each day’s sampling will be used to set final First-Flush sampling schedules because river inputs, changes in atmospheric pressure, and wind that can occur during intense storms can significantly alter the currents in the north delta (Figure 13) and thus the timing of slack water. Revised estimates of the sampling start times will be determined by shifting the data collected the previous day by 50 minutes. This sampling protocol will be repeated for three weeks (beginning daily but likely backing off to sampling every other day), or until it is determined that: 1) no migratory response is occurring, or 2) the migratory response is over, or 3) the take limit has been reached.

Table 1 - Schedule of work tasks for years 1-4, with specific activities timed in relation to the calendar-date of the first-flush winter storm and field sampling.

Work Task	**Key Personnel**	**Year 1: 2010-11**				**Year 2: 2011-12**			
		Month							
		09 – 11	12 - 02	03-05	06-08	09-11	12-02	03-05	06-08
Field Study Preparation	All								
Field Sampling	Burau, Bennett, Staff								
Data & sample Analysis	Burau, Bennett, Teh, Kimmerer,								
Annual Report; Conferences	Burau, Bennett								
Journal Articles	Burau, Bennett, Teh, Kimmerer								
Work Task	**Key Personnel**	**Year 3: 2012-13**				**Year 4: 2013-14**			
		Month							
		09 – 11	12 - 02	03-05	06-08	09-11	12-02	03-05	06-08
Field Study Preparation	All								
Field Sampling	Burau, Bennett, Staff								

Data & sample Analysis	Burau, Bennett, Teh, Kimmerer,								
Annual Report; Conferences	Burau, Bennett								
Journal Articles	Burau, Bennett, Teh, Kimmerer								

VI. Budget

A detailed budget for this year's field experiment will be developed upon IEP and Federal Agency Task Force approval of the sampling plan. It is expected that Bennett will work full time and Burau 1/4 time on this effort whether the field sampling occurs this year or not. If the field experiment is delayed until next winter, then Burau and Bennett will focus their efforts on analysis and report writing this year. We expect the budget for the field work this year to be significantly less than last year given the overall reduction in effort proposed for this year. Finally, samples from last year's experiment still need to be processed, as described above, and these costs will be incurred this year (see the relevant budget items from last year's proposal).

VII. Management (STEAM) Team

As with last year, a group, the so-called, Smelt/Turbidity Experiment Adaptive Management (STEAM) team, will be formed to make key decisions regarding the study execution and to keep all of the participating agencies informed as the study unfolds, as was done to favorable reviews last year. These teams functioned well last year and expect to make good use of this team this year, building on what we learned last year.

The STEAM team will be responsible for decisions such as: is the storm is big enough to start sampling, and when sampling should cease due to weather, take limits, or other factors. This group will be small, so that decisions can be made quickly. The proposed make-up of this group will include the Principal Investigators, a representative from the USBR, a field general (a person in charge of day-to-day staffing and logistics), and a representative from each of the management agencies (NOAA, USFWS, CDFG) involved in take issues associated with the study.

VIII. Literature Cited

Bennett, W.A. 1993. Interaction of food limitation, predation, and anthropogenic intervention on larval striped bass in the San Francisco Bay estuary. Dissertation, UC Davis.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science. 3(2): 71pgs. (http://repositories.cdlib.org/jmie/sfews/ vol3/iss2/art1/)

Bennett, W.A., D.J. Ostrach, and D.E. Hinton. 1995. Condition of larval striped bass in a drought-stricken estuary: evaluating pelagic food web limitation. Ecological Applications 5:680-692.

Bennett, W.A., W.J. Kimmerer, and J.R. Burau. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography 47: 1496-1507.

Bennett, W.A., J.A. Hobbs, S.J. Teh. 2008 Interplay of environmental forcing and growth-selective mortality in the poor year-class success of delta smelt in 2005. Final Report submitted to IEP. < http://www.science.calwater.ca.gov/pod/pod_reports.html>

Bergamaschi, B.A., Kuivila, K.M., and Fram, M.S., 1999, Pesticides associated with suspended sediments in the San Francisco Bay during the first flush, December 1995, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program--Proceedings of the Technical Meeting, Charleston, South Carolina, March 8-12, 1999--Volume 2 of 3--Contamination of Hydrologic Systems and Related Ecosystems: U.S. Geological Survey Water-Resources Investigations Report 99-4018B, p. 23-33.

Bernatchez, L. and J.J. Dodson. 1987. Relationship between bioenergetics and behavior in anadromous fish migrations. Canadian Journal of Fisheries and Aquatic Sciences 44:399-407.

Feyrer, F., M. L. Nobriga, and T.R. Sommer. 2007. Multi-decadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California. U.S.A. Canadian Journal of Fisheries and Aquatic Sciences 64:723-734.

Fisch, K.M., J.L. Petersen, M.R. Baerwald, J.K. Pedroia, and B. May. 2009. Characterization of 24 microsatellite loci in delta smelt, *Hypomesus transpacificus*, and their cross-species amplification in two other smelt species of the Osmeridae family. Molecular Ecology Resources 9:405–408.

Grimaldo, L.F., P.B. Moyle, T. Sommer, N. Van Ark, G. Jones, E. Holland, P. Smith, and B. Herbold. 2009. The effects of large-scale water diversions in a freshwater tidal

estuary: can fish losses be managed? North American Journal of Fisheries Management 29:1253-1270.

Hobbs, J.A., W.A. Bennett, and J.E. Burton. 2006. Assessing nursery habitat quality for native smelts (*Osmeridae*) in the low-salinity zone of the San Francisco Estuary. Journal of Fish Biology 69:907-922.

Juaneda, P. and G. Rocquelin. 1985. Rapid and convenient separation of phospholipids and non-phosphorus lipids from rat heart using silica cartridges. Lipids 20:40–41.
Kimmerer, W.J., J. Burau, and W.A. Bennett. 2002. Persistence of tidally-oriented vertical migration by zooplankton in a temperate estuary. Estuaries 25:359-371.

Newman. K.B. 2008. Sample design-based methodology for estimating delta smelt abundance. San Francisco Estuary and Watershed Science 6(3): article 3. Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art3

Nobriga, M.L., T.R. Sommer, F. Feyrer, K. Fleming. 2008 Long-Term Trends in Summertime Habitat Suitability for Delta Smelt (*Hypomesus transpacificus*). <http://repositories.cdlib.org/jmie/sfews/vol6/iss1/art1/>

Person-Le Ruyet, J., Skalli, A., Dulau, B., Le Bayon, N., Le Delliou, H., Robin, J.H., 2004. Does dietary n−3 highly unsaturated fatty acids level influence the European sea bass (Dicentrarchus labrax) capacity to adapt to a high temperature? Aquaculture 242:571–588.

Resource Management Associates (RMA), 2009, Particle Tracking and Analysis of Adult and Larval/Juvenile Delta Smelt for 2-Gates Demonstration Project, Draft Report, http://science.calwater.ca.gov/events/reviews/review_2gates.html .

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

Teh, S. J. and D.E. Hinton. 1993. Detection of enzyme histochemical markers of hepatic preneoplasis and neoplasia in medaka (*Otyzias latipes*). Aquatic Toxicology, 21:163-182.

Teh, S.J., Adams, S.M. and Hinton, D.E. 1997. Histopathologic biomarkers of anthropogenic stress in resident redbreast sunfish (*Lepomis auritus*) and largemouth bass (*Micropterus salmoides*) from contaminant impacted sites. Aquatic Toxicology 37:51-70.

IX. List of Appendices

Appendix A – Preliminary results from WY2011 experiment

Appendix B – Concise description of sampling strategy