Selection of Environmental Covariates for Consideration in Developing a Lifecycle Model for the San Francisco Bay-Delta Population of Longfin Smelt[1]

Charles H. Hanson

Hanson Environmental, Inc.

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Introduction

Longfin smelt are a native fish species that inhabit the San Francisco Bay-Delta estuary. The indices of population abundance based on results of the California Department of Fish and Wildlife (CDFW) Fall Midwater Trawl (FMWT) surveys suggest a trend of substantially declining abundance that led to the listing of longfin smelt as a threatened species under the California Endangered Species Act (CESA). However, results of CDFW Bay Study sampling have shown a broad geographic distribution of juvenile and adult longfin smelt downstream in San Pablo and San Francisco bays where a more moderate declining trend in abundance is suggested. The U.S. Fish and Wildlife Service (USFWS) has also evaluated the status of the Bay-Delta longfin smelt population and has concluded that although the species warrants protection under the federal Endangered Species Act (ESA) staff limitations have precluded listing at this time. Several other pelagic species in the San Francisco estuary have also experienced declines, but the causes of decline are still uncertain (Bennett 2005; Sommer *et al.* 2007; Mac Nally *et al.* 2010; Thomson *et al.* 2010; Maunder and Deriso 2011; Baxter *et al.* 2010).

Given the apparent declining trend in longfin smelt abundance over the past decade, along with declines in abundance of other pelagic fish species (Baxter *et al.* 2010, Bennett 2005; Sommer *et al.* 2007; MacNally *et al.* 2010; Thomson *et al.* 2010; Maunder and Deriso 2011), there is considerable interest among resource managers and other interested parties in developing analytical tools, including a lifecycle model, for longfin smelt. Estimation of

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survival and the factors influencing survival are vital in the research and management of natural resources (Quinn and Deriso 1999). The development of these analytic tools will provide greater understanding of the biotic and “abiotic” factors that affect the population dynamics of longfin smelt, establish testable hypotheses to help guide future monitoring and experimental investigations, and provide a scientific foundation for identifying and evaluating the performance of management actions that would protect and enhance habitat conditions, reduce mortality, improve growth and survival, increase abundance, and contribute to recovery of the species. Managers benefit from understanding the most influential factors affecting the survival of endangered species to focus limited financial and other resources on research and management actions that obtain the most benefit. Anthropogenic effects have to be separated from natural impacts to determine the relative importance of restricting human activities (e.g. Deriso *et al.* 2008).

As part of the scientific foundation for developing a lifecycle model of the longfin smelt population, a series of conceptual models of factors potentially affecting longfin smelt survival and abundance have been developed. These factors help identify environmental covariates that can be tested statistically to assess their relative contribution, individually and in combination with other environmental factors, to the observed patterns and trends in longfin smelt abundance. The purpose of this paper is to describe the process used in selecting environmental covariates for consideration in the lifecycle model developed by Maunder *et al.* (2014) titled “Use of state-space population dynamics models in hypothesis testing: a lucid explanation and a description of advantages over simple log-linear regressions for modeling survival illustrated with application to longfin smelt (*Spirinchus thaleichthys*)”..

The environmental covariates selected for consideration included both so-called “abiotic” variables such as Delta outflow that has been hypothesized to affect larval and early juvenile longfin smelt through downstream transport, the location and areal extent of the low salinity zone, zooplankton (longfin smelt prey) abundance and distribution within the estuary, Old and Middle River (OMR) reverse flows in the central Delta that may affect the geographic distribution and risk of entrainment of longfin smelt at the south Delta export facilities, water temperatures, and salinities (Rosenfield and Baxter 2007, CDFG 2009, MacNally *et al.* 2010, Rosenfield 2010). In addition, biotic factors are thought to be important to longfin smelt growth and survival. These biotic factors include the availability (density) of suitable zooplankton prey at the time and in the locations where longfin smelt occur, as well as predation by a number of resident and migratory fish (Rosenfield 2010). A similar approach to assessing the relative contribution of various environmental covariates on pelagic fish inhabiting the Bay-Delta estuary has been applied to delta smelt (Maunder and Deriso 2011) as well as to other pelagic fish species (MacNally *et al.* 2010, Thomson *et al.* 2010). The approach and rationale for selecting a suite of environmental covariates included in the lifecycle model analyses is briefly outlined below.

Longfin Smelt Life History

The longfin smelt is a small, slender-bodied fish that measures about 3 inches in length as an adult. The species generally lives for 2 years although some individuals may live to spawn at age 3. Populations of longfin smelt occur along the Pacific Coast of North America, from Hinchinbrook Island, Prince William Sound, Alaska to the San Francisco estuary (Lee *et al.* 1980).

Information on the various aspects of the biology and ecology of the species has been documented based mainly on what is known about the populations in San Francisco Bay (e.g. Kimmerer 2002a and b; Moyle 2002; Rosenfield 2010; CDFG 2009; Merz et al. 2013, see also review by Robinson and Greenfield 2011) and Lake Washington (Moulton 1970, 1974; Dryfoos 1965; Traynor, 1973; Chigbu and Sibley 1994a, b, 1998a, b; Chigbu *et al.* 1998, Chigbu 2000, Sibley and Chigbu 1994, Martz *et al.* 1996).

Additional information on the life history of longfin smelt is presented on pages 5-12 of Hobbs *et al*. 2014, attached as Appendix A titled "Field, laboratory, and data analyses to investigate the distribution and abundance of longfin smelt in the San-Francisco Estuary"..

Conceptual Models

The current conceptual model of longfin smelt population biology and potential factors associated with their decline in abundance is presented in Figure 1. A much more detailed conceptual model is available in Rosenfield (2010). Several additional conceptual models of the San Francisco Bay longfin smelt population have also been used as a basis for identifying potential environmental covariates considered in model development (Rosenfield and Baxter 2007, Baxter *et al.* 2008, Rosenfield 2010). Conceptual models for the longfin smelt population have been proposed by Miller (unpublished; Figures 2 and 3). A generalized conceptual model of the lifecycle of longfin smelt was also developed as part of the covariate selection process for this investigation (Figure 4). The lifecycle conceptual model (Figure 6) includes consideration of a variety of factors that may affect the dynamics of longfin smelt spawning and larval dispersal within the lower rivers and Suisun Bay as well as the growth, survival and behavioral movement of juvenile and subadult longfin smelt downstream into the more marine habitats of San Pablo and central Bay. The conceptual model reflects the 2-year lifecycle of longfin smelt and associated stock-recruitment relationships.

Based on the lifecycle conceptual model, the set of environmental covariates selected for inclusion in the initial lifecycle model statistical analyses reflects various geographic regions of the estuary and seasonal periods associated with the life history and seasonality of each lifestage of longfin smelt. A total of 38 potential covariates were identified in the initial selection process. The covariates included various flow variables (e.g., spring X2 location, winter-spring Delta outflow, winter-spring Napa River flow, spring outflow thresholds of 34,500 cfs and 44,500 cfs, spring Sacramento River inflow in addition to various variations of Sacramento and San Joaquin river runoff, zooplankton (prey) densities (e.g., mysid, *Eurytemora*, and *Pseudodiaptomus* densities over various seasonal time periods), predators and competitors (e.g., juvenile Chinook salmon densities in the spring, predators in various regions, and the Asian overbite clam *Potamocorbula*), and a variety of "abiotic" environmental variables (e.g., Secchi depth used as an index of turbidity, water temperature, ammonium loading to various regions of the estuary, and the ratio of ammonium loading to Delta inflow). Based on the conceptual model the sign (positive or negative) in the relationship between each covariate and the predicted longfin smelt population response was also assigned to each covariate. The index of longfin smelt abundance used in the analysis was based on combined monthly abundance indices derived using the CDFW Bay Study midwater and otter trawl sampling results beginning in 1980. Results of the Bay Study sampling program were selected for use in these analyses. These results were used because (1) they reflect a wider geographic distribution of sampling sites that was more representative of the geographic distribution of longfin smelt than the CDFW FMWT, (2) sampling occurred monthly year-round providing better information on life history stages of longfin smelt, and (3) sampling included both the upper portion of the water column (midwater trawl) and lower portion of the water column (otter trawl) which is thought to better represent longfin smelt occurrence throughout the water column.

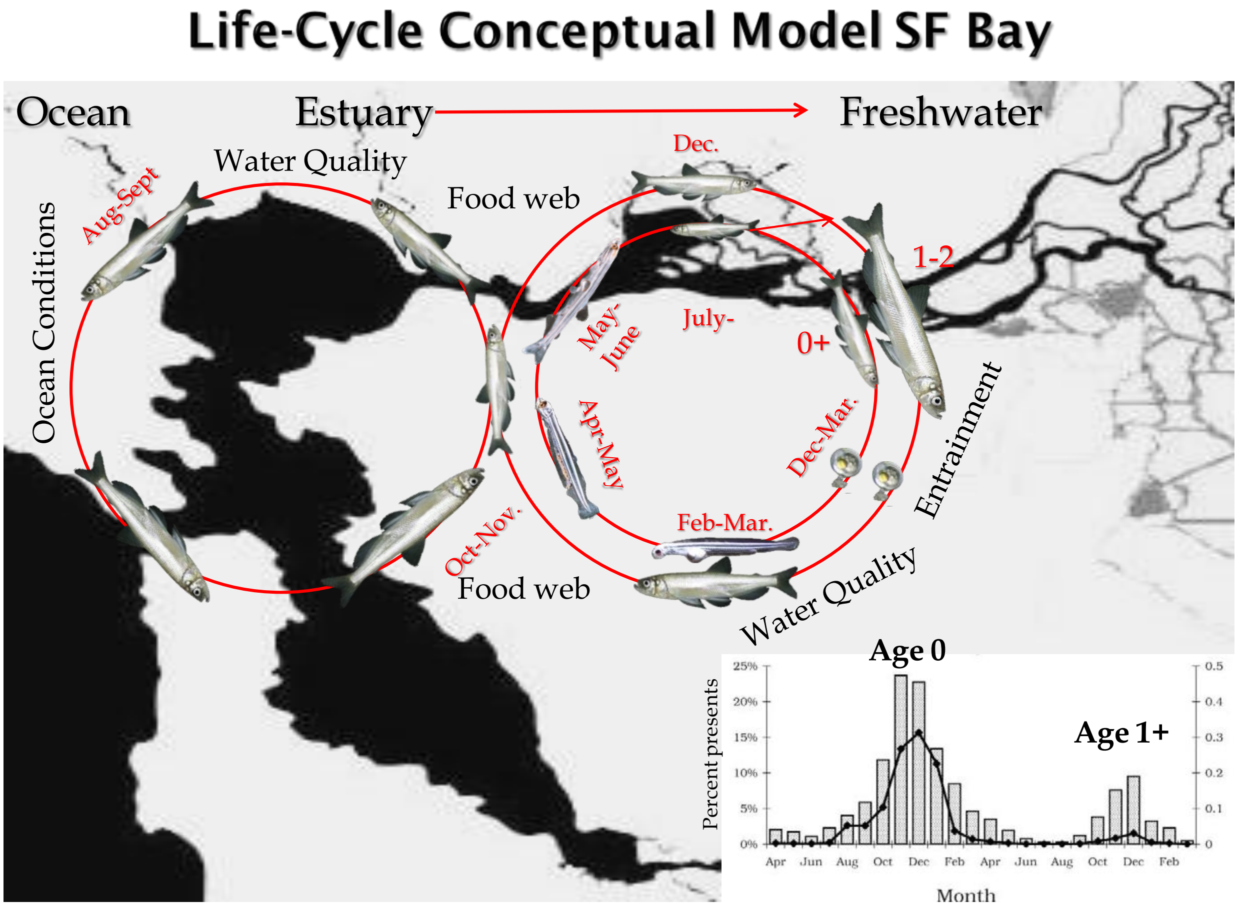
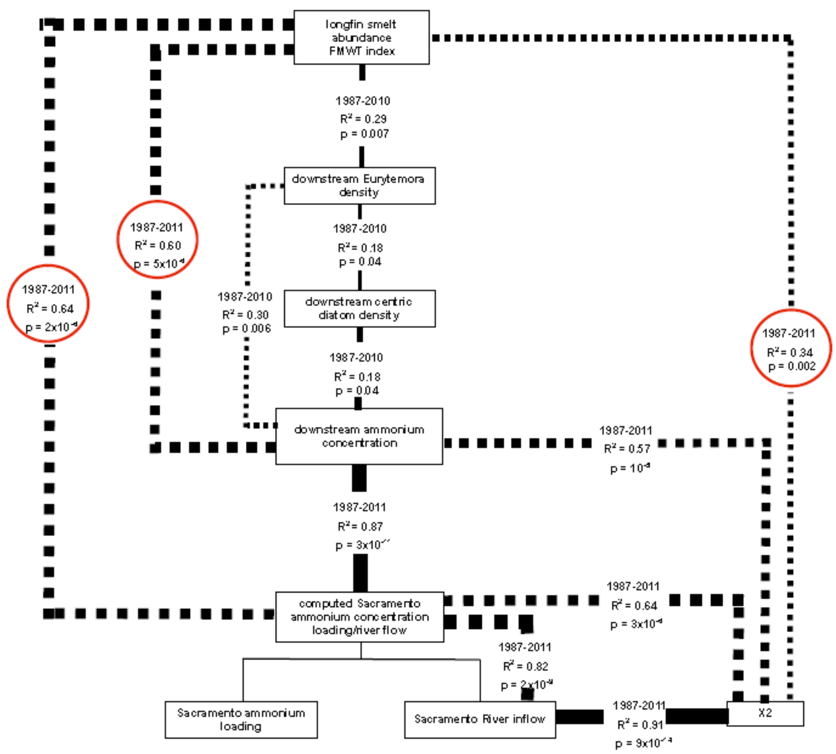


Figure 1. **Life cycle conceptual model of longfin smelt inhabiting the Bay-Delta (Source: Rosenfield 2010).**



Food web and X2 relationships after 1986. All data are averages for January-June. Dashed lines indicate relationships that bridge more than one link. Width of lines is proportional to R^2 values. Ammonium loading data from CVRWQCB self-monitoring reports. Downstream ammonium and diatom data from Environmental Monitoring Program stations in Suisun Bay. Eurytemora data from Monthly Zooplankton Survey stations in Suisun Bay. River flow and X2 data from Dayflow. Data are not available for diatom and Eurytemora densities in 2011.

Figure 2. Conceptual model of food web and X2 relationships for longfin smelt (Source: Miller unpublished).

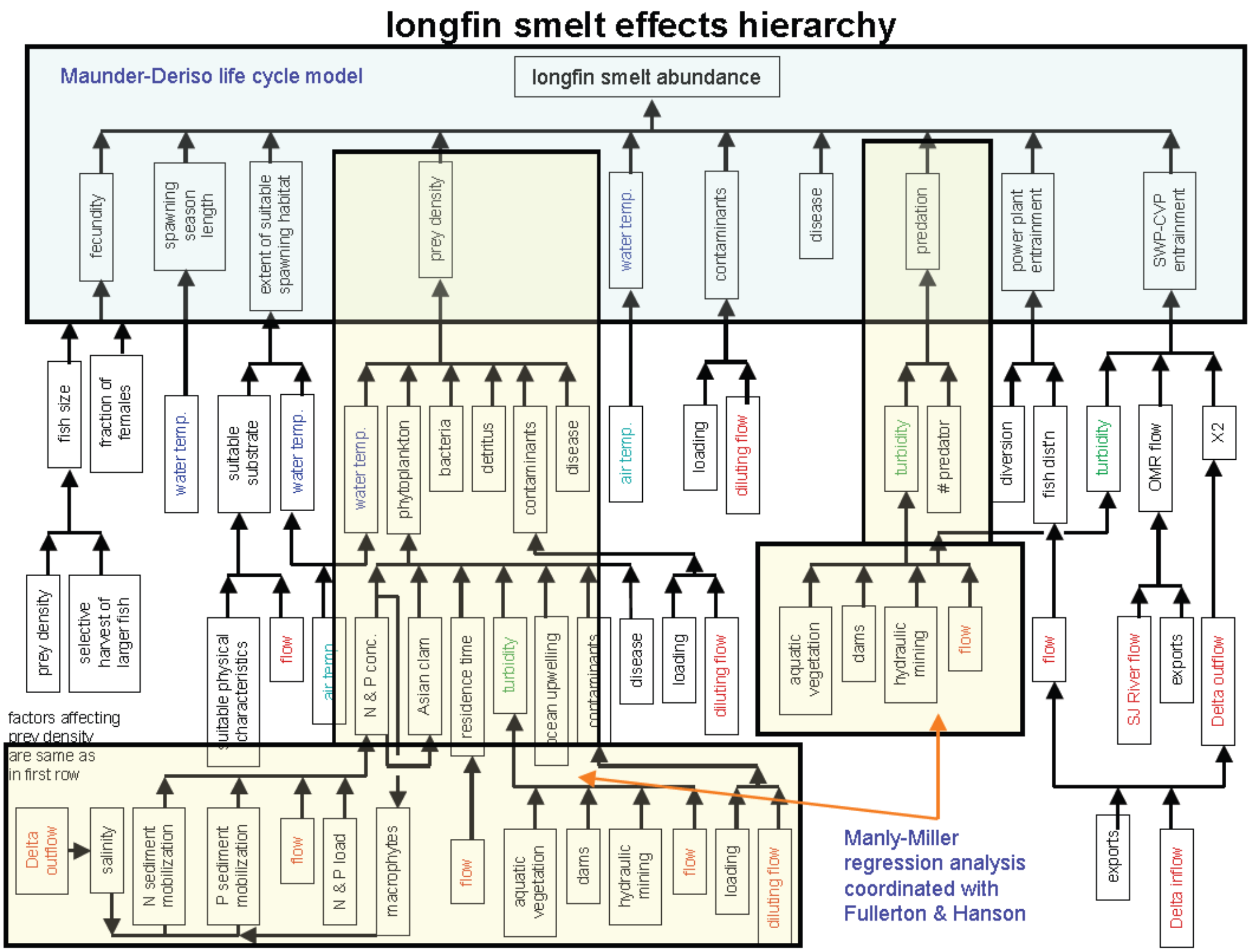


Figure 3. Longfin hierarchy conceptual model for longfin smelt (Source: Miller unpublished).

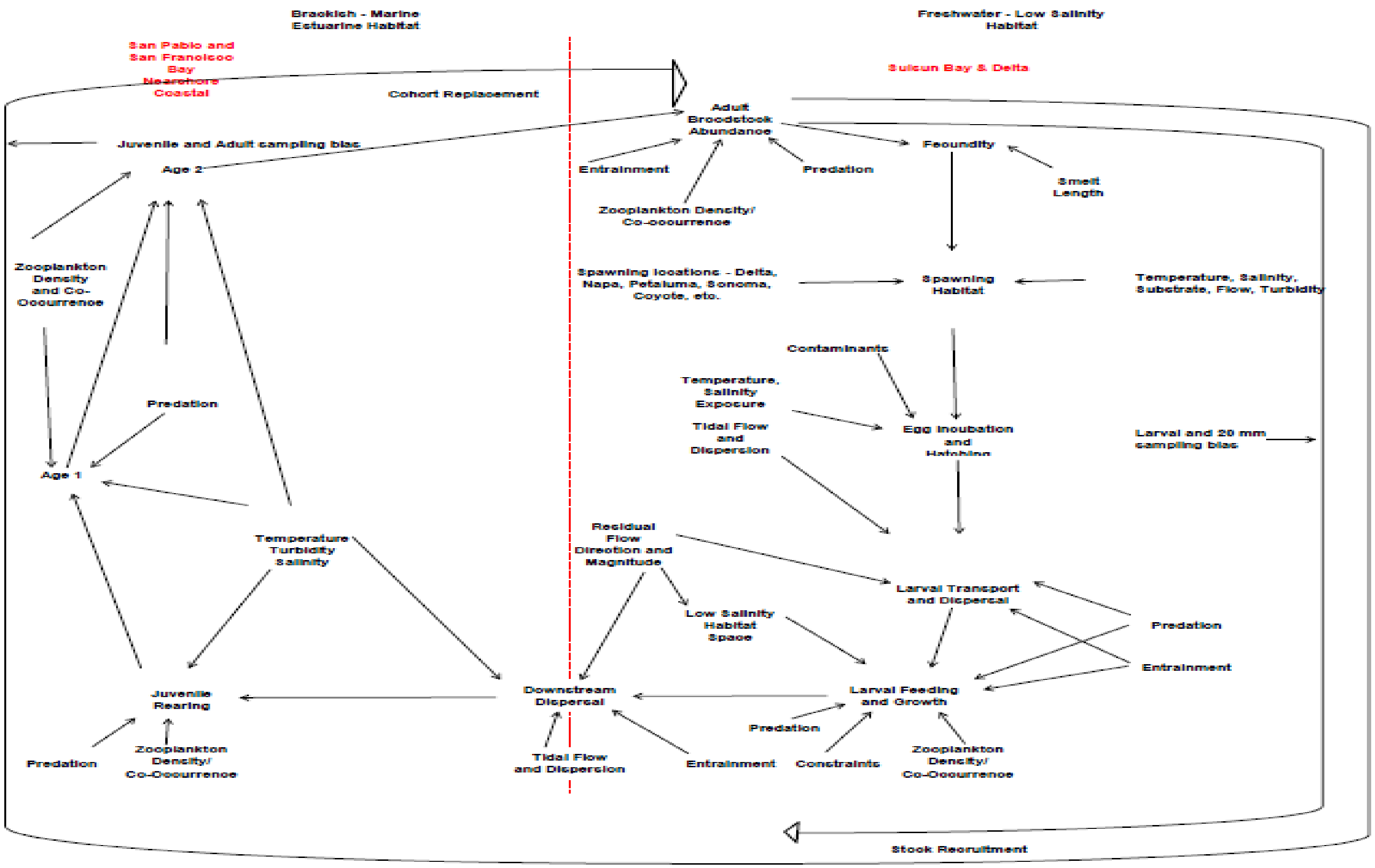


Figure 4. Lifecycle conceptual model of longfin smelt.

Covariate Selection Process

All of the environmental covariates selected for consideration in the initial statistical analyses were entered into two formulations of the longfin smelt lifecycle model: (a) a model in which spawners are the adult lifestage (November-March) ages 1 and 2, and (b) an alternative model in which pre-adults (October-March) ages 0 and 1 and adults (November-March) ages 1 and 2 were equally weighted in the model as spawners. A series of statistical analyses was then performed to identify those covariates with the greatest contribution to model development (Maunder *et al.* 2014). AIC_C was used to conduct forward stepwise covariate selection. The procedure selects the covariate with the best AIC_C improvement conditional on the inclusion of all previous selected covariates. The procedure is stopped when there are no further improvements to AIC_C. The covariates selected and the ΔAIC_C are used to compare methods. The covariates were normalized (mean subtracted and divided by the standard deviation) to improve model performance. Many of the factors in the larger set of potential environmental covariates were highly correlated. Two flow variables that were highly correlated were kept in the model to illustrate some of the difficulties in hypothesis testing (Maunder *et al.* 2014). The model was fit to abundance indices for each lifestage of longfin smelt included in the model and used in the calculation of the regression models. Results of the covariate statistical analyses are presented by Maunder *et al.* (2014).

Maunder and Deriso (2011) recommend that all possible combinations and interactions of covariates and density dependent factors should be evaluated in model covariate selection because some factors may only be detected in combination with other factors or in the presence of density dependence. Conducting analyses of all possible combinations of covariates can, however, be computationally demanding. To reduce the computational time, Maunder and Deriso (2011) applied a strategy that evaluates two covariates at a time and uses AIC_c summed over all possible one and two covariate combinations to select a covariate that has general support. In contrast, Anderson *et al.* (2000) warn against testing all possible combinations unless using model averaging. Practical advice is to ensure that covariates included in the model have *a prior* biological support and that the framework of Maunder and Deriso (2011) is followed to identify the life stage and the relationship to density dependence before conducting analyses of covariate combinations. Given the availability of distributed computing resources, all combinations of covariates in the model analysis should be practical, but care needs to be taken to ensure that all models have converged on the optimal solution, since this may be difficult to achieve with a large number of model runs. Results should be used to rank models and provide an idea of the data-based evidence for alternative hypotheses rather than strict acceptance-rejection hypothesis testing (Maunder and Deriso 2011).

Factors potentially impacting the longfin smelt population were then evaluated by Maunder *et al.* (2014) by fitting a population dynamics model to age class indices of longfin smelt abundance. The population is modeled as a series of Beverton-Holt stock-recruitment relationships that reflect potential density dependent survival. Three life stages of longfin smelt were modeled by Maunder *et al.* (2014) and related to age class abundance indices identified in the Bay Study surveys. The names juveniles, pre-adults, and adults are given to these three life stages. Juveniles are age zero longfin caught in June and July. Pre-adults are age zero longfin caught in October to December and age one longfin were caught in January to March. Adults are age one longfin caught in November to December and age two or older longfin caught in January to March.

Longfin Smelt Abundance Indices (Response Variable)

Developing a lifecycle model for longfin smelt requires a long-term time series reflecting fluctuations in abundance and age structure of the population. Since longfin smelt may live two or more years the abundance data set must quantitatively distinguish between young-of-the-year (age 0), yearlings (age 1) and pre-spawning adults (age 2). The time series needs to be long enough to represent a wide range of environmental conditions, such as periods of high winter and spring Delta outflows as well as drought conditions when Delta outflows are substantially reduced. In addition, since many longfin smelt inhabit the freshwater and the low salinity zone (Suisun Bay upstream) for a portion of their lifecycle, and the more marine waters of San Pablo, central San Francisco bays and other more saline waters for an even longer portion of their lifecycle, the time series of abundance data should reflect changes in the spatial distribution of the species. Two major long-term fishery monitoring programs were considered in developing the time series of longfin smelt indices of abundance and age structure. The CDFW FMWT and the CDFW Bay Study data were both considered for use in developing the lifecycle model. Data on the age class, spatial and seasonal distribution, and changes in indices of abundance of longfin smelt from both of these fishery sampling programs is available at http://www.dfg.ca.gov/delta/.

The CDFW FMWT sampling program has sampled fish populations since 1967 with the exception of 1974 and 1979. The original sampling design was targeted on developing an abundance index for young-of-the-year striped bass in the fall. The sampling program, however, also provides data on other fish collected including longfin smelt. Sampling is conducted using a midwater trawl at 122 sampling stations that extend from San Pablo Bay upstream to Stockton on the San Joaquin River and the Sacramento Deep Water Shipping Channel on the Sacramento River (Figure 5). Sampling is primarily conducted monthly during September-December. The midwater trawl has a stretch mouth opening 12 ft by 12 ft with a graded mesh size from 8 inches at the mouth to 0.5 inches at the cod end. At each sampling station a 12 minute tow is made obliquely through the water column from the bottom to the surface. The sampling methods have remained consistent over the period of the surveys which allows for comparisons of catch and indices of abundance among months and among years. Following each sampling event all fish and macroinvertebrates are identified, counted, and length of fish measured. In addition, water temperature, electrical conductivity (a measure of salinity), Secchi depth, and turbidity are measured at the surface for each sample. The numbers of each species collected in a sample are then reported as the density (number per 10,000 m^3 sampled) as well as a composite estimate of abundance calculated by multiplying the densities for a given fish species collected at a group of sampling stations representing an area of the region (Figure 6) times the water volume in the region which are then summed over the entire sampling area and expressed as a population abundance index for a given sampling period (e.g., month when the survey was conducted) for each species and age class.

As an alternative to using the fall midwater trawl surveys to represent longfin smelt abundance, the CDFW Bay Study has collected fishery samples approximately monthly year round since 1980. The Bay Study sampling area includes South San Francisco Bay, Central San Francisco Bay, San Pablo, Bay, Suisun Bay, and the Sacramento River upstream to Steamboat and Cache sloughs as well upstream on the San Joaquin River to Old River Flats (Figure 7). Sampling is conducted at each open water station using both an otter trawl (sampling fish on or near the bottom) and a midwater trawl (sampling fish from the water column). The otter trawl is sampled 5 minutes at each station and the midwater trawl is sampled 12 minutes at each station. Sampling is conducted currently at 52 stations with a core of 35 stations that have routinely been sampled since inception of the program. The sampling methods have remained consistent over the period of the surveys which allows for comparisons of catch and indices of abundance among months and among years. Following each sampling event all fish and macroinvertebrates are identified, counted, and length of fish measured. In addition, distance towed and volume of water filtered are measured for use in calculating densities (number per 10,000 m^3 for the midwater trawl and number per 10,000 m^2 for the otter trawl). Water temperature, electrical conductivity (a measure of salinity), Secchi depth, and station water depth are also measured at the surface for each sample. The catch and density of each species collected in a sample are then reported as well as a composite estimate of abundance calculated by multiplying the densities for a given fish species collected at a group of sampling stations representing an area of the region times the water volume in the region for the midwater trawl samples and bottom area for the otter trawl which are then summed over the entire sampling area and expressed as a population abundance index for a given sampling period (e.g., month when the survey was conducted) for each species and age class.

In evaluating which data set on the age class abundance of longfin smelt to use in developing the longfin smelt lifecycle model, consideration was given to the length of the time series of data available, the geographic area sampled for each survey relative to the geographic distribution of longfin smelt, sampling consistency for multiple age classes throughout the year, and the areas of the water column sampled relative to the vertical distribution of longfin smelt. The CDFW fall midwater trawl survey has an advantage in that the survey has been conducted since 1967 offering the longest time series of data available. The midwater trawl sampling, however, is limited to sampling only during the fall months in the water column using a midwater trawl at sampling stations that do not fully cover the more marine areas of the estuary that longfin smelt are known to inhabit (e.g., Central San Francisco Bay). The Bay Study, although having a shorter time series (starting in 1980), samples nearly the entire area where longfin smelt are thought to occur within the estuary on a monthly basis year round. The Bay Study also employs both an otter trawl and midwater trawl at each sampling site. Longfin smelt, although a pelagic fish species, are thought to preferentially inhabit the lower portion of the water column during the daytime, potentially following the diel vertical movement patterns of mysid shrimp, a primary prey resource, and would be more effectively sampled during daylight hours using the otter trawl in the lower portions of the water column. Sampling using both the midwater and otter trawls as part of the Bay Study sampling design was viewed as a benefit in developing a composite index of abundance for the lifecycle model for each age class of longfin smelt that reflected changes in abundance and geographic distribution throughout the year. A comparison of indices of longfin smelt abundance between the fall midwater trawl survey and the Bay Study (Figure 8) showed good agreement (high r^2). In addition, data for a number of the potential environmental covariates was not available or considered to be reliable (including length measurements used to assess longfin smelt age classes) for years before 1980, which diminished the potential value of the use of the longer time series of data offered by the fall midwater trawl data base. Based on these considerations it was decided that the use of the Bay Study midwater and otter trawl data on longfin smelt age class abundance would be the most appropriate time series data source for developing the longfin smelt lifecycle model.

The years included in the lifecycle model development, namely, the monthly time periods between 1980 and 2008 when the Bay Study undertook sampling are shown in Table 1. The number of longfin collected by month and year is shown in Table 2 for the midwater trawl samples and in Table 3 for the otter trawl samples. Note that there are months within the time series when sampling was not conducted or only a partial number of stations were sampled by the Bay Study. Sampling may not have been conducted in a given month for a number of reasons including mechanical failures and breakdowns of the sampling vessel requiring an extended period for repair, short-term curtailment of sampling to avoid excessive incidental take of delta smelt, and for other reasons. The resulting indices of longfin smelt abundance, including actual monthly indices of longfin smelt abundance and those estimated for missing or incomplete sampling, used in the statistical analyses are summarized in Appendix B.

The formulation of the statistical analysis used in developing the lifecycle model is more robust when the time series of variables is continuous (Maunder and Deriso 2003). To develop a continuous time series of indices of monthly longfin smelt abundance, interpolation was used to fill in missing data points within the time series matrix. Missing values of abundance indices were estimated as the average of the previous monthly index and the subsequent monthly index for each age class of longfin smelt using data from both the midwater trawl and otter trawl sampling. The method for estimating missing monthly abundance indices using the averaging approach was considered to be the best scientific method available for developing a continuous time series of data on longfin smelt from the Bay Study, including the estimates of missing values, which was consistent with the geographic distribution of longfin smelt within the estuary, and represented longfin smelt abundance throughout the water column on a monthly basis reflecting the age class distribution of longfin throughout the year for young-of-the-year (age 0) as well as age 1 and age 2 longfin smelt.

In addition to sampling larger juvenile and adult longfin smelt as part of Bay Study surveys, CDFW currently conducts two sampling programs designed to provide data on the seasonal and geographic distribution of larval and early juvenile longfin smelt life stages. In 1995 CDFW implemented a sampling program known as the 20 mm smelt survey designed to collect early juvenile smelt. A larval smelt survey program was implemented in 2009 to collect early larval life stages of longfin and delta smelt. As part of the original Bay Study sampling design larval fish sampling was conducted starting in 1980 but was stopped in 1989. Although these three surveys provide useful information on the larval and early juvenile life stages of smelt inhabiting the estuary, the relatively short time series of data available from these sampling programs precluded their use in developing the long-term time series of larval longfin smelt abundance for the longfin smelt lifecycle model.

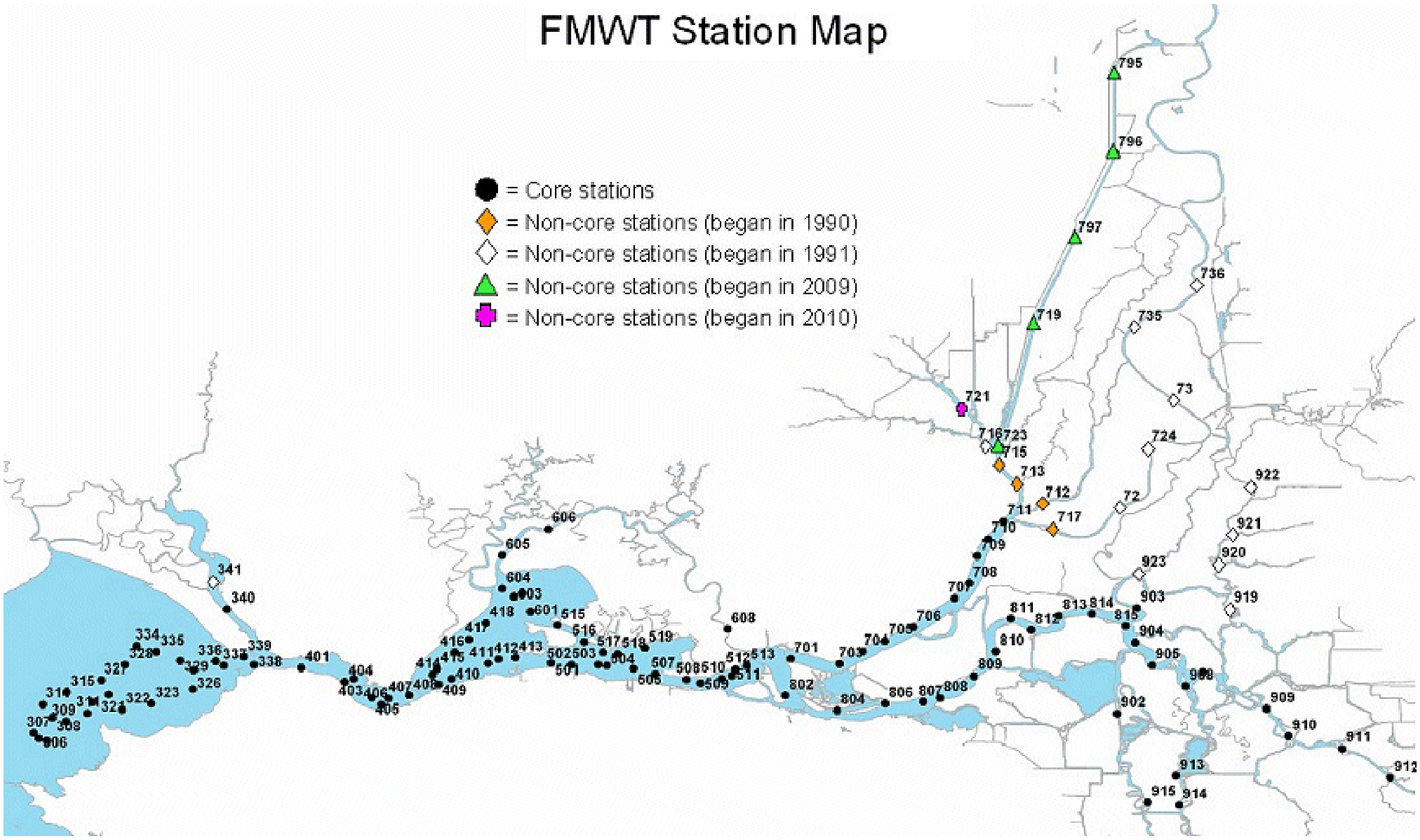


Figure 5. CDFW fall midwater trawl sampling sites.

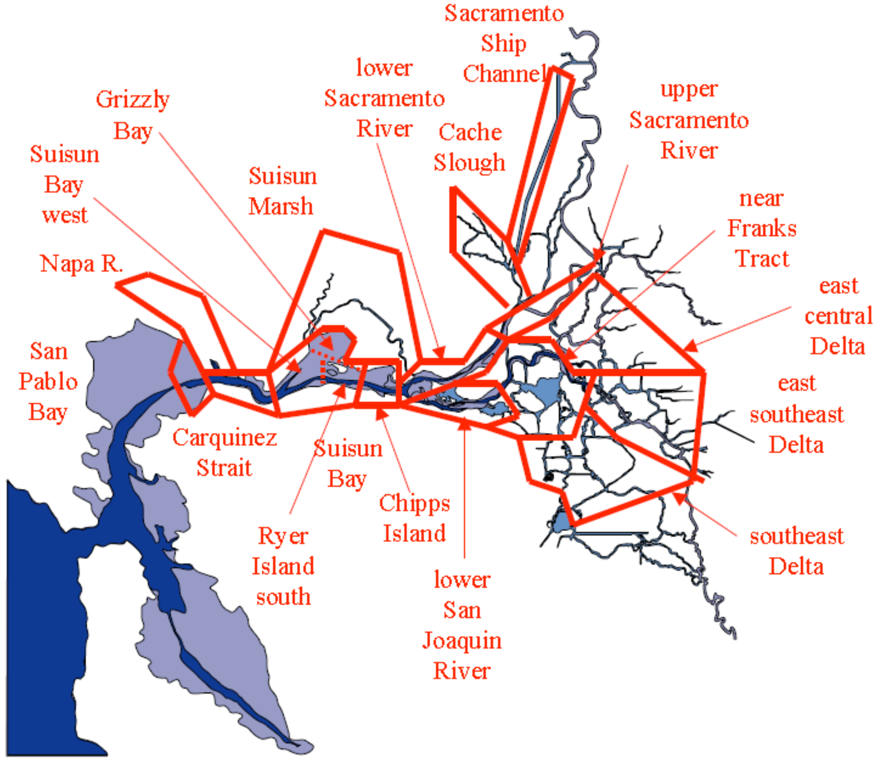


Figure 6. **Sub-regional areas within the Delta used in estimating longfin smelt abundance.**

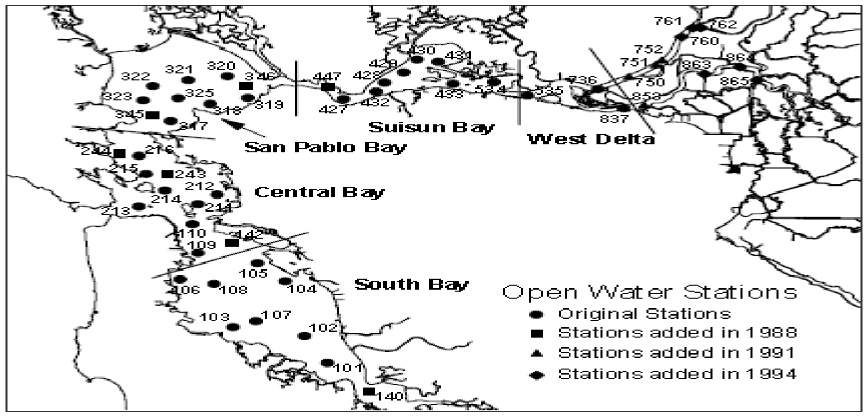


Figure 7. CDFW Bay Study otter trawl and midwater trawl sampling sites.

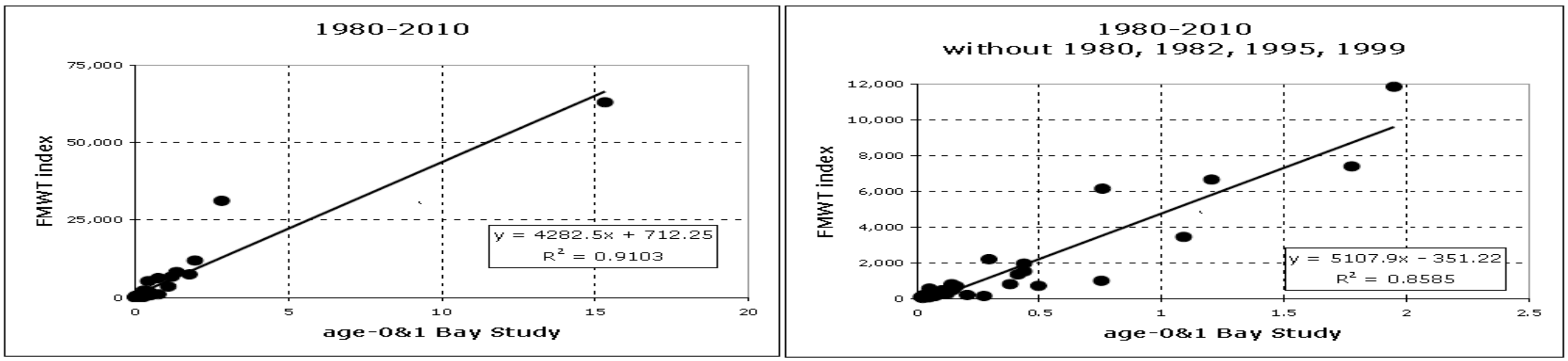


Figure 8. **Correlation between indices of longfin smelt abundance based on the CDFW FMWT and Bay Study fishery sampling.**

Table 1. Summary of seasonal distribution of fishery sampling effort by CDFW in the Bay Study: 1980-2008.

Year	Midwater Trawl	Otter Trawl
1980	January-November[1]	January-November[1]
1981	January-December	January-December
1982	January-December	January-December
1983	January-December	January-December
1984	January-December	January-December
1985	January-December	January-December
1986	January-December	January-December
1987	January-December	January-December
1988	January-December	January-December
1989	January-August	January-August
1990	February-October	February-October
1991	February-October	February-October
1992	February-October	February-October
1993	February-October	February-October
1994	February-April	February-October
1995	April-December[2]	January-December[2]
1996	April-December	January-December
1997	January-December[3]	January-December[4]
1998	January-December[5]	January-December
1999	January-October	January-October
2000	January-December	January-December
2001	January-December[6]	January-December[6]
2002	February-December	February-December

2003	January-December	January-December
2004	January-December	January-December
2005	January-December	January-December
2006	January-December	January-December
2007	January-December[7]	January-December[8]
2008	January-December[9]	January-December[9]

[1]In 1980 there were 11 surveys - sampled South Bay to mid-San Pablo Bay mid-month from January through November, then 1-2 weeks later (February-December) sampled the upstream portion of the study area.

[2]Did not sample August 1995 due to mechanical problems.

[3]MWT: In 1997 sampled only San Pablo Bay January to March, all stations April to December.

[4]OT: In January 1997 did not sample upstream of Carquinez Strait due to extremely high outflow.

[5]MWT: In 1998, sampled from South to San Pablo bays January to March, all stations April to December.

[6]Both nets, did not sample March 2001.

[7]Did not sample upstream of Honker Bay (station 534) with the midwater trawl in June and July 2007.

[8]Did not sample upstream of the confluence (stations 736 and 837) with the otter trawl in June 2007.

[9]Did not sample May 2008 (boat down) and skipped several stations in several months to minimize delta smelt take.

Table 2. **San Francisco Bay Study monitoring using the midwater trawl. Months sampled by year and gear type, 1980-2008. No range entered indicates no sampling. Yellow highlights reflect missing or partial surveys.**

Count of Tow	Survey											
Year	1	2	3	4	5	6	7	8	9	10	11	12	Grand Total
1980	35	34	35	34	34	34	35	32	33	32	31		369
1981	35	34	34	33	32	35	34	35	34	35	35	35	411
1982	34	35	35	31	35	35	35	35	35	34	34	35	413
1983	34	35	34	34	35	35	35	35	35	35	35	35	417
1984	35	35	35	35	35	35	35	35	35	35	35	35	420
1985	35	35	35	35	35	35	35	35	35	35	35	35	420
1986	35	35	35	35	35	35	35	35	35	35	35	35	420
1987	35	35	35	35	35	35	35	35	35	35	35	42	427
1988	42	42	42	42	42	42	42	42	42	42	42	42	504
1989	42	42	42	42	42	42	42	42					336
1990		42	42	42	42	42	42	42	42	42			378
1991		46	46	46	46	46	46	46	46	46			414
1992		46	46	46	46	46	46	46	46	46			414
1993		46	46	46	46	46	46	46	46	46			414
1994		46	46	46									138
1995				52	52	49	49		52	52	52	52	410
1996				52	52	52	52	52	52	52	52	52	468
1997	10	10	10	52	52	52	52	52	52	52	52	52	498
1998	30	30	30	52	52	52	52	52	52	52	52	52	558
1999	52	52	52	52	52	52	52	52	52	52			520
2000	52	52	52	52	52	52	52	52	52	52	52	52	624
2001	52	52		52	52	52	52	52	52	52	52	52	572
2002		52	52	52	52	52	52	52	52	52	52	52	572
2003	52	52	52	52	52	52	52	52	52	52	52	52	624
2004	52	52	52	52	52	52	52	52	52	52	52	52	624
2005	52	52	52	52	52	52	52	52	52	52	52	52	624
2006	52	52	52	52	52	52	51	52	52	52	52	52	623

2007	52	52	52	52	52	39	39	52	52	52	52	52	598
2008	50	52	52	52		52	49	48	49	52	49	49	554
Grand Total	**868**	**1,148**	**1,096**	**1,310**	**1,216**	**1,255**	**1,251**	**1,213**	**1,224**	**1,226**	**990**	**967**	**13,764**

Limited sampling upstream in June and July 2007 to minimize delta smelt take.

Limited sampling upstream in January, July - September, November and December 2008 to minimize delta smelt take.

Table 3. **San Francisco Bay Study monitoring using the otter trawl. Months sampled by year and gear type, 1980-2008. No range entered indicates no sampling. Yellow highlights reflect missing or partial surveys.**

Count of Tow	Survey											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Grand Total**
1980	32	34	35	35	33	34	35	32	33	33	31		367
1981	35	34	35	33	31	35	32	33	33	32	34	34	401
1982	31	34	33	34	34	35	34	35	34	34	33	34	405
1983	34	34	33	34	35	34	32	35	35	35	35	35	411
1984	35	35	35	35	35	35	35	35	35	35	35	35	420
1985	35	35	35	35	35	35	35	35	35	35	35	35	420
1986	35	35	35	35	35	35	35	35	35	35	35	35	420
1987	35	35	35	35	35	35	35	35	35	35	35	42	427
1988	42	42	41	42	42	42	42	42	42	42	42	42	503
1989	42	42	42	42	42	42	42	42					336
1990		42	42	42	42	42	42	42	42	42			378
1991		46	46	46	46	46	46	46	46	46			414
1992		46	46	46	46	46	46	46	46	46			414
1993		46	46	46	46	46	46	46	46	45			413
1994		46	46	46	52	52	52	52	52	52			450
1995	52	52	52	52	52	51	49		52	52	52	52	568
1996	52	52	52	52	52	52	52	52	52	52	52	52	624
1997	32	52	52	52	52	52	52	52	52	52	52	52	604
1998	52	52	52	52	52	52	52	52	52	52	52	52	624
1999	52	52	52	52	52	52	52	52	52	52			520
2000	52	52	52	52	52	52	52	52	52	52	52	50	622
2001	52	52		52	52	52	52	52	52	52	52	52	572
2002		52	52	52	52	52	52	52	52	52	51	51	570

2003	52	51	51	52	52	52	52	52	52	52	52	51	621
2004	52	52	52	52	52	52	52	52	52	52	52	52	624
2005	52	52	52	52	52	52	52	52	52	52	52	51	623
2006	51	52	52	52	52	51	51	52	51	52	52	52	620
2007	52	52	52	52	52	42	52	52	52	52	52	52	614
2008	50	52	52	52		52	52	52	52	52	52	52	570
Grand Total	**1,009**	**1,313**	**1,260**	**1,314**	**1,265**	**1,310**	**1,313**	**1,267**	**1,276**	**1,275**	**990**	**963**	**14,555**

Limited sampling upstream in June 2007 to minimize delta smelt take.

Limited sampling upstream in January 2008 to minimize delta smelt take.

Environmental Covariate Selection

Based on a consideration of the linkages shown in the lifecycle conceptual model (Figure 4), the discussion outlined above, and various analyses showing potential relationships between environmental covariates and indices of longfin smelt abundance or indirect effects on longfin smelt food resources, a number of covariates were identified for initial consideration in the development of the lifecycle model. The covariates included in the initial statistical screening used as a foundation for developing the lifecycle model are presented in Table 4 and briefly discussed below.

Table 4. Initial list of environmental covariates included for consideration in the lifecycle model statistical analyses.

Factor	Time	Stage	Sign Direction
River Flow (habitat and transport)			
Sacramento River Runoff	Previous October - March	Adult to Juveniles	Positive
Sacramento River Runoff	April - June	Adult to Juveniles	Positive
Sacramento River Runoff	Previous October - July	Adult to Juveniles	Positive
Sacramento River Inflow	April to June	Adult to Juveniles	Positive
Sacramento + San Joaquin Runoff	Previous October - March	Adult to Juveniles	Positive
Sacramento + San Joaquin Runoff	April - July	Adult to Juveniles	Positive
Sacramento + San Joaquin Runoff	year round	All stages	Positive
Delta outflow threshold indicator at 34,500 cfs	Mar-May	Adult to Juveniles	Positive
Delta outflow threshold indicator at 44,500 cfs	Mar-May	Adult to Juveniles	Positive
Delta outflow	January - March	Adult to Juveniles	Positive
Napa River flow	January-March	Adult to Juveniles	Positive
Location of the Low Salinity Zone (habitat)			
Location of the low salinity zone (X2 location)	April - June	Adult to Juveniles	Negative
Sea Surface Temperature (ocean upwelling and productivity)			
Ocean temperature (SST)	July-September	Juvenile to pre-adult	Negative
Invasive Species (competition for food)			
Overbite clam presence	Year round	All stages	Negative
Predation Risk (mortality)			
Chinook salmon at Chipps Island	Apr-May	Adult to Juveniles	Negative
Predators in central and San Pablo bays	Annual	All stages	Negative
Predators in Suisun Bay	January-March	Adult to Juveniles	Negative
Predators in Suisun Bay	March-July	Adult to Juveniles	Negative
Predator abundance where smelt occur total 12 months	year round	All stages	Negative

Alternative prey	Year round	All stages	Positive
Prey Resources (food availability)			
Mysid shrimp density	July - September	Juveniles to pre-adult	Positive
Mysid shrimp density	May - June	Adult to Juveniles	Positive
Eurytemora density	April - May	Adult to Juveniles	Positive
Pseudodiaptomus density	April - July	Adult to Juveniles	Positive
Risk of Entrainment/Geographic Distribution and Transport (mortality)			
Old and Middle river (OMR) flow	January - March	Adult to Juveniles	Positive
Water Quality (habitat)			
Secchi depth (a measure of turbidity and visibility)	April - June	Adult to Juveniles	Negative
Secchi depth	August - September	Juveniles to pre-adult	Negative
Secchi depth (San Pablo Bay and upstream)	March - June	Adult to Juveniles	Negative
Average MWT temperature	January - March	Adult to Juveniles	Negative
Average MWT temperature	April -June	Adult to Juveniles	Negative
July MWT temperature	July	Adult to Juveniles	Negative
Water temperature (San Pablo Bay and upstream)	March - June	Adult to Juveniles	Negative
Contaminants (toxicity and inhibition of algal growth)			
Area weighted ammonium concentrations	April - June	Adult to Juveniles	Negative
Central Bay ammonium concentrations	April - June	Adult to Juveniles	Negative
San Pablo ammonium concentrations	April - June	Adult to Juveniles	Negative
Suisun Bay ammonium concentrations	April - June	Adult to Juveniles	Negative
Metric tons of ammonium discharged from the Sacramento Waste Water Treatment Plant	April - June	Adult to Juveniles	Negative
Ammonium concentration/Sacramento River inflow	April - June	Adult to Juveniles	Negative

River Flow (habitat and transport)

A number of analyses have been developed exploring the potential relationship between indicators of Delta outflow and the abundance and population dynamics of longfin smelt. These analyses have included simple regressions between the seasonal magnitude of freshwater flow in the late winter and spring months when longfin smelt larvae and early juvenile life stages are present in Suisun Bay and the western Delta and subsequent abundance of later juvenile smelt the following fall based on results of CDFW FMWT sampling (Rosenfield and Baxter 2007, Rosenfield 2010, Kimmerer 2002a and b, MacNally *et al.* 2010, Thomson *et al.* 2010, Kimmerer *et al.* 2009, and others). Thomson *et al.* (2010), MacNally *et al.* (2010), Rosenfield and Swanson (2010), and Nobriga (unpublished) focused their analyses on Delta outflow during the March-May period. More recently, analyses have focused on stock-recruitment relationships such as cohort replacement rates (CRR) as a function of spring outflow from the Delta (Nobriga unpublished, Rosenfield and Swanson 2010). Both log-linear and flow threshold relationships have been presented as part of these analyses. The CRR for longfin smelt has been defined in these analyses as the FMWT index in one year divided by the index from two years prior reflecting the 2-year lifespan of longfin smelt. Some of the analyses have used the combination of two years of FMWT indices to reflect ages 1 and 2 in the adult population. Each of these analyses show correlations between various metrics of Delta outflow and a population response by longfin smelt; however, the underlying mechanisms remain unknown. It has been hypothesized that the relationships reflect greater larval transport and dispersal downstream when Delta outflows are high, which improves larval growth and survival. It has also been hypothesized that higher spring outflow results in a greater surface area of low salinity rearing habitat that may benefit larval and early juvenile growth and survival leading to greater adult abundance. Mongan and Miller (2011) hypothesized that greater outflow provides greater dilution of ammonium based on the hypothesis that some combination of ammonium inhibition of phytoplankton growth rates and increasing N:P ratios stemming from wastewater treatment plant discharges to the Sacramento River is reducing production of phytoplankton and zooplankton within the estuary (Wilkerson *et al.* 2006; Dugdale *et al.* 2007; Glibert *et al.* 2011; Parker *et al.* 2012) contributing to food limitations affecting the growth and survival of longfin smelt. Although there are a number of alternative hypotheses regarding the mechanisms through which the magnitude of Delta outflow in the late winter and spring months could be affecting longfin smelt, the results of these analyses clearly support the inclusion of metrics of Delta outflow as environmental covariates in the lifecycle model development.

The flow based covariates selected for analysis included Sacramento River Runoff over various seasonal time periods, Sacramento River Inflow, and Sacramento + San Joaquin Runoff over various seasonal time periods (Table 4). These relationships between indices of longfin smelt abundance and river flows reflect strong linear correlations (autocorrelations) between river runoff, Delta inflow and Delta outflow. Since the Sacramento River system is the dominant source of freshwater entering the Delta, several of the environmental covariates focused on hydrodynamic conditions in the Sacramento River basin. Because the San Joaquin River also contributes to Delta outflow, the combined runoff from the two river systems was also used in the analysis. Many of the earlier analyses showed evidence of a relationship between Delta outflow during the winter and spring on subsequent abundance of longfin smelt, and therefore a linear relationship with Delta outflow was included in the initial analyses. Recently, Rosenfield and Swanson (2010) conducted a series of analyses using logistic regression to estimate that a threshold flow of approximately 34,500 cfs during March-May (a total of 6.3 million acre feet of Delta outflow) in 50% of years would be needed to provide a positive cohort replacement rate as shown in Figure 9. The estimated Delta outflow threshold of 34,500 cfs proposed by Rosenfield and Swanson (2010) was similar to a threshold developed by Nobriga (unpublished) to achieve a positive cohort replacement rate (Figure 10) based on analyses that showed that a natural Log line fitted to the data appears fairly robust ($r^2 \approx 0.49$) and crosses the zero line (neutral growth) at approximately 30,000-35,000 cfs. Nobriga (unpublished) conducted additional statistical analyses of the longfin smelt population assuming a density dependent stock-recruitment function that suggested the longfin smelt population would experience positive growth (a cohort replacement rate greater than 1.0) under conditions in which Delta outflow exceeded 44,500 cfs over the March to May period in half the years. Based on results of these analyses a number of environmental covariates reflecting hydrologic conditions within the Sacramento and San Joaquin rivers and Delta during the winter and spring months were included in the initial lifecycle model statistical analyses (Table 4). Daily estimates of river and Delta outflows are available from DWR DAYFLOW and CDEC records.

Based on results of limited larval smelt surveys conducted by CDFW in the lower reaches of the Napa River, it appears that longfin smelt are successfully using tributaries other than the Sacramento and San Joaquin rivers as spawning habitat. The extent of longfin smelt spawning in these smaller tributaries, and whether spawning occurs every year or only under wet hydrologic conditions, is unknown. Results of fishery studies conducted in the Napa River (Stillwater Science 2006) also showed that pre-spawning longfin smelt inhabit the tributary, although estimates of abundance are not available. Evidence of successful longfin smelt spawning in the Napa River suggests that spawning may also occur in other tributaries to the Bay. The Napa River and other tributaries have similar characteristics in which hydrologic conditions are determined by local rainfall events and there is a low salinity estuarine transition zone as freshwater from the tributary flows into the higher salinity Bay waters. Recognizing the potential for smaller tributaries to contribute to the reproductive success of longfin smelt, an environmental covariate reflecting average flow in the Napa River over the seasonal period from January to March was included in the initial statistical analysis of lifecycle model covariates. The pattern of flows in the Napa River were found to be highly correlated with runoff and flows in the Sacramento River as a result of the generally similar hydrologic conditions occurring in the two watersheds each year.

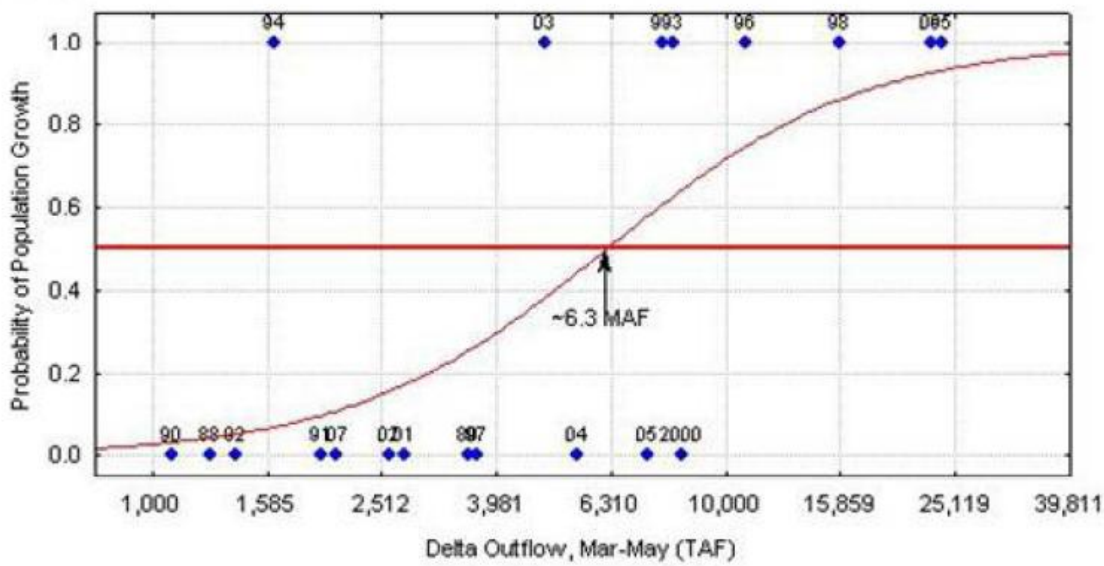


Figure 9. **Relationship between probability of longfin smelt population growth and March-May Delta outflow (Source: Rosenfield and Swanson 2010).**

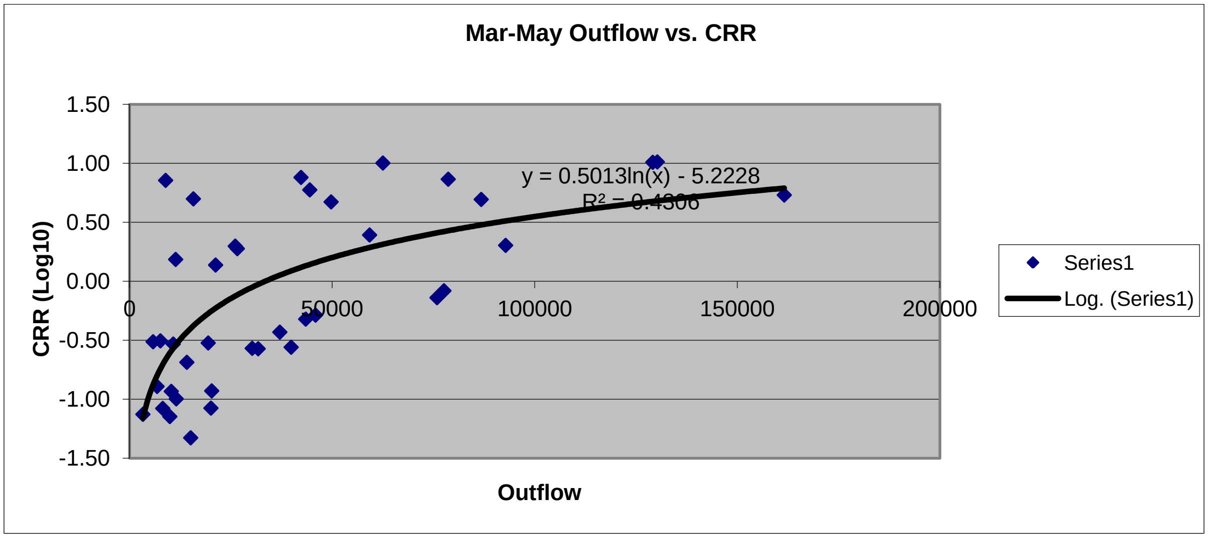


Figure 10. **Relationship between the Log10 cohort replacement rate and March-May Delta outflow (Source: Nobriga unpublished).**

Location of the Low Salinity Zone (habitat)

As discussed above, a number of studies have identified a correlation between river flow and Delta outflow during the late winter and spring months, and indices of longfin smelt abundance based on results of the annual CDFW FMWT surveys. The location of the low salinity zone in the estuary, as reflected in the location of the 2 psu bottom isohaline (X2 location in km upstream of the Golden Gate Bridge), is determined by the balance of freshwater flowing out of the Delta (Delta outflow) and tidal intrusion of saltwater from coastal marine waters passing into Central San Francisco Bay and San Pablo Bay that affect the salinity distribution in Suisun Bay and the western Delta. A correlation has been reported between annual indices of longfin smelt abundance, and the average January-June X2 location (and for other subsets of late winter and spring months; Figure 11), as reflected in analyses by Mongan and Miller (2011) and others. This and similar correlations seem to be the basis of management actions to control X2 location during the spring under State Water Resources Control Board D-1641 designed to provide low salinity habitat for longfin smelt and other species. However, the relationship between X2 location (and Delta outflow) and longfin smelt abundance has changed over the past two decades. In recent years (e.g., after about 2000) the observed abundance of longfin smelt has been substantially less than that predicted by the earlier X2 vs. abundance and Delta outflow vs. abundance relationships. The cause-effect mechanisms underlying the apparent relationship between X2 location and longfin smelt abundance are unknown. Mongan and Miller (2011) hypothesized that the observed relationship between X2 location and longfin smelt abundance resulted from an autocorrelation in which higher Delta outflows result in X2 moving further downstream to the west, causing greater dilution of ammonia concentrations that are thought to inhibit phytoplankton production and subsequent zooplankton production. In turn, this condition is hypothesized to result in decreased food supplies for longfin smelt and decreased longfin smelt growth and survival rates.

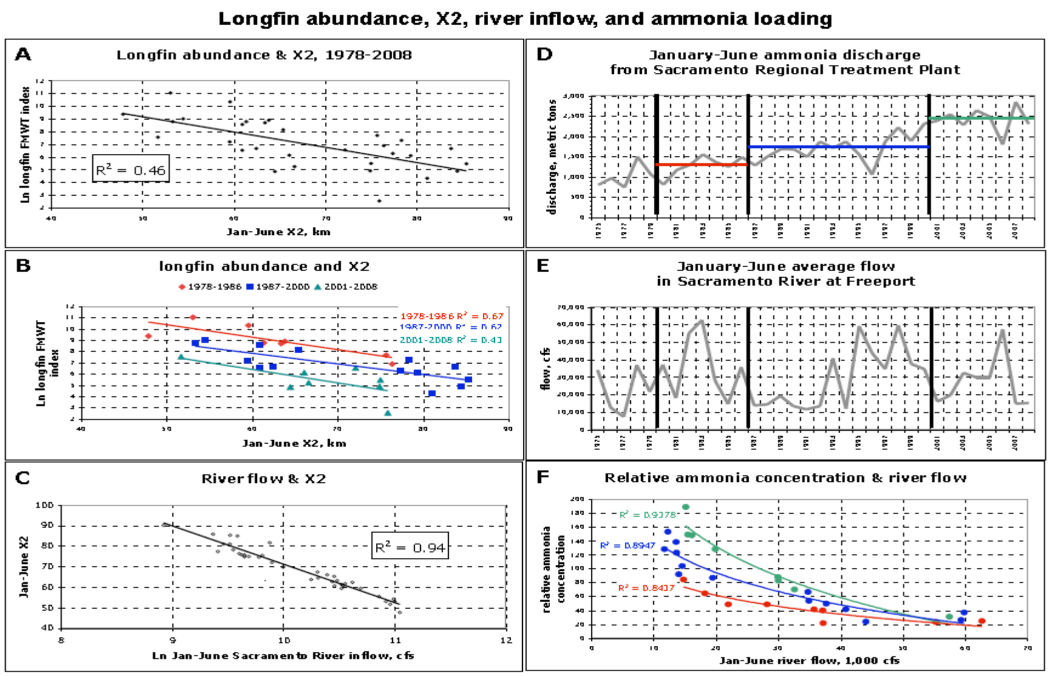


Figure 11. **Relationships between longfin abundance (Fall Midwater Trawl index), average January-June X2 location, and an index of ammonia loading to the estuary: 1987-2009. (Source: Mongan and Miller 2011).**

Thomson *et al.* (2010) found that X2 location and water clarity explained patterns in annual variation in FMWT indices of longfin abundance. MacNally *et al.* (2010) found that X2 location explained annual variation in longfin abundance, but they also identified a correlation with densities of zooplankton prey species. In contrast, Maunder and Deriso (2011) did not find that flow variables explained the rate of survival of delta smelt, which inhabits the Delta. Maunder and Deriso (2011) found that temperature, prey, and predators dominated the covariates that best explained delta smelt population dynamics. Maunder *et al.* (2014), however, did not find X2 location to be an important covariate in the initial screening of potential environmental covariates associated with longfin smelt population dynamics, after the inclusion of flow variables that had higher support in the data. Therefore, for the reasons set forth in Maunder *et al.* (2014), X2 location was not included in the covariates evaluated in greater detail in the lifecycle model formulation.

Sea Surface Temperature (ocean upwelling and productivity)

Juvenile and adult longfin smelt inhabit San Pablo and Central San Francisco bays and near shore coastal marine waters over an extended portion of their lifecycle (Rosenfield and Baxter 2007, Rosenfield 2010). During their residency in these marine habitats, longfin smelt forage on copepods, mysids, and other zooplankton species (Rosenfield and Baxter 2007, Rosenfield 2010). A number of investigations have shown that coastal upwelling of cold, nutrient rich, marine currents originating in the northwest and the subarctic is a significant factor affecting phytoplankton and zooplankton production in near-shore coastal marine waters (Thompson *et al.* 2012, Huete-Ortega *et al.* 2011, Ward *et al.* 2006, Takahashi *et al.* 2012, Cole 2000, Jutla *et al.* 2011). In contrast, Kim *et al.* (2009) reported that phytoplankton (chlorophyll a) levels measured at the Scripps Pier in the south California Bight were independent of local winds, sea surface temperature, and coastal upwelling. In general, the production and densities of phytoplankton and zooplankton increase during periods of more significant cold water upwelling and decrease during periods when upwelling is reduced and sea surface temperatures are increased.

Thompson *et al.* (2012) report that some of the earliest, strongest, and most variable winds and upwelling in California are found between Monterey and Point Arena, referred to as the Gulf of Farallones region. Investigations have shown evidence that the survival of juvenile fish such as Coho salmon and northern anchovy improves in response to increased coastal upwelling, which may reflect the availability of increased zooplankton food supplies (Cole 2000, Ward *et al.* 2006). Variability in recruitment success of Pacific sardines has also been linked with the intensity of coastal upwelling (Rykaczewski and Checkley 2008). Takahashi *et al.* (2012) reported that growth rates of juvenile northern anchovy were greater during periods when upwelling was greatest, and phytoplankton and zooplankton densities were increased. Checkley and Barth (2009) concluded that the production of small pelagic fish depends on nutrient upwelling from deep waters to the surface in the California Current. In general, individual fish that encounter higher densities of food organisms (e.g., zooplankton) experience greater growth rates, higher lipid concentrations, and greater survival leading to increased abundance.

In addition to affecting nutrients and the production of phytoplankton and zooplankton in surface waters, cold water upwelling has also been hypothesized to effect predatory fish in various ways. It has been hypothesized that during periods of cold water upwelling there is a reduced risk of predation mortality as a result of reduced metabolic rates for predators, thus depressing their appetites or the quantity of food intake (Cole 2000). Further, the abundance of several species of small pelagic fish, such as northern anchovy and sardine, has been observed to increase in response to higher zooplankton food availability. This circumstance may contribute to a greater abundance of alternative prey (e.g., increases in herring, sardine, and anchovy abundance in coastal waters) that may contribute to a reduced risk of predation on juvenile and adult longfin smelt. Thompson *et al.* (2012) found that that the abundance of predators such as seabirds (Cassin's auklet and common murre), humpback whales, and Chinook salmon increased in response to increased food supplies in coastal waters associated with upwelling. However, the abundance of other predators (splitnose rockfish) appeared to be independent of upwelling factors. Ward *et al.* (2006) reported an increase in predator abundance (southern Bluefin tuna) in response to increased abundance of sardine and anchovy associated with increased zooplankton densities and upwelling.

The potential for coastal upwelling conditions to affect food supplies and survival of juvenile and adult longfin smelt is consistent with the longfin smelt lifecycle conceptual model (Figure 4). This circumstance supported the inclusion of a coastal upwelling index as an environmental covariate in the initial longfin smelt lifecycle model analyses. There are several potential alternative indices and metrics for assessing coastal upwelling (e.g., Bakun upwelling index, Wells upwelling index, sea surface temperature, wind speed, direction, and sea surface stress, Ekman transport, turbulent mixing, and daily upwelling intensity). For this analysis, sea surface temperature (SST), which is a commonly used metric for assessing oceanographic conditions at specific locations along the California coast, was selected as an indicator of coastal upwelling near San Francisco Bay. The Point Reyes Bird Observatory (PRBO) has collected sea surface temperatures on a daily basis at the Farallone Islands (37^0 41.8'N 122^0 59.9'W) from 1925 forward. For purposes of the covariate used in the longfin life cycle model statistical analyses of environmental covariates, daily sea surface temperatures were compiled over the period from 1980 through 2008 to correspond with the time period encompassed by the CDFW Bay Study fishery data for longfin smelt that serve as the foundation for the abundance indices used in the lifecycle model. In formulating the covariate data, daily sea surface temperatures were compiled from the PRBO data set (ftp://ccsweb1.ucsd.edu/shore/active_data/farallon/temperature/) to represent coastal upwelling conditions that could have a direct influence on zooplankton densities as a food resource for juvenile and adult longfin smelt located in coastal nearshore waters off the Golden Gate, as well as those entering San Francisco Bay through tidal currents and coastal transport mechanisms. The three month average SST during July-September was used as the environmental covariate analyzed as part of the lifecycle model development in the initial statistical analyses. This is because summer and fall upwelling, and increased nutrients and zooplankton production, were thought to be potentially important drivers of juvenile longfin smelt growth and survival.

Invasive Species (competition for food)

In the late 1980s the Bay-Delta estuary was colonized by a non-native invasive filter feeding clam, the Asian overbite clam *Potamocorbula amurensis.* Biomass and density of the clams increased rapidly. As a result of the high volumes of water siphoned by these clams during filter feeding, large numbers of zooplankton and phytoplankton are removed from the water column and are no longer available to pelagic fish, such as longfin smelt, as a forage base (Kimmerer and Orsi 1996). As a consequence of the effects of the clam on the trophic web of the estuary, we used the annual presence of the overbite clam in regions of the estuary inhabited by longfin smelt as one of the environmental covariates included for consideration in the lifecycle model development.

Predation Risk (mortality)

Larval, juvenile, and adult longfin smelt are a relatively small pelagic fish species that reside in the lower Sacramento and San Joaquin rivers, Suisun Bay, San Pablo and Central San Francisco bays, and near shore coastal marine waters throughout their life. All lifestages of longfin smelt are vulnerable to predation mortality by a variety of resident and migratory fish species. The longfin smelt conceptual model (Figure 6) identifies potential predation mortality as a factor impacting the population dynamics and abundance of longfin smelt throughout their life cycle, although the actual magnitude of predation mortality on the survival and abundance of each life stage of longfin smelt is unknown (Rosenfield 2010). To assess potential relationships between predation risk and population dynamics of longfin smelt as part of the lifecycle model covariate analysis, a series of metrics were developed as indices of potential predation within various regions of the estuary. CDFW Bay Study fisheries surveys have demonstrated changes in the species composition of predatory fish within different regions of the estuary where longfin smelt are present which, to a large extent, reflect regional variation in salinity conditions (Baxter *et al.* 1999).

To account for this regional variation in fish species composition, we compiled and analyzed predatory fish species occurrence data from monthly fishery surveys conducted as part of the CDFW Bay Studies over the period from 1980 through 2008. We assessed the relative abundance of various fish species collected in the otter trawl (sampling near the bottom) and midwater trawl (sampling in the water column) for sampling stations located in Central San Francisco Bay, San Pablo Bay, and Suisun Bay. We included in our analysis the most abundant predatory fish in each of the regions. Data were compiled based on the densities (number per 10,000 m^2) from the CDFW Bay Study otter trawl results to develop a monthly composite predator index (sum of the densities of the selected predatory fish separated for each of the three regions of the estuary). Fish species included in the monthly predator index were:

Central Bay

- Bay goby
- English sole
- Pacific staghorn sculpin
- Speckled sanddab

San Pablo Bay

- Bay goby
- English sole
- Pacific staghorn sculpin
- Plainfin midshipman
- Specked sanddab

Suisun Bay

- Channel catfish
- Pacific staghorn sculpin
- Starry flounder
- Striped bass
- White catfish
- Yellowfin goby

The data analysis used the monthly composite density for the selected group of predatory fish over the period from 1980 to 2008. For those months when CDFW did not complete fish sampling (e.g., as a result of boat or equipment failure, bad weather, etc.; Tables 2 and 3) a predation index was estimated for the missing month as the average predator density in the region during the prior and subsequent months (Maunder and Deriso 2003). The composite index of predator densities assumes longfin smelt would have a greater risk of predation when they co-occur in time and space with a higher density of potential predators.

We developed an additional index of potential predation mortality to larval longfin smelt based on the average monthly catch-per-unit-effort of juvenile Chinook salmon within Suisun Bay in the USFWS midwater trawl sampling at Chipps Island. Data on juvenile salmon catches were compiled for the period from 1980 through 2008. The longfin smelt conceptual model (Figure 4) identified as a potential source of predation mortality on larval and early juvenile smelt lifestages in the lower Sacramento and San Joaquin rivers and Suisun Bay during the late winter and spring months by juvenile Chinook salmon outmigrating when longfin smelt larvae are present in the Delta (Rosenfield and Baxter 2007, Rosenfield 2010). Larval longfin smelt and juvenile Chinook salmon co-occur in time and space within the lower rivers, Delta, and Suisun Bay during the late winter and spring (CDFW larval smelt survey data, CDFW 20mm smelt survey data, USFWS Chipps Island juvenile salmon survey data). It has been hypothesized that the tens of millions of juvenile salmon emigrating through the Delta at that time of year would prey on larval and early juvenile longfin smelt. The average monthly catch of juvenile salmon each year in trawling by USFWS at Chipps Island was used as a covariate in the lifecycle model analysis to assess the potential relationship between juvenile salmon abundance and the population dynamics of longfin smelt. We assumed that the risk of predation on larval smelt would increase when the index of juvenile salmon abundance in Suisun Bay increased. The predation covariates included in the initial statistical analyses are summarized in Table 4. The actual risk of predation mortality for larval longfin smelt by juvenile salmon is unknown.

Alternative Prey

It was hypothesized that the vulnerability of juvenile and adult longfin smelt to predation mortality would vary in response to the availability of alternative prey for smelt predators. For example, if the abundance of northern anchovy in Central San Francisco Bay is high, predators may be more likely to prey on anchovy than on longfin smelt. In contrast, when the abundance of alternative prey is reduced, the risk of predation mortality for longfin smelt would be expected to increase. For the purpose of evaluating the potential importance of alternative prey abundance as part of the longfin smelt lifecycle model covariate analysis, data from the CDFW Bay Study midwater trawl surveys were used to develop a metric of monthly alternative prey densities (number per 10,000 m^3). Northern anchovy from Central San Francisco Bay were selected as a potential alternative prey based upon their abundance in that region. The monthly average density of northern anchovy collected at central bay stations in the CDFW midwater trawl was used to represent the availability of alternative prey in the covariate analysis.

Prey Resources (food availability)

Larval, juvenile, and adult longfin smelt forage exclusively on zooplankton, including mysid shrimp, and the copepods *Eurytemora* and *Pseudodiaptomus.* CDFW has conducted a zooplankton survey program in the estuary since 1972. The monitoring program samples at 17 fixed locations (Figure 12) and 2 locations that vary based on the location of the low salinity zone (electrical conductivities of 2 and 6 psu). In high flow periods, 3 additional sampling stations located in the Carquinez Straight and San Pablo Bay are included in the monitoring program to assess abundance and species composition of zooplankton that may have been transported further downstream by high Delta outflows. Zooplankton sampling locations and sampling dates, however, are not synoptic with delta smelt sampling and therefore the analyses required estimating zooplankton density indices used in these analyses were derived using the average density of a taxa for several sampling stations within a regional area of the estuary that corresponded to the sub-regions used in estimating longfin smelt abundance (Figure 6). In addition to providing information on seasonal and geographic distribution of native zooplankton species, the monitoring program also detects and monitors the species composition and abundance of non-native introduced zooplankton. Zooplankton sampling targets various species and sizes of invertebrates by sampling using three types of survey methods that include (1) a pump sampling for microzooplankton less than 1 mm long such as rotifers, copepod nauplii, and other small species, (2) a modified Clarke-Bumpus net that samples zooplankton approximately 0.5 to 3 mm including caladocerans and copepods, and (3) a macrozooplankton net that samples zooplankton 1 to 20 mm including mysid shrimp. Data on the species-specific densities of zooplankton are available from the surveys which are used to estimate zooplankton abundance for various regions of the estuary by multiplying the average density for each taxa at several sampling locations within each region of the estuary sampled by the estimated water volume within the sampling region. A second index of zooplankton abundance was derived based on the density of each zooplankton taxa and associated regional water volume but was limited to only those survey dates and locations where longfin smelt were also collected (an index of the co-occurrence of zooplankton and longfin smelt). Sensitivity analyses were conducted comparing the two alternative approaches to developing zooplankton abundance indices against process error in the model version with age 2 and ages 1 and 2 longfin smelt spawners. Results of the analyses showed high correlations between the two approaches for different zooplankton taxa (mysids, *Eurytemora*, and *Pseudodiaptomus*) utilizing various combinations of months used in the lifecycle model development. Based on the similarities in results using these two alternative indices, the index approach based on zooplankton abundance weighted by the occurrence of longfin smelt in each geographic region was used in the covariate analyses for each of the zooplankton taxa.

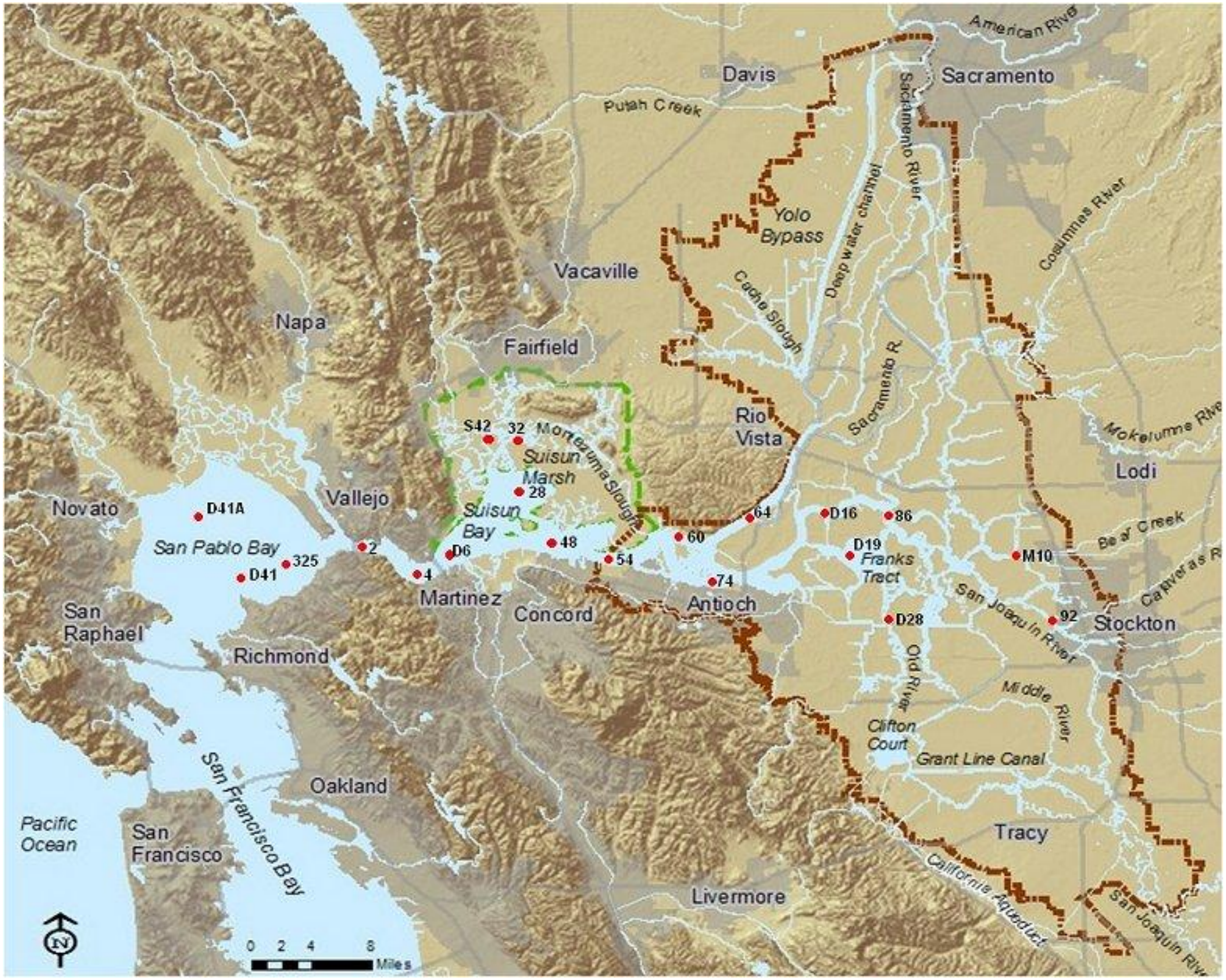


Figure 12. CDFW zooplankton sampling stations.

Mysid Shrimp

Mysids are an important prey species for larger juvenile longfin smelt later in their first year as well as for pre-spawning and adult longfin smelt. Slater (2009) analyzed the stomach content of longfin smelt and concluded that as longfin smelt increased in length they foraged on larger zooplankton and that mysids dominated the selected prey during the summer months. Estimates of mysid densities are available from the CDFW monthly zooplankton surveys which show a substantial decline in abundance coincident with the invasion of the estuary by the non-native invasive overbite clam, *Potamocorbula amurensis*, in the late 1980s. The overbite clam is a filter feeder that has established very high densities in Suisun Bay and elsewhere in the estuary, and serves as a competitor to longfin smelt by reducing mysid densities. Based on these observations mysid densities were included as an environmental covariate in the initial screening and statistical analyses conducted as part of the longfin smelt lifecycle model development (Table 4).

The mysid covariate was specified for two periods each year, May-June and July-September, to bound the summer period when, according to Slater (2009), mysids are most important in the diet of longfin smelt. For each period, mysid densities in sub-regions of the San Francisco Bay and Delta were weighted by the fraction of the total longfin population in each sub-region to produce estimates of the average mysid density encountered by longfin smelt. Density data from the CDFW zooplankton surveys were first corrected for gear efficiency using factors developed by Kimmerer for delta smelt for his paper on proportional entrainment (Kimmerer 2008) and obtained by request (Wim Kimmerer, San Francisco State Univ., pers. comm.). Fractions of the mysid population in each sub-region of the estuary were estimated as a function of the fraction of relative abundance of longfin smelt in each sub-region. Relative abundance was estimated as the average density of mysids in each sub-region, weighted by the volume of water in the sub-region. Water volumes were estimated from NOAA navigation maps for the San Francisco Bay region.

Eurytemora

Eurytemora are an important prey species for early juvenile life stage longfin smelt. Slater (2009) analyzed stomach content of longfin smelt and concluded that juvenile longfin smelt relied heavily upon *Eurytemora affinis* as a food resource during the spring months. Estimates of the density of *Eurytemora* are available from the CDFW monthly zooplankton surveys that show a substantial decline in copepod abundance coincident with the invasion of the estuary by the non-native invasive overbite clam, *Potamocorbula amurensis*, in the late 1980s. Monthly densities of *Eurytemora* at each sampling station were segregated into sub-regions of the estuary, and the average density was estimated for each sub-region and month. These averages were weighted with the fraction of the total longfin smelt population observed in each sub-region, to produce an estimate of *Eurytemora* encountered by longfin smelt, as described above for mysids.

Pseudodiaptomus

Slater (2009) analyzed stomach content of longfin smelt and concluded that *Pseudodiaptomus* were somewhat important in the diet of longfin smelt. Estimates of the density of *Pseudodiaptomus* are available from the monthly CDFW zooplankton surveys (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=ZOOPLANKTON). Monthly zooplankton survey stations were segregated into sub-regions of the estuary, and the average density of *Pseudodiaptomus* was estimated for each sub-region and month. These averages were weighted with the fraction of the total longfin smelt population observed in each sub-region, to produce an estimate of *Pseudodiaptomus* encountered by longfin smelt, as described above for mysids.

Risk of Entrainment/Geographic Distribution and Transport (mortality)

Longfin smelt are believed to spawn in the lower reaches of the Sacramento and San Joaquin rivers, although the longfin smelt lifecycle model and field collections described in Appendix A will also be used to test the alternative hypothesis that longfin smelt spawning is dispersed throughout local tributaries into the estuary. Adult longfin smelt migrate upstream prior to spawning through the Delta and river channels, and the planktonic larvae are believed to be transported by freshwater flows and tidal currents downstream to juvenile rearing areas located in the western Delta and Suisun Bay (Moyle 2002, Rosenfield 2010). During their movement through the interior Delta, longfin smelt may be exposed to currents affected by tidal exchange, river flows, and exports from the SWP/CVP south Delta pumping facilities (CDFG 2009). The magnitude of reverse flows in Old and Middle rivers (OMR) is a measure of flow through interior Delta channels toward the state and federal export pumps (CDFG 2009). OMR flow is affected by exports and inflow from the San Joaquin River. According to CDFG (2009), when exports are relatively high and inflow from the San Joaquin River is relatively low, flow in Old and Middle rivers can be upstream (negative, that is, south), toward the export pumps. According to CDFG (2009), OMR flow is a measure of the potential to guide or transport longfin smelt toward the export pumps and is one measure of entrainment risk on longfin smelt at the state and federal export pumps. As a result, the lifecycle model included OMR flow as an environmental covariate. Daily average OMR data were obtained from USGS (http://waterdata.usgs.gov/ca/nwis/feedback/?to=California%20Water%20Data%20Inquiries). Daily values were averaged over January-March, the period when entrainment of longfin smelt is most likely, and included as an environmental covariate in the lifecycle model data analyses.

Water Quality (habitat)

The quality and availability of suitable habitat conditions for various life stages of longfin smelt is influenced by a number of what have been characterized as "abiotic" environmental factors (Rosenfield and Baxter 2007, Rosenfield 2010, CDFG 2009). Among the factors hypothesized to affect the geographic distribution of longfin smelt is the turbidity of water / the visibility of the species to predators. Other similar pelagic fish species, such as delta smelt, have shown a behavioral preference for habitats characterized by increased turbidity. It has been hypothesized that longfin smelt may show a similar behavior. Secchi depth is one indicator of the turbidity or visibility of water. Exposure to seasonally elevated water temperatures has also been identified as a factor affecting the seasonal and geographic distribution of longfin smelt.

Secchi Depth

The effect of turbidity (i.e., low water clarity and visibility) on longfin smelt geographic distribution or habitat preferences is unknown. Based on examination of data from current fishery monitoring studies it has been hypothesized that juvenile and adult longfin smelt undergo a diel (daily) vertical migration in the water column being close to the bottom in deeper water during the day and migrating toward the surface at night. Survey data suggest that the effect is magnified as transparency increases (Figure 13). A similar vertical migration pattern between longfin smelt and their prey has been observed in Lake Washington (Quinn *et al.* 2012).

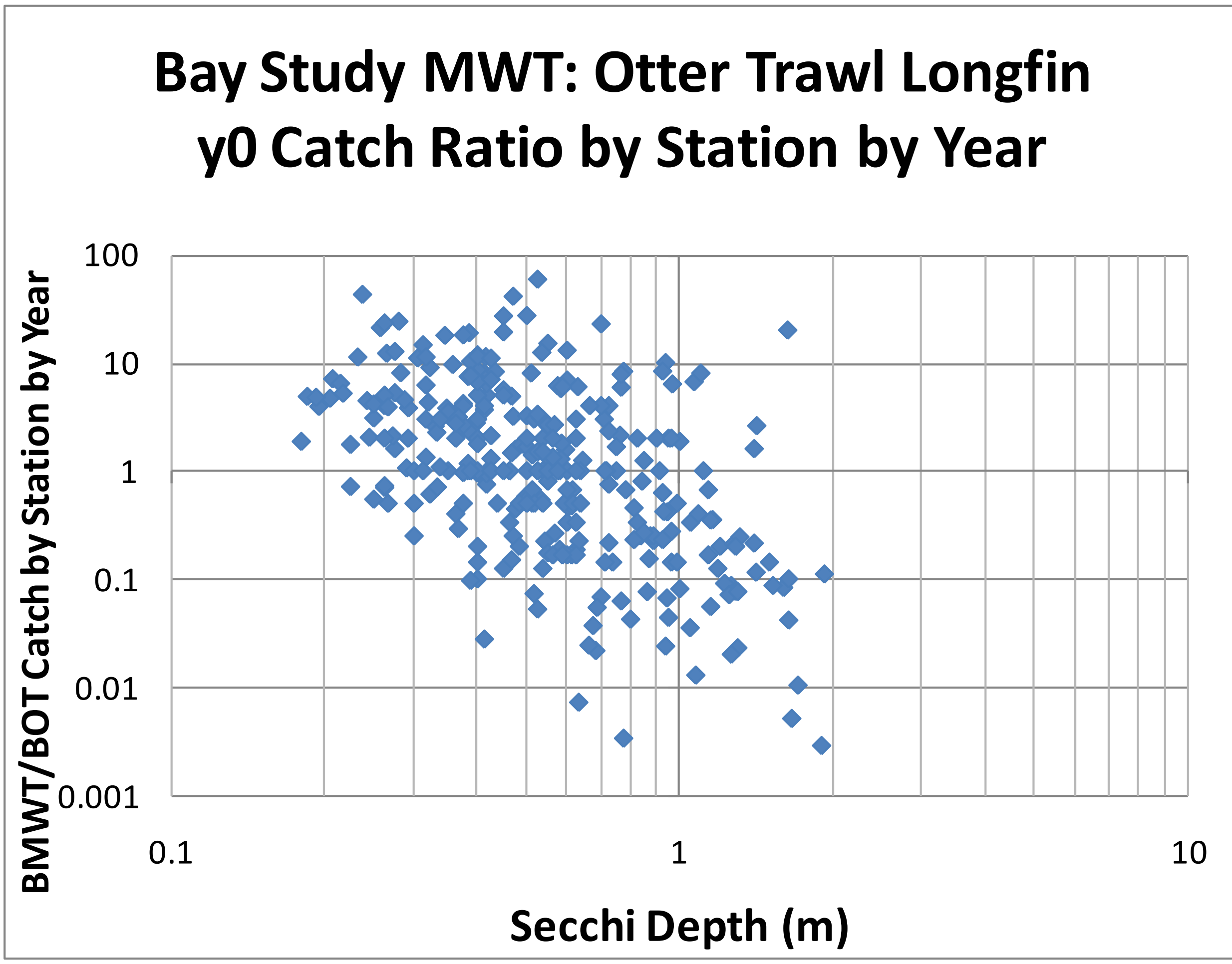


Figure 13. Bay Study MWT and otter trawl longfin Y_0 catch ratio as a function of turbidity (Secchi depth).

One hypothesis to explain this apparent behavior is that longfin smelt are mirroring the vertical distribution of mysid shrimp, an important prey resource for longfin smelt. An alternative hypothesis is that longfin smelt preferentially select locations in the water column where light levels are low (*e.g.*, near the bottom during the day and moving up into the water column at night as light levels decrease but also moving higher in the water column during the day in areas where turbidity levels are high) perhaps in order to reduce the risk of predation. If many more longfin smelt are caught at night than during the day, this would be evidence either of gear avoidance or of vertical migration.

Secchi depth is routinely measured in all CDFW fishery surveys. Manly (2009) reported that longfin smelt are rarely found in water with Secchi depth greater than 55 to 60 cm (11-12 NTU turbidity), presumably because turbid water provides protection for the species from visual predators. The relationship between longfin smelt young-of-the-year collections in the Bay Study otter trawl and mid water trawl sampling as a function of Secchi depth is shown in Figure 13. Efforts are currently underway to further evaluate the effects of turbidity on potential sampling bias for longfin smelt (see Appendix A) and how variation in turbidity may have effected fishery survey results and associated indices of longfin smelt distribution and abundance (Fullerton presentation at the April 2013 IEP annual conference). Baskerville-Bridges *et al.* (2004) report that at low turbidity, even in the presence of adequate prey density, delta smelt feeding success is limited. Lindberg (Joan Lindberg, University of California, Davis, pers. comm.) suggests that the feeding success of larval longfin smelt is similarly affected, given the similarity of the two species.

We prepared covariates for Secchi depth for use in the life cycle model. We prepared different covariates for the periods April-June and August-September. The earlier period is intended to capture effects on longfin smelt feeding success. The later period is intended to represent more general effects on longfin smelt, such as the availability of turbidity to provide cover from predators. Secchi depth data were compiled for eight routine surveys, namely, the Environmental Monitoring Program, Fall Midwater Trawl, Summer Townet Survey, Suisun Marsh Fisheries Monitoring, Monthly Zooplankton Survey, 20 mm Survey, Kodiak Trawl, and Bay Study, comprising approximately 80,000 samples. These turbidity data were averaged by month and sub-region. Averages for turbidity levels for the two periods, April-June and August-September, were estimated as the average Secchi depth encountered by longfin smelt. These calculations are equivalent to those described for mysids. It should be noted that there is uncertainty in the underlying causal mechanism between turbidity (Secchi depth) and the interpretation of longfin smelt catches in the CDFW fishery sampling (e.g., Secchi depth affects longfin smelt survival and abundance through predator interactions or the effectiveness of the fishery sampling gear varies in response to Secchi depth through gear avoidance). As a result of these uncertainties caution should be given to the interpretation of the interaction between longfin smelt and water turbidity and Secchi depth.

Water temperature

Like Secchi depth, surface water temperature has been routinely measured in all ongoing CDFW fishery surveys. We used Bay Study water temperature data measured in association with both the MWT and otter trawl sampling efforts to represent temperature as an environmental covariate. We utilized the Bay Study data because that study covers the entire area occupied by longfin smelt landward of the Golden Gate. Longfin smelt are rarely collected at locations where water temperatures are greater than approximately 22 C in September, with this maximum level declining to approximately 15 C in December (Manly 2009). Furthermore, water temperature affects longfin smelt metabolic rates and can, therefore, affect feeding success, fish and prey movement, and abundance and species composition seasonally within various regions of the estuary. We segregated Bay Study sampling stations, and associated water temperature measurements, into six sub-regions, South Bay (Stations 101-108), Central Bay (Stations 109-244), San Pablo Bay (Stations 317-346), Carquinez Strait (Stations 427 and 447), Suisun Bay (Stations 428-535), and the Delta (Stations 736 and 837). The environmental covariates used in the initial statistical analyses were based on the average surface temperatures measured at each sampling station for both the midwater trawl and otter trawl collections each month. The resulting calculations were then averaged over the sampling stations representing each of the six sub-regions of the estuary.

Contaminants: Ammonium Concentration (toxicity and inhibition of algal growth)

Ammonium has been found to inhibit the production of desirable phytoplankton in both laboratory studies and in the Bay-Delta estuary, with inhibition beginning at approximately 0.015 mg/L and increasing to maximum effect at 0.056 mg/L (4 µmoles/L; Dugdale *et al.* 2007). Phytoplankton serves as an important food resource for the production of copepods and mysids that are important food resources for longfin smelt. Lower densities of these phytoplankton as a result of inhibition by ammonium exposure, in turn, results in lower densities of the zooplankton that longfin smelt prey upon. Manly (2012) reported correlations between ammonium concentrations and centric diatoms, the dominant phytoplankton group, when longfin smelt and other pelagic fish were abundant prior to the invasion of the non-native invasive overbite clam, *Potamocorbula amurensis*, in the late 1980s. Manly (2012) also reported negative correlations between ammonium concentrations and densities of *Eurytemora*.

As noted above, longfin smelt abundance indices have shown evidence of a declining trend in abundance over the past two decades. It has been hypothesized that the observed decline in longfin smelt abundance is affected indirectly by increasing loads of ammonia to the estuary associated with urban growth in the watershed and waste water treatment plant discharges. The increased ammonia loading to the estuary is thought to have exceeded thresholds that now inhibit phytoplankton production and blooms that historically supported the production of high densities of zooplankton foraged on by longfin smelt (Dugdale *et al.* 2007, Glibert 2010).

For example, ammonia loading from the Sacramento County Regional Sanitation District wastewater treatment plant has shown an increasing trend over time (Figure 14). This hypothesis does not require that ammonia directly affect longfin smelt. Ammonia has been hypothesized to adversely affect longfin smelt by inhibiting phytoplankton production, and an associated reduction in zooplankton production that serves as the prey base for the longfin smelt population (Dugdale *et al.* 2007, Glibert 2010). Mongan and Miller (2011) reported that this hypothesis is supported by the correlation between indices of longfin abundance and the ratio of ammonia loading from Sacramento County Regional Sanitation District wastewater treatment plant/Sacramento River inflow shown in Figure 15. The ratio (ammonia load)/(Sacramento River flow), or average January-June ammonium concentration, accounts for 20% ($r^2 = 0.57$ minus $r^2 = 0.37$) more of the variation in the trend observed in indices of annual abundance of longfin smelt than the location of the low salinity zone during the spring (X2 location). Based on results of these analyses several environmental covariates were derived for ammonia concentrations and loading to the estuary for inclusion in the initial lifecycle model statistical analyses (Table 4).

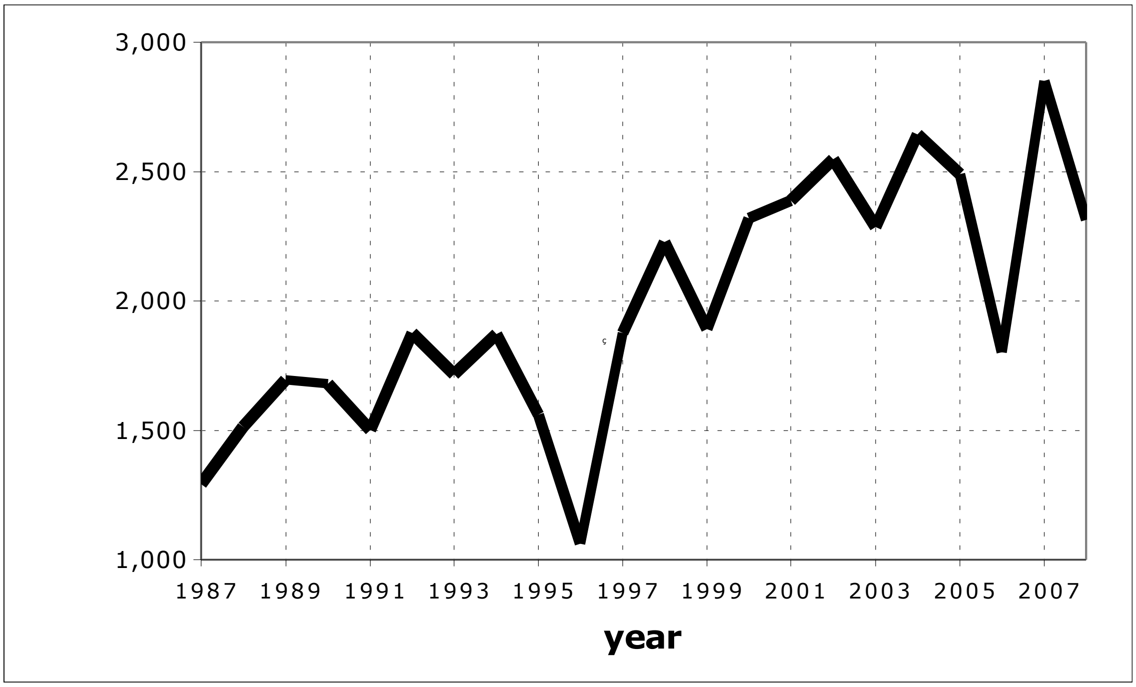


Figure 14. January-June ammonia loading to the Sacramento River from Sacramento Regional County Sanitation District waste water treatment plant discharge (Source: Mongan and Miller 2011).

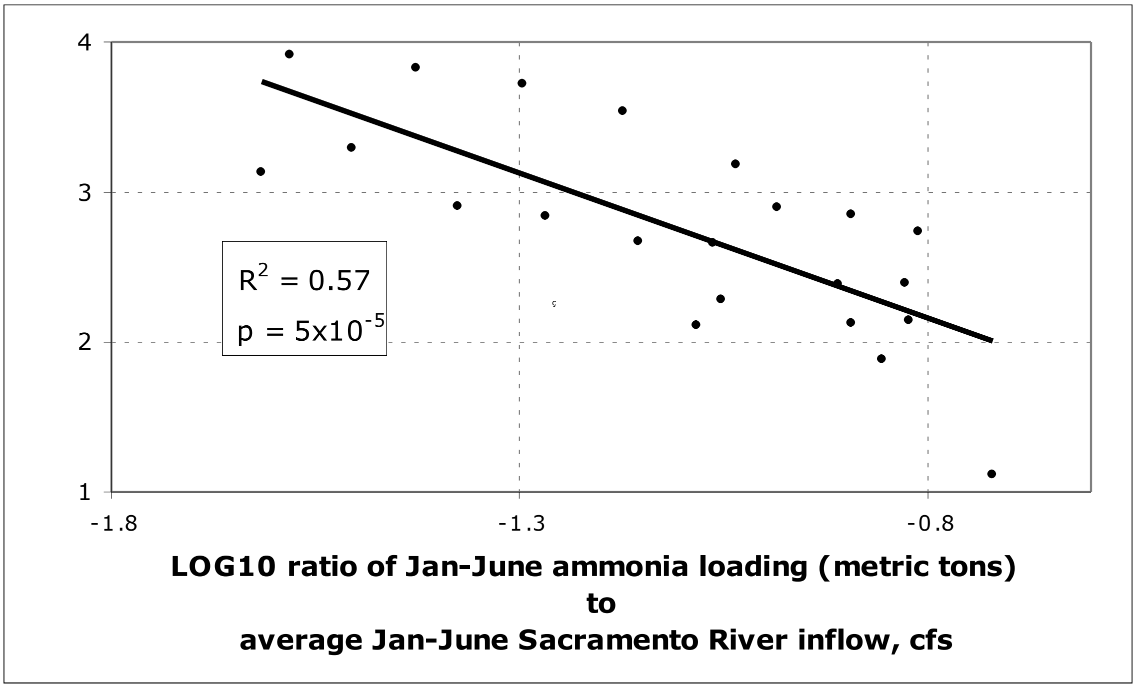


Figure 15. LOG10 longfin abundance (Fall Midwater Trawl index) vs. LOG 10 ((Jan-June ammonia load from Sacramento County Regional Sanitation District)/(Jan-June average Sacramento River flow). Source: Mongan and Miller 2011.

Data on ammonium concentrations were obtained from the Environmental Monitoring Program (General EMP information and data requests: Karen Gehrts, (916) 375-4825) and the USGS San Francisco Bay Water Quality monitoring program (http://sfbay.wr.usgs.gov/access/wqdata/query/index.html). Stations from both monitoring programs were grouped by major embayment, Central Bay, San Pablo Bay, and Suisun Bay. Data were then averaged by month and embayment. Embayment averages were weighted by the volume of water in each embayment to estimate average ammonium over all three embayments. We used this average ammonium calculation as an environmental covariate in the longfin smelt lifecycle model development. The environmental covariates we used in the statistical analyses included area weighted ammonium concentration, ammonium concentrations in Central Bay, ammonium concentrations in San Pablo Bay, and ammonium concentration in Suisun Bay (Table 4). The ratio of ammonia loading to Sacramento River flow (an indicator of freshwater dilution) based on data from the Sacramento County Regional Sanitation District waste water treatment plant discharge to the Sacramento River was also used as an environmental covariate in the initial statistical analyses.

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Appendix A

Field, Laboratory, and Data Analyses to Investigate the Distribution and Abundance of Longfin Smelt in the San-Francisco Estuary

Final Study Plan

January 6, 2014

Field, laboratory, and data analyses to investigate the distribution and abundance of Longfin Smelt in the San-Francisco Estuary

Final Study Plan
January 6, 2014

Principal Investigators: Jim Hobbs (UCD), Dave Fullerton (SWC) and Chuck Hanson (Hanson Environmental, Inc.), Bob Fujimura (DFW)

Collaborators: Ted Sommer and Louise Conrad (DWR); Randy Baxter (DFW).

Background

The State Water Contractors (SWC), the California Department of Fish and Wildlife (CDFW), and collaborators have identified a suite of studies that would expand our current understanding of Longfin Smelt distribution, abundance, abundance trends, spawning location(s), and the relationship between Delta outflow and Longfin Smelt abundance (e.g. Kimmerer 2002).

This document serves as an overview of the range of proposed studies to be conducted by UC Davis researchers and other contractors to address new observations and data analyses regarding the population biology of Longfin Smelt in the San Francisco Estuary, and how it may pertain to current management of the species. A conceptual model for our current understanding of Longfin Smelt biology and life cycle in the San Francisco Estuary is presented. As a result of recent observations and data analyses pertaining to the conceptual model, eight study questions were derived to further explore these new observations. This study plan describes the approach for addressing each of these 8 study questions during an initial pilot year of research. After initial pilot field studies and analyses are conducted, the study questions will be refined with newly gained knowledge. Field research is planned for 6 of the 8 study questions for up to five years, while follow-up field research to address the final two study questions may be conducted if deemed worthwhile by the Longfin Smelt Technical Team (described below), and if the studies are feasible given resources of the Interagency Ecological Program (IEP). The array of study elements included in these investigations may increase or be refined based on subsequent collaborative discussions with various experts. Towards that end, we propose the formation of a new IEP Project Work Team (PWT) to help guide the study in coordination with the Longfin Smelt Technical Team. The IEP PWT will provide a collaborative basis for reviewing and obtaining feedback from the broader scientific community about study plans and results of analyses from these and other investigations, and assist in identifying further areas of investigation and refining the study design of this research in future years. The Longfin Smelt Technical Team will work collaboratively with the IEP PWT to determine project direction and implement and coordinate the suite of studies. As additional necessary investigations are identified (e.g., for the final two study questions posed in this study plan), detailed study plans (*e.g.*, experimental design, specific methods, staffing, resource needs, logistics and coordination with other studies and CDFW monitoring activities) will be distributed for IEP review.

Problem statement

Two IEP surveys identify different Longfin Smelt distribution and abundance patterns based on different sampling methods. Since the mid-1980s, data from the Fall Midwater Trawl (FMWT, which samples the upper 35-40 ft of the water column) suggest severe declines in species abundance (MacNally et al. 2010), while data from the San Francisco Bay Study otter trawl (which only samples the bottom meter of the water column) suggest only moderate declines in species abundance. With respect to distribution, the FMWT data since the mid-1980s indicates that the population geographic distribution is much more heavily weighted toward Suisun Bay and the Delta while the otter trawl indicates that the Longfin Smelt population is more centralized in the San Francisco Bay below Carquinez Strait (Rosenfield and Baxter 2007; CDFW unpublished data). The ability of the FMWT and otter trawl surveys to accurately characterize species density and distribution may be influenced by several factors, including environmental variables such as turbidity, survey station depth, and the behavior of the fish (e.g., diel movements of Longfin Smelt).

Furthermore, preliminary results from exploratory surveys conducted as part of other monitoring programs have shown evidence that Longfin Smelt use tributaries to northern, central, and south Bay as spawning habitat; however, the frequency (e.g. wet vs dry years) and magnitude of the contribution of tributary spawning to adult abundance and year class strength is currently unknown, as these areas are not included in routine monitoring work. Evidence of successful spawning by Longfin Smelt has been reported as part of expanded 20 mm smelt surveys in the lower Napa River as well as observations of pre-spawning adult Longfin Smelt associated with South Bay Salt Pond restoration monitoring (Hobbs *et al*. 2012). Moreover, Longfin Smelt likely use ocean habitat for rearing during a portion of their life cycle (Rosenfield and Baxter (2007), but the timing and magnitude of offshore use is very poorly understood.

As recently described by Cowin and Bonham (2013), a more complete understanding of the geographic extent of the population at each life stage and how various factors may influence monitoring results is needed to inform more effective management and protection of the species, including habitat restoration and water project operations. In a broad context, this understanding is critically important to management for activities under the Ecosystem Restoration Program, and design and implementation of the Bay Delta Conservation Plan.

In this study plan, we develop a series of special studies, designed to enhance our understanding of (a) distribution of Longfin Smelt reproduction and relative contribution of geographic areas used for spawning to overall abundance; (b) the influence of environmental factors, such as hydrology, on the distribution of reproduction; and (c) the influence of time of day, water transparency, or tidal fluctuation on catch of Longfin Smelt in various IEP surveys.

Objectives

The overarching goal of this new set of proposed Longfin Smelt studies is to provide additional information about Longfin Smelt that is expected to improve management and protection of this species in the San Francisco Estuary. Generally, these studies aim to enhance our knowledge of the life history and ecology of Longfin Smelt and to refine our understanding of the drivers of population distribution, and abundance, including the relationship between freshwater outflow and the abundance of Longfin Smelt. We separate our specific study objectives into two broad categories: (1) Longfin Smelt distribution and regional contribution to overall abundance; and (2) Longfin Smelt vertical migration behavior.

The first general goal (detailed by Objectives 1 – 4, below) is to investigate Longfin Smelt distribution and quantify the relative contribution of geographic areas used for spawning to overall population abundance. Since most Bay tributaries are not sampled by current long-term surveys, a key question is to determine if Longfin Smelt spawn and recruit in Bay tributaries; and if so, whether they do so in appreciable numbers to have an effect on overall species abundance. Sampling of tributaries to San Francisco and San Pablo Bays (Bay tributaries) not previously monitored by IEP-DFW for adult and larval stages of Longfin Smelt will thus enhance our knowledge of the distribution of the species. Furthermore, analysis of otolith geochemical signatures from Bay tributary fish and fish collected by DFW abundance index surveys will provide for an assessment of the contribution of different geographical areas and salinity zones to the recruited juvenile and adult populations. Conducting this research during both wet and dry years will allow us to understand how freshwater inflow into and outflow from the estuary and its tributaries may influence tributary use and the contribution of Bay tributary spawning to the population abundance index.

In addition to improving our understanding of Longfin Smelt distribution in the Estuary, a second overall objective of this work (detailed in Objectives #5-7) is to evaluate movements of Longfin Smelt in the water column with respect to changes in environmental conditions (e.g. diel and tidal cycles, turbidity, seasons, regions). Conducting research on the effects of environmental conditions (e.g., diel and tidal variation, turbidity, seasonal changes) should improve our understanding and interpretation of monitoring survey results from the FMWT and Bay Study.

Specifically, the proposed study's primary objectives are as follows:

Longfin Smelt distribution and regional contribution to overall abundance:

1. Quantify the relative abundance of early life stages and adult Longfin Smelt in Bay tributaries (e.g. Napa River, Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek) during the spawning and rearing seasons occurring during wet and dry years.
2. Determine if geochemical signatures of Bay tributaries vary to the extent that otolith geochemistry could be used to determine the relative contribution of Bay tributaries to recruited juvenile and adult fish collected in IEP-DFW surveys in the San Francisco Bay.

3. Determine the extent to which initial rearing in different salinity zones and geographic areas contribute to the Longfin Smelt population and compare these contributions between wet and dry years.

4. Determine if geochemical signatures of the ocean environment can inform the extent to which Longfin Smelt use the near-shore ocean environment using otolith geochemical signatures.

Longfin Smelt vertical migration behavior

5. Determine the extent to which Longfin Smelt exhibit regular vertical movements within the water column during the day-night cycle, and whether these behaviors vary among different regions of the estuary or seasonally.

6. Determine the relationship between water transparency and the Longfin Smelt catch in the Bay Study MWT and otter trawl surveys.

7. Determine whether changes may be needed in current Longfin Smelt survey index calculation methods, and whether the new information provides better insight into the proper formulation of quantitative population estimates.

Conceptual model

The current conceptual model of the Longfin Smelt basic population biology and potential factors associated with their decline in abundance is presented in Figure A. A much more detailed conceptual model is available in Rosenfield (2010). Key aspects of the life history relevant to the proposed investigation are described below along with new analyses of existing data and new surveys being conducted by DFW and UCD.

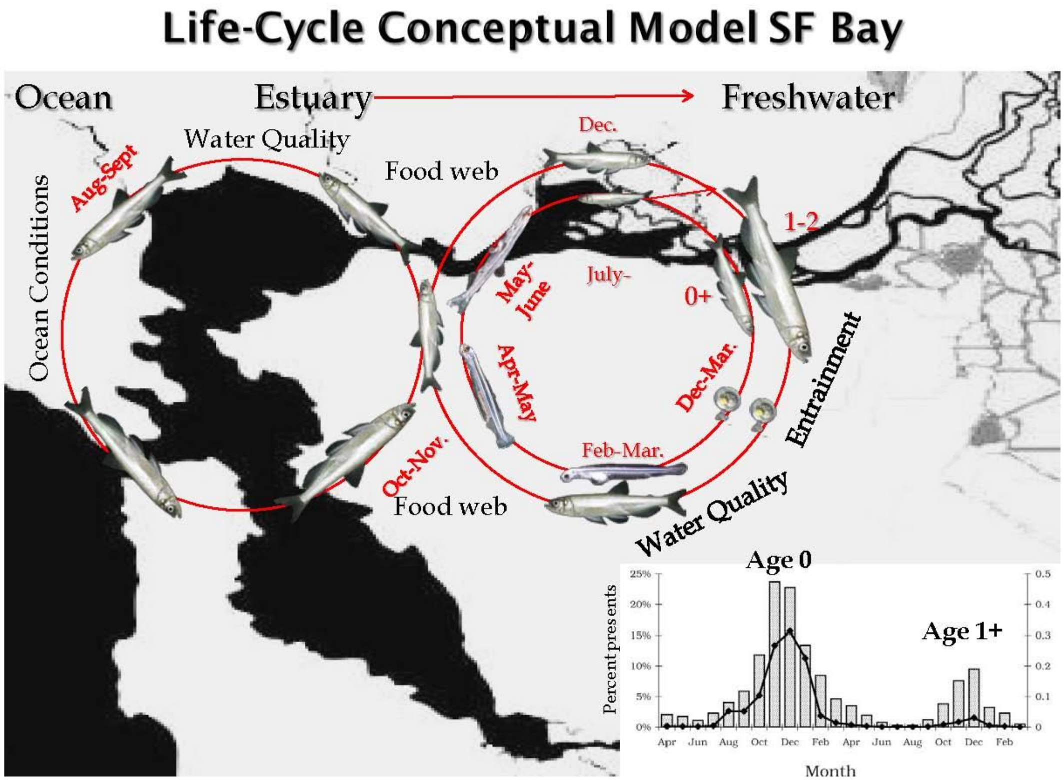

Figure A. Life cycle conceptual model of SF Bay with spawning only occurring in Suisun Bay and the Delta.

General life-cycle

Longfin Smelt have been found to utilize a variety of habitats including, freshwater, low-salinity, brackish and near shore ocean habitats throughout their 2-3 year life-cycle. Larvae occur in freshwater to brackish habitats, whereas juveniles and sub-adults can be found throughout San Francisco Bay including nearshore marine areas with salinities greater than 30-ppt. It appears that juvenile and adult Longfin Smelt are sensitive to warmer water conditions in the late summer-early fall, either residing in deep, cool, bay channel habitats or, marine habitats, potentially outside San Francisco Bay in the fall (Rosenfield and Baxter 2007). There also appears to be a movement to the ocean during the second summer (1+ year olds) of life; however, the frequency and magnitude of the contribution of ocean rearing or ocean conditions to the adult population is unknown. Our current knowledge regarding spawning habitat is based on observations of increased catch in DFW surveys and a spawning run of adults observed in the Delta near the confluence of the Sacramento and San Joaquin rivers starting around December (Rosenfield and Baxter 2007). Spawning is known to occur in freshwaters upstream of the confluence of the Sacramento and San Joaquin rivers; however, recent evidence suggests that some Longfin Smelt may utilize low-salinity habitats and other Bay tributaries to spawn, particularly during wet years. Significant numbers of Longfin Smelt post-larvae have been observed in the IEP-DFW 20-mm Survey in the Napa River. Moreover, salt pond restoration monitoring in lower South SF Bay has observed a high frequency of occurrence of adult Longfin Smelt and mysid shrimp, that migrate into the restoration area in late fall and remain there during the spawning season, including ripe fish(Hobbs *et al* 2012), (Figure B).

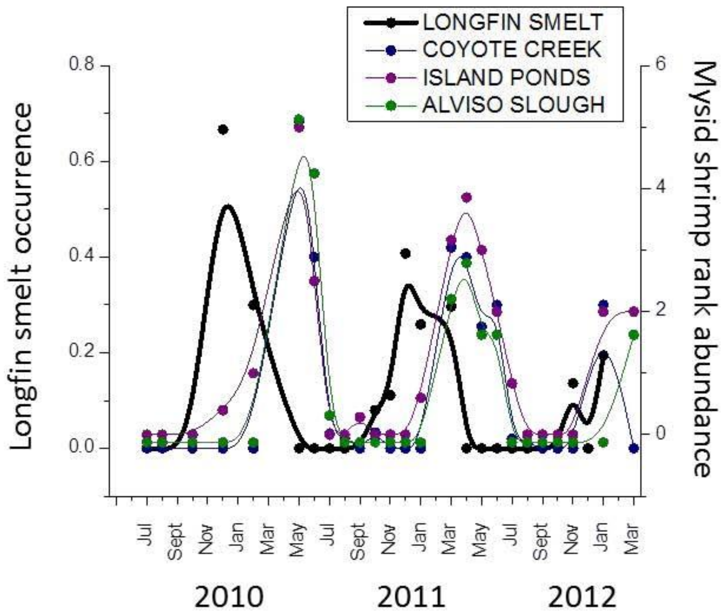

Figure B. Left; Longfin Smelt (black dots and line, frequency of occurrence among 12-15 monthly otter trawls conducted over three years in Lower South Bay) and the ranked abundance of mysid shrimp (colored dots and lines). Right; 3 year classes of Longfin Smelt collected with a restoration pond on Coyote Creek. Note the top fish was in reproductive condition. (*n* = 229 individuals for 42 trawls up through spring of 2012)

Reproductive biology of Longfin Smelt: comparison between Lake Washington and Bay-Delta populations

Longfin Smelt, an important forage fish to larger piscivorous fishes, is distributed from San Francisco Bay to Alaska (Hart 1980). Information on the various aspects of the biology and ecology of the species has been documented based mainly on what is known about the populations in San Francisco Bay (e.g. Kimmerer 2002; Moyle 2002; CDFG 2009; see also review by Robinson and Greenfield 2011) and Lake Washington (Moulton 1970,1974; Dryfoos 1965; Traynor, 1973; Chigbu and Sibley 1994a,b, 1998a,b; Chigbu *et al*. 1998, Sibley and Chigbu 1994). Nevertheless, the two systems are different: the population in San Francisco Bay is anadromous whereas - the Lake Washington population is currently believed to be land-locked, but it connected to Puget Sound historically. This major difference may have important implications with regard to the life history and reproduction of the species.

Lake Washington and the associated tributaries in which Longfin Smelt spawn are freshwater (< 1 ppt) hence, the smelt eggs, larvae, juveniles and adults are not exposed to brackish water conditions. In contrast, smelt in the San Francisco Bay Delta system are believed to spawn in tidal freshwater environments (Robinson and Greenfield 2011). The larval stages are thereafter transported into brackish water areas where they are most abundant at low salinities (< 2 ppt), although they have been captured at higher salinities at relatively low numbers (Kimmerer 2002), perhaps because larval mortality increases with increasing salinity (Hobbs *et al*. 2010).

Information is scarce on the reproductive biology of Longfin Smelt, especially in the San Francisco Bay where the migratory and spawning behavior of the adults and characteristics of the microhabitats in which they spawn are unknown. In Lake Washington, Dryfoos (1965) and Moulton (1970, 1974) noted that Longfin Smelt mature and spawn after two years between January and May in tributaries (May Creek, Coal Creek, Juanita Creek, Cedar River) that flow into Lake Washington, although most spawning occurs in the Cedar River, the largest of the tributaries. Few, if any of the Longfin Smelt survive until the following year after spawning. In the San Francisco Estuary, adult Longfin Smelt may migrate short distances upstream into the lower tidal reaches of the Sacramento and San Joaquin rivers during the winter as water temperatures decline below 18 ^{o}C (mature smelt generally migrate upstream during December-February; CDFG 2009) and spawn in the late winter-early spring (December-March). In Lake Washington, spawning migrations and subsequent spawning takes place at night (Moulton 1974). Migration from Lake Washington into rivers and creeks to spawn occurs such that males precede the females in their peak migration times. Temperature during the spawning run of Lake Washington smelt is 5.6 to 6.7 $_{o}$C. In San Francisco Estuary it is higher and ranges from 7 – 14.5 $_{o}$C (Moyle 2002).

Longfin Smelt eggs are adhesive and tend to attach to the surface of any substrate with which they first come in contact soon after fertilization. In the Lake Washington tributaries, eggs were collected from a variety of substrates, but mostly at sites with some sand and a significant proportion of the eggs were attached to sand grains. A preliminary experiment conducted to evaluate spawning substrate preference in the San Francisco Estuary showed that Longfin Smelt preferred sandy to gravel substrates (Martz *et al*. 1996). Longfin Smelt eggs have not been collected in the Bay-Delta system. The egg development time of Longfin Smelt in Lake Washington varies depending on the temperature, ranging from 25 days (9.6-10.6 $_{o}$C, Moulton 1970 to and 40 days at 7 $_{o}$C (Dryfoos 1965).

Egg sampling in Lake Washington conducted in the Cedar River (Sibley and Brocksmith 1996; Martz *et al*. 1996) indicated egg presence up to 1200 m upstream from the river mouth, peaking at that 300 - 600 m. No eggs were collected above 1200 m from the river mouth. Water depths at which the highest densities of eggs were found did not exceed 1 m, and the water velocities were less than 0.6 m/s; usually between 0.3 and 0.55 m/s. There are many areas in the San Francisco Bay and its tributaries (e.g. Coyote Creek, Petaluma River, Napa River) with environmental characteristics similar to those in which Longfin Smelt are known to spawn in Lake Washington tributaries, but detailed systematic sampling has not been conducted to determine the extent to which Longfin Smelt utilize such areas to spawn. The Longfin Smelt in the San Francisco Bay may therefore not only be spawning at the boundaries of brackish and fresh water in deeper channels as has been previously hypothesized (see CDFG 2009; Robinson and Greenfield 2011), but may in fact be utilizing shallow brackish and freshwater tributary areas with flow and substrate characteristics similar to those described above for Lake Washington tributaries.

Observations suggesting that Longfin Smelt may also utilize Bay tributaries to spawn and rear include the following: (1) The San Francisco Bay Study (DFW) has observed post-larval stages in South San Francisco Bay during extreme wet years in the 1980s (Baxter *et al*. 1999); observing a length frequency trend that suggested Longfin Smelt successfully spawned in South Bay tributaries with smaller fish being found in lower South Bay (south of the Dumbarton Bridge), near Coyote Creek and larger fish in the mid (between the Dumbarton and San Mateo Bridges) and upper South Bay (north of the San Mateo Bridge) (R. Baxter, unpublished SF Bay Study data). (2) Recent monitoring studies of newly restored shallow salt pond habitats in lower South Bay have detected adult Longfin Smelt during the spawning season, even observing a few ripe individuals (Hobbs *et al* 2012). The relative contribution of Longfin Smelt spawning in these different geographical areas is unknown. However, studies by Hobbs *et al*. (2010) at least suggest that there may be differences in the relative contribution of different salinity zones (e.g. <1 ppt; 1-6 ppt; >6ppt).

The broad distribution of adult Longfin Smelt, further supporting the idea of highly dispersed spawning is illustrated by Merz *et al*., in review, Figure C. These spawning age adult Longfin Smelt are distributed up and down the Bay.

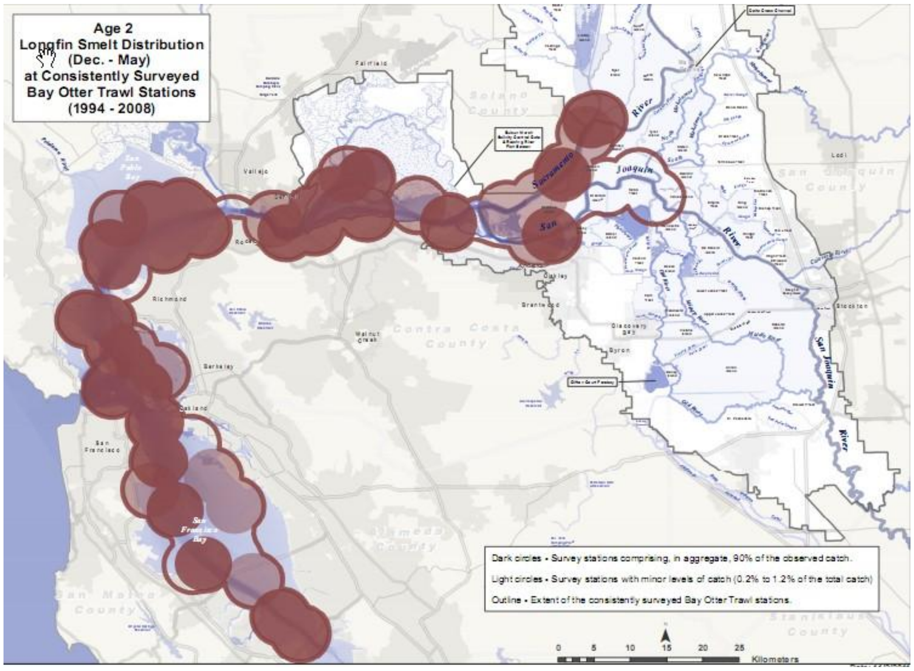

Figure C. Spawning age Longfin Smelt distribution (December-May).

Distribution of Longfin Smelt within the water column.

Longfin Smelt exhibit a daily vertical migration behavior in Lake Washington (Quinn *et al*. 2012; Figure D). Given this evidence from another population, we hypothesize that adult Longfin Smelt in the San Francisco Bay also engage in a daily vertical migration pattern. Evidence for this behavior in the San Francisco estuary has been observed in juvenile Longfin Smelt in Suisun Bay (Bennett el al. 2002); however, this phenomenon has not been investigated in existing IEP survey datasets, nor have directed field studies been carried out for adults.

Spatial and temporal patterns of vertical distribution

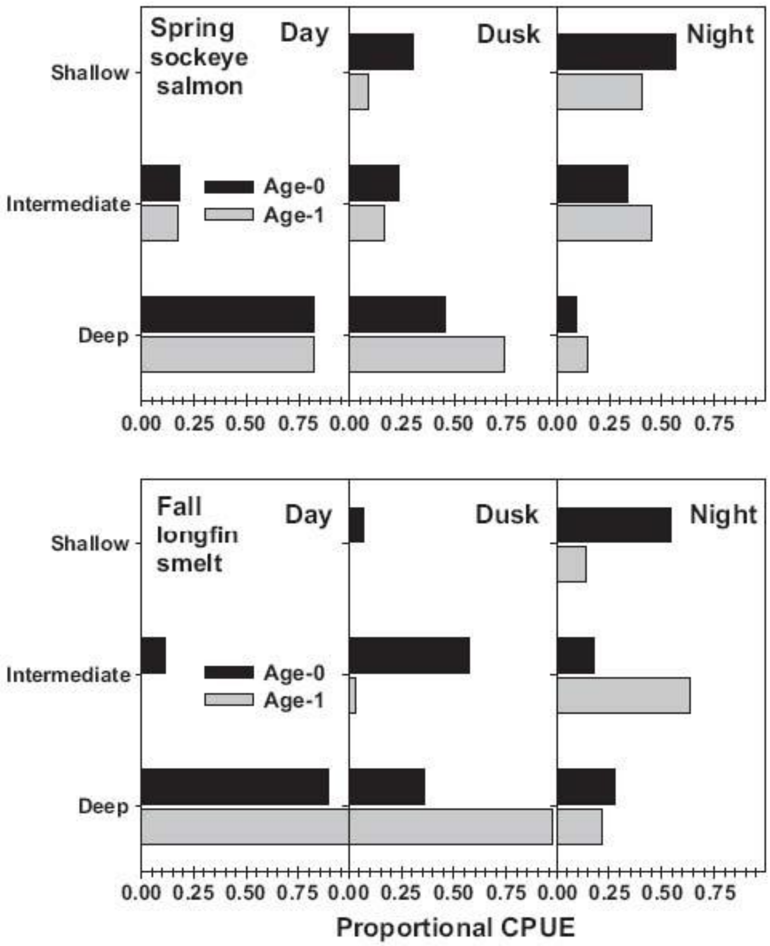

Fig. 3. Diel vertical distributions of age-0 and age-1 sockeye salmon in the spring (top) and longfin smelt in the fall (bottom). Catch-per-unit-effort (CPUE, $N{\cdot}min^{-1}$) was standardised by the total CPUE for each age class × diel period.

Figure D. Diel vertical distribution of age 0 and age 1 Longfin Smelt (lower panel) in Lake Washington during fall surveys (Source: Figure 3, Quinn *et al*. 2012)

Relationship between Longfin Smelt abundance-Delta Outflow and Salinity

The abundance index of age-0 Longfin Smelt has been found to be positively related to freshwater outflow during the winter to spring period (Kimmerer *et al*., 2002a,b). The relationship of age-0 Longfin Smelt abundance and outflow has been robust over two different periods in which the abundance of Longfin Smelt sharply declined. The first decline in abundance occurred in 1986 after the introduction of the Asian clam *Potamocorbula amurensis*, and a second decline occurred in the early 2000s, when several pelagic species declined simultaneously and was termed the "pelagic organism decline (POD)" (Sommer *et al*. 2007; Fish *et al*., 2009; Thomson *et al*. 2010) (Figure E). The second step change in abundance was detected in FMWT and Bay Study MWT catch; however, this change was not observed in the Bay Study otter trawl (Figures E, F). The reduction in Longfin Smelt FMWT abundance index after 1987 has been attributed to the reduction in upper estuary productivity which declined to very low levels by the mid-1990s (Jassby *et al*. 1995, 2002; Kimmerer and Orsi 1996; Orsi and Mecum 1996; Kimmerer 2002). However, the mechanism resulting in the more recent decline in Longfin Smelt production remains to be determined (MacNally *et al*. 2010, Thomson et al. 2010). Several competing hypothesis exist for the decline of Longfin Smelt abundance measured by the FMWT and Bay Study MWT, and are consistent with those proposed for the POD, including reduced food abundance, increased export mortality, predation and poor water quality (Baxter et al 2008). A potential hypothesis for the discrepancy of the FWMT, Bay MWT with the Bay Study otter trawl is that the difference in the Longfin Smelt abundance index trends are the result of changes in the vertical migration behavior associated with increased water clarity

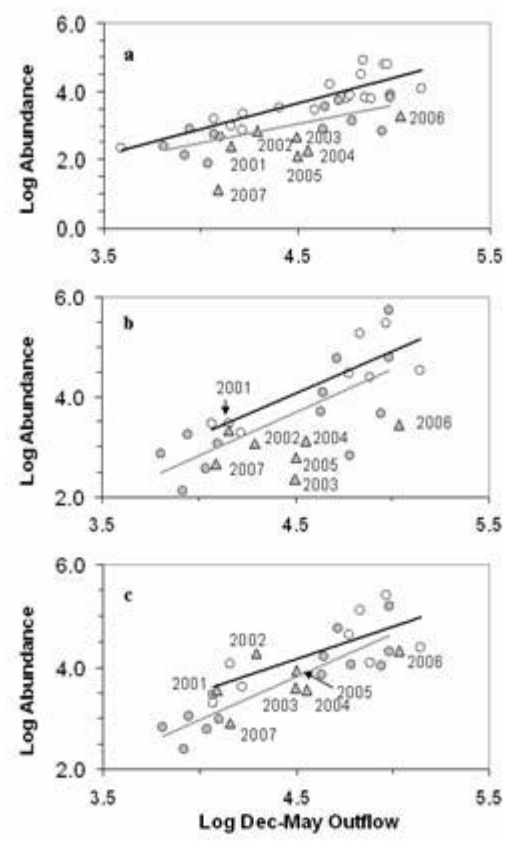

Figure 3. Longfin smelt annual abundance indices plotted on December through May average delta outflow for a) Fall Midwater Trawl (all ages); b) Bay Study Midwater Trawl Age 0; c) Bay Study Otter Trawl Age 0. Relationships depicted are pre-*Corbula amurensis* (1967-1987; open circles, black line) and post-*Corbula amurensis* (1988-2000; filled circles, grey line) and more recent years during the Pelagic Organism Decline (POD) (2001- 2007, grey triangles, no line).

Figure E. Relationships of indices of Longfin Smelt abundance and Delta outflow (Source: Figure 3, Fish *et al*., 2009).

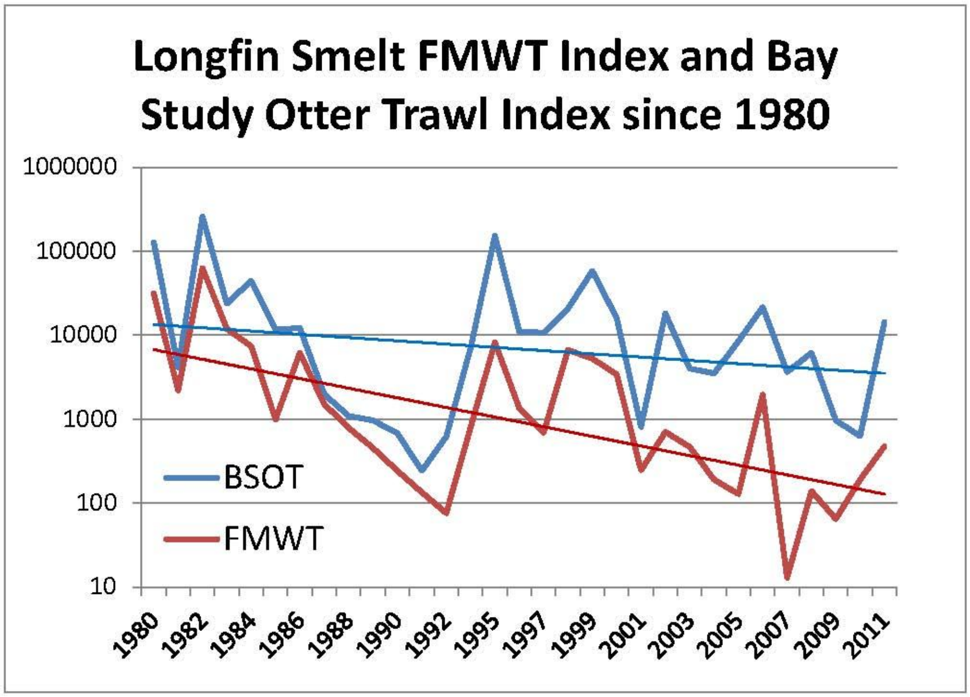

Figure F. Longfin Smelt FMWT Index and Bay Study Otter Trawl Index since 1980. FMWT Index values have declines by nearly two orders of magnitude while Bay Study Otter Trawl values have declined by a little more than 50%.

Gaps in our understanding of the biology of Longfin Smelt

Through our collaborative efforts to better understand the biology of Longfin Smelt and the potential factors associated with decline in abundance, we have advanced our understanding of the species. However we have identified several major data gaps that preclude our ability properly manage the species and assess the different factors associated with the abundance of the fish. The data gaps are primarily associated with recent observations of the spatial distribution of the Longfin Smelt from existing monitoring surveys and new surveys being conducted in habitats not currently sampled by ongoing long-term monitoring programs. The objectives, questions and hypothesis put forth in this study plan are intended to directly address these data gaps, and provide managers with a better understanding of the biology of the species. A second, related, goal is to explore factors that may be associated with the ability of current survey methods to catch Longfin Smelt and thus monitor population trends.

Research Questions and Hypotheses

Longfin Smelt distribution and regional contribution to overall abundance:
1. Do Longfin Smelt spawn in Bay tributaries?

a. H_o : Longfin Smelt will not be found to spawn in Bay tributaries

H_a : Longfin Smelt will be found to spawn in Bay tributaries

2. If spawning occurs in Bay tributaries, are there substantial differences in production during wet versus dry years?

a. H_o : The magnitude of Longfin Smelt production in Bay tributaries does not vary by water year type.
b. H_a : The magnitude of Longfin Smelt production in Bay tributaries is substantially higher in wet years.

3. Is Longfin Smelt larval production in Bay tributaries sufficient to influence the abundance indices of YOY and adult (age 1+) Longfin Smelt captured by DFW surveys in the estuary? How does the contribution of Bay tributary spawning to year class strength vary in response to variation in hydrologic conditions (e.g., wet vs. dry years, etc.)?

a. H_o : Larval production in Bay tributaries does not influence the abundance index of YOY and/or adult Longfin Smelt.
b. H_{a1} : Larval production in Bay tributaries does influence the abundance index of YOY and adult Longfin Smelt.

c. H_{a2} : The magnitude of tributary spawning and the survival of Longfin Smelt spawned in Bay tributaries (i.e., contribution of tributary spawning to population abundance of juveniles and adults) varies among years in response to hydrologic conditions.

4. Will Bay tributaries have unique geochemical signatures that allow identification of regional geographic areas of production (e.g., differentiate production in Bay tributaries from Sacramento and San Joaquin river production) and, under the best case scenario, have geochemical signatures that would allow differentiation of production among individual tributaries?

a. H_o : Geochemical signatures will not differ among the Sacramento and San Joaquin rivers and Bay tributaries.
b. H_a : Geochemical signatures will be sufficiently different to discriminate between the Sacramento and San Joaquin rivers and Bay tributaries and possibly among individual Bay tributaries.

5. If geochemical signatures are discernible among geographical areas and salinity zones, what is the relative contribution of larvae rearing in different geographical areas and salinity zones to the YOY and adult (age 1+) population? a. H_o: Most Longfin Smelt production originates from upstream areas, specifically the low salinity zone of the Sacramento and San Joaquin rivers.
b. H_a: Bay and Bay tributary production is a major contributor to the Longfin Smelt population.

6. Will geochemical signatures of the Bay differ from the nearshore marine coastal waters such that fish moving into or out of San Francisco Bay could be identified? a. H_o : Geochemical signatures of Longfin Smelt in San Francisco Bay will not differ from the nearshore coastal environment.
b. H_a : Geochemical signatures of Longfin Smelt in San Francisco Bay will be significantly different from the nearshore coastal environment.

Longfin Smelt vertical migration behavior.

7. Do Longfin Smelt undergo a diel (daily) or tidal migration in the water column? If present, does this behavior vary regionally (i.e., in central San Francisco Bay vs. Suisun Bay)?

a. H_0: Longfin Smelt do not exhibit any diel or tidal vertical migration behavior: catch in the upper part of the water column (as measured by FMWT and Bay MWT) and deeper waters (as measured by the Bay otter trawl) do not vary between night and day, or over tidal cycles.
b. H_{a1}: Longfin Smelt do exhibit diel or tidal vertical migration behavior: catch in the upper part of the water column (as measured by FMWT and Bay MWT) and deeper waters (as measured by the Bay otter trawl) varies between night and day, or over tidal cycles, or both.

c. H_{a2}: Longfin Smelt diel or tidal vertical migration behavior varies between regions of the estuary.

8. Is Longfin Smelt catch affected by water transparency?

a. H_0: Water transparency does not influence MWT or otter trawl catch of Longfin Smelt.
b. H_a: Longfin Smelt catch in the upper part of the water column (as measured by FMWT and Bay MWT) and deeper waters (as measured by the Bay otter trawl) varies with water transparency, with decreased catch in the upper water column at high levels of water clarity. This effect of water transparency would result in variation in the catch ratio of BWT:OT across water clarity levels.

Project Approach
Longfin Smelt distribution and regional contribution to overall abundance: (Questions #1 – 6)

This multi-year study would determine if adult and larval Longfin Smelt occur in Bay tributaries and if so, the abundance of Longfin Smelt spawning and successfully rearing in San Francisco Bay tributaries outside of what is thought to be primary spawning grounds at the confluence of the Sacramento and San Joaquin rivers and Delta. The multi-year study design is intended to test hypotheses regarding Bay tributary use by Longfin Smelt between wet and dry years. The specific research questions, study designs and associated hypotheses in this study plan are largely exploratory in nature and thus we anticipate taking an adaptive approach to the overall study, with the first year of the study designed to determine optimal sampling sites for each of the Bay tributaries, compare different gear types (UCD vs. DFW), and investigate the efficacy of otolith geochemistry to distinguish different habitats. and potentially different tributaries. During year one, significant input from the newly formed IEP PWT and Technical Team will be sought to refine study questions and design appropriate approaches and methods, thus the study plan is intended to be flexible in specific question and approaches, yet will seek to address the overarching study objectives.

Year One Study Plan

To get a better understanding of the potential contribution of Bay tributaries to the population, reconnaissance of several Bay tributaries including the Napa River and adjacent restored salt ponds, Sonoma Creek and the Petaluma River in San Pablo Bay; Alameda Creek in South Bay and Coyote Creek in Lower South Bay and adjacent restored salt ponds. Reconnaissance will involve determining specific stations within each Bay tributary, determining safe access points, clearing of debris and other obstructions, mapping of habitat and quantification of available habitat and water volumes for expanding catch for abundance estimates and comparing difference gear types to determine the most effect sampling approach. We will also explore the utility of otolith geochemistry to detect Bay tributary derived fish among the recruited juvenile and adult populations to assess the degree to which Bay tributary spawning contributes to juvenile and adult abundance. Lastly we will expand on the otolith geochemistry approach and investigate the potential to use otolith geochemistry to estimate the proportion of Longfin Smelt that use nearshore ocean environments (rather than staying in the Bay) for the summer-fall period and if adults individuals could overwinter in the ocean.

Using our established data on the geochemistry of the Sacramento-San Joaquin Delta and Napa Rivers (Hobbs 2010) and new geochemistry data collected in the initial year of this study, we will determine the degree to which we can reliably distinguish different habitats and tributaries, and determine our ability to quantify Longfin Smelt spawning and rearing in Bay tributaries and address questions regarding Bay tributary contributions to fall and winter indices of adult and juvenile Longfin Smelt abundance. The following tasks and methods are derived from existing experience in sampling shallow Bay tributaries. Again, the study is proposed as a multi-year effort to assess our tools to =determine the contribution of different geographical areas and salinity zones across different water year types to the abundance of recruited juvenile and adult Longfin Smelt. Ideally, these studies would be at least a 5-year effort; however the timeline would depend on future climate conditions, and could potentially be completed in less than 5 years. In the first year, reconnaissance will be conducted to establish specific sampling locations in South Bay tributaries under the environmental conditions of the study year. Given varying field challenges in different water conditions, specific sites and gears may be subject to change across water year types. Otolith geochemistry methods from Year 1 will be expanded to determine the reliability of such signatures in different hydrologic conditions. The multi-year effort would allow the evaluation of the effects of different water year types (e.g. hydrologic conditions in the tributaries during the spawning/early rearing period) on smelt reproduction, and to follow individual cohorts to adulthood.

These studies would be initiated in Year 1 of the research program and would continue potentially through Year 5 depending on results of initial sampling and analyses and hydrologic conditions that occur during the spawning and early larval rearing period each year. A general timeline for sampling and reporting is provided in Table 1. All progress and final reports will be provided to both the IEP PWT and the Longfin Smelt Technical Team.

Longfin Smelt Vertical Migration Behavior (Questions #7-8)

A second set of studies will examine the degree to which Longfin Smelt behavior, and thus their catchability by survey nets, may be affected by factors such as turbidity, tidal cycles, and any diel movements of Longfin Smelt. Such behaviors could substantially influence the interpretation of long-term data sets such as the FMWT. The initial effort will focus on evaluating existing FMWT and Bay Study data sets to examine whether there is evidence of substantial variability in fish catch related to the environmental variables of interest. Results of the analysis of existing monitoring data from the FMWT, Bay Study, and other data sources have the potential to identify sources of variability of abundance indices that could affect the interpretation of long-term trends in indices of abundance. If relationships are detected and they are of sufficient magnitude to influence data interpretation, then field studies will be planned to further quantify the results. Once additional field studies are identified, the IEP PWT will detail the study objectives, methods, and projected take of Longfin Smelt in a separate study plan that will be reviewed by newly created Longfin Smelt PWT and Technical Team, and subsequently by the IEP Management Team.

Based on initial analyses and logistical planning efforts, the additional studies proposed would attempt to directly address the potential effects of diel, tidal, and turbidity on variation in Longfin Smelt catch. Currently, we anticipate that any additional field effort would occur during the fall months (September-December to coincide with FMWT sampling or other times as appropriate, identified during refinement of the study design and study plan development) at designated locations using the Bay Study MWT and otter trawls during the day and during the night. Sampling locations will be chosen to reflect the wide geographic distribution observed for Longfin Smelt and will include one or more stations in the lower Sacramento River near Sherman Island, one or more stations in Suisun Bay channel, one or more stations in San Pablo Bay, and one or more stations in central San Francisco Bay.

The analyses of existing datasets will start in Year 1. Based on results of the initial data analysis, further experimental field studies to collect specific data (e.g., day vs. night collections with the MWT and otter trawl) may be conducted beginning in year 2 of the study. A general timeline for initial analyses, sampling, and reporting is provided in Table 1. All progress and final reports will be provided to both the Longfin Smelt PWT and the Longfin Smelt Technical Team.

Description of Tasks

Task 1: Adult Fish Sampling in Bay Tributaries (Principal Investigator: James Hobbs, UC Davis)
Year 1: Reconnaissance Sampling

The UC Davis research group will base fish sampling in Bay tributaries for this project on recent experience gained conducting the ongoing South Bay Salt Pond Restoration Fish Monitoring Program as well as many other fish surveys in the estuary and elsewhere. For this project, we will sample Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek, and potentially other areas if deemed likely to be sites of Longfin Smelt spawning by the Longfin Smelt PWT and Technical Team. During the first year, adult sampling will be conducted to find regions with the highest likelihood of finding adult and larval Longfin Smelt. This will be considered the pilot project year. Sampling will occur during the months of January-February, when fish are most likely to be ripe and ready to spawn. This will not provide evidence of successful spawning; however, it will allow us to target locations where the probability of finding larvae is high for larval sampling, rather than taking a shot-gun approach and sampling all locations over many months with a larval plankton net, creating a large volume of plankton to sort and larval fish to identify. The goal of this approach is to increase efficiency and reduce costs.

Years 2-4

Based on the pilot year results, we will determine a sampling design for the following four years of the project that will maximize success of locating adult and larval Longfin Smelt during the spawning season. Larval sampling is described below. With full funding of this project, we propose that adult Longfin Smelt sampling occur monthly from October to March using a four-seam otter trawl with a 1.5 m X 4.3 m mouth opening, a length of 5.3 m, and a mesh size of 35-mm stretch in the body and 6-mm stretch in the cod end. To sample shallow waters (less than 1.5-m), we will run a trawl behind a medium sized boat (we currently use a 26-ft Bayrunner modified for trawling). A 16-ft shallow bottom tracker boat will be used to tow a small four-seam otter trawl with a mouth size of 2.44 m x 0.75 m, a length of 3 m, a mesh size of 32-mm stretch in the body and 6-mm stretch in the cod end. Paired samples using the two collection methods will be made periodically during the study to determine comparative gear collection efficiency. Preliminary side-by side comparisons have been conducted in Coyote Creek as part of the South Bay Salt Pond Restoration Fish Monitoring Program (*Hobbs unpublished data*), with some mixed results. In general, however, the smaller net scales in volume to the larger net. In addition, larger, slower moving fish have been caught with the smaller trawl, but large mobile species like striped bass may be able to avoid the small net. We have caught similar numbers of adult Longfin Smelt with the smaller trawl compared to the larger trawl. In three years of trawling in the Alviso-Coyote Creek complex we have conducted 42 trawls from Oct to March that have netted a total of 229 adult longfin smelt.
Within each tributary, otter trawl stations will be stratified by salinity (1-3ppt, 4-6ppt and ~12-ppt) where spawning staged Longfin Smelt have been found historically. A total of 2-3 replicate trawls will be made per stations per Bay tributary on a monthly basis in the initial pilot year of the investigation. Up to 100 adult longfin smelt from each Bay tributary will be archived for otolith analysis.

Based on results of initial trawl replication and take permissions, modifications to sampling frequency and locations will occur for subsequent years. Along with otter trawl sampling, longitudinal profiles of water quality with be conducted at each site using a Hydrolab 5S, connected to a Trimble GPS unit to record a gradient of water quality parameters associated with adult fish catch (occupancy). Water samples will also be collected from the various tributaries sampled for use in developing a baseline for determining the potential for unique geochemical signatures on both a regional scale and tributary-specific scale for comparison with collected otoliths.

Representative samples of adult Longfin Smelt will also be collected as part of routine Bay Study sampling. Longfin Smelt adults collected from a variety of locations represented by Bay Study sampling locations will be used to assess geochemical signatures. The initial phase of the otolith assessment of adult Longfin Smelt will include a target sample size of 100 adults for analysis. Sample sizes will be refined based on results of initial analyses.

Task 2: Larval Fish Sampling (Principal Investigators: James Hobbs, UC Davis; Bob Fujimura, DFW)
Task 2a:

DFW currently conducts a Smelt Larval Survey (SLS) in winter and early spring (January-March) using a ski-mounted plankton net in the upper San Francisco Estuary[1] . Such gear is too large for sampling smaller Bay tributaries, so a smaller diameter net is proposed to be used for routine larval collections in the small and shallow tributaries. As part of developing the comparative baseline for this study, the smaller net will be used in parallel with the standard DFW SLS sampling nets to assess comparative collection efficiency. For the DFW portion of Task 2, the DFW SLS study will extend larval smelt sampling into the lower reaches of the Napa River and conduct a single ichthyoplankton tow at 10 stations biweekly beginning in early January and ending late March. Expansion of the DFW larval smelt surveys into the Napa River provides the opportunity to develop estimates of larval density and abundance for the Napa River to compare with similar estimates for the upper Estuary, as well as to conduct a series of paired sample collections to develop the data necessary to allow a comparison of relative densities in Bay tributaries to other locations sampled by the SLS. These paired samples will be collected in February and March during two of the biweekly surveys conducted by the DFW SLS during the first year both studies conduct fieldwork; based on results additional samples may be required. Samples collected during this paired sampling will be preserved in 10% buffered formalin to facilitate fish size comparisons between gear types.

[1] http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SLS

Task 2b:
Year 1: Pilot Project

For the UC Davis portion of Task 2, in addition to the side-by-side gear efficiency testing, several additional Bay tributaries will be sampled for larval Longfin Smelt including Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek. In the pilot year, only tributaries where adults were observed will be sampled from January to March bi-weekly.

Larval fish will be sampled using a replicate DFW SLS net if possible with our current boat otherwise we will use our standard a 0.75-m diameter x 3-m length, 505 µm mesh, General Oceanics plankton net with a 1-L cod end jar with 250-micron mesh bottom. The net will be towed by a 26-ft Bayrunner , in an oblique fashion for 10-minutes starting at the bottom of the water column and bringing the net up 1/5 of the depth every 1 minute. Water volume sampled will be determined with a General Oceanics flow meter, recording serial numbers before and after each tow and using the General Oceanics algorithm to calculate volume of water sampled (http://www.environmental-expert.com/products/model-2030-flowmeter-17301). Three replicate tows will be conducted at freshwater sites and where available at sites having salinities of 1-3ppt, 4-6ppt and ~12-ppt. The contents of the sample will be washed into the cod-end jar and preserved in 95% ETOH or 10% buffered formalin, so that otoliths could be used from collected samples, and labeled accordingly. Water quality vertical profiles will be measured with a YSI-6000 water quality meter for electrical conductivity, salinity, water temperature, dissolved oxygen and pH.

Larval fish will be separated from detritus and other organisms under a class 100 fume hood and stored in 25-mL glass vials with fresh 95% ETOH. Larvae will be identified to the lowest taxonomic level, enumerated and measured for length to the nearest 0.1mm under a stereo microscope fit with an ocular micrometer. Fish identification will follow the dichotomous key and taxonomic features using the "Tracy Fish Facility Studies: Fishes of the Sacramento-San Joaquin River Delta and Adjacent Waters, California, A Guide to the Early Life-History, Volume 44-Special Publications, December 2010". All larval fish will be reported in units of fish per 1,000 cubic meters of water sampled to be consistent with DFW smelt survey results. Data for the detections of Longfin Smelt larvae and post-larvae will be reported to DFW within 5 business days to ensure the required sampling frequency is conducted.

Figure G. RV Triakis with zooplankton net and otter trawl deck over the motor.

Task 3: Otolith Geochemistry (Principal Investigator: James Hobbs, UC Davis)

Using the unique geological properties of watersheds and tributaries to the San Francisco Bay and the Central Valley measurements will be made of the chemical elements and isotopic ratios of many trace and minor elements from various tributaries sampled and compared to otolith geochemistry signals. Dr. Hobbs' UC Davis research group has been conducting this research for over 10 years and has created a geochemistry "road map" of the San Francisco Bay to distinguish different tributaries that serve as natal origins for several native species, including Splittail, Delta Smelt and Longfin Smelt (Hobbs et al 2005, 2007, 2010, Feyrer et al 2007). Using laser ablation inductively coupled plasma mass spectrometry (ICPMS) and multi-collector ICPMS, measurements can be made of the chemical composition of fish otoliths to less than weekly resolution in some species (e.g. Delta Smelt). Thus far, the Hobbs lab at UC Davis has been able to reliably identify natal origins of Central Valley and the Napa-Petaluma stock of Splittail, natal origins and life history of Delta Smelt, and the salinity history of Longfin Smelt (Figure H). Research to date on Longfin Smelt has shown the ability to definitively show that individuals surviving to the adult stage and returning to the spawning grounds of the Sacramento-San Joaquin confluence were derived from fish that had reared in the low-salinity zone (1-3ppt). Hobbs has also compared retrospectively the rearing areas of successful recruits to the distribution of Longfin Smelt larvae collected in the 20-mm survey and has shown that a large proportion of fish that reared in salinities greater than 6-ppt did not return as adults to the confluence spawning grounds; presumably they did not survive.

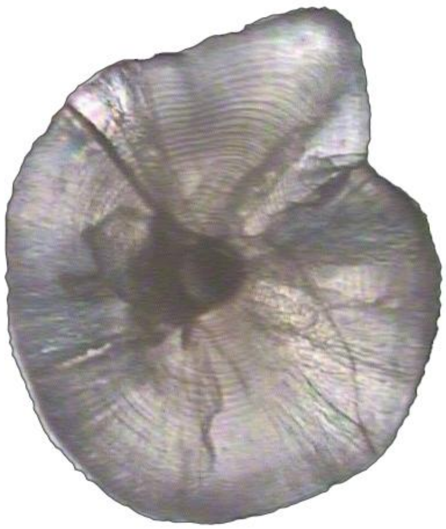

Figure H. Longfin Smelt otolith with a 40 µm laser spot on the natal core.

In this study, we propose that the initial "road map" of geochemistry further developed by the Hobbs lab be expanded to include additional Bay tributaries where Longfin Smelt may spawn and rear as larvae (e.g. Coyote Creek in South Bay). Using facilities at UC Davis (The Interdisciplinary Center for Plasma Mass Spectrometry; http://icpms.ucdavis.edu/), it is proposed that up to 52 trace and minor elements be measured using the Agilent 7500ce, in addition to measurements of the isotopes of several elements that can further be used to help resolve differences in the geochemical signatures among tributaries, including strontium isotopes and lead isotopes. In addition, it is proposed that the project quantify the isotopic composition of oxygen, carbon, nitrogen and sulfur at the UC Davis Stable Isotope Facility (http://stableisotopefacility.ucdavis.edu/). Details of the proposed analytic methods for these geochemical measurements have been reported in previous publications (Hobbs *et al.* 2005, 2007, 2010, Feyrer *et al.* 2007 and at the UC Davis ICPMS website).

Natal Tributary Origin

Year 1: Pilot Project

Water samples from Bay tributaries will be collected by UC Davis in triplicate in each salinity zone sampled during the spawning and larval rearing periods (January-March). Otoliths from larval and adult Longfin Smelt from tributary collections during the pilot year (up to 100 per lifestage and tributary) will be extracted and polished for laser ablation geochemistry analysis to determine Bay tributary chemical fingerprints. In addition, otoliths will be aged; daily for larval fish and annual for adult fish. These analyses will also be initially performed on approximately 100 juvenile and adult Longfin Smelt collected as part of the routine San Francisco Bay Study sampling program.

Results of the initial year of investigation will be critically reviewed by the proposed IEP Project Work Team and used to refine the sampling program and otolith analysis in subsequent years of this investigation.

As this is a pilot project, a precise estimate of the minimum sample size for larval, and adult stage catch, or number of otoliths required to be examined cannot be provided at this time and will need to be developed based on initial results and could likely depend on the numbers of fish collected in Bay tributaries. From previous research conducted by UC Davis a minimum sample size of at least 25 larval and adult fish, as well as up to 6 water samples per Bay tributary would be required to discern unique chemical signatures to have project success. The targeted sample size for this study includes up to 100 juvenile and adult Longfin Smelt collected as part of the DFW Bay Study sampling program in addition to the water and larval and adult Longfin Smelt collected from the various tributaries sampled.

Adult Ocean Residency

Several studies, including the San Francisco Bay Study and a peer reviewed publications (Rosenfield and Baxter 2007), have suggested that adult Longfin Smelt (age 1+) may venture outside of the San Francisco Bay proper into the nearshore ocean. Collections by the San Francisco Bay Public Utility Commission, the NOAA Fisheries Ocean Midwater Trawl Survey and collections at the Bodega Marine Laboratory in the 1970's have captured Longfin Smelt in the nearshore ocean outside of San Francisco Bay. The use of otolith geochemistry to determine if a fish has resided in the nearshore ocean has been examined by several researchers with equivocal results. The use of several trace and minor element ratios has been useful for distinguishing both upwelling hotspots in central and northern California, (e.g. Pt. Reyes, Bodega Head vs. Monterey) (Brian Wells *unpublished data*), and distinguishing Central from Southern California (Nishimoto et al 2010).

In addition to trace and minor elemental ratios differences between San Francisco Bay and the nearshore ocean, other constituents of water could be examined to distinguish nearshore habitats from San Francisco Bay. Rosenfield and Baxter (2007) observed the Longfin Smelt abundance significantly decline in the late summer when Bay water temperatures are highest, consistent with the thermal tolerance of the species, meanwhile nearshore habitats would be several degrees cooler in the summer compared to the Bay due to ocean upwelling of cool, deep, nutrient-rich waters which are also comprised of high concentrations of many trace and minor elements. Oxygen isotope ratios have been used for decades to determine the temperature history of fish, as the lighter isotope of Oxygen ^{16}O is lost to evaporation in warmer waters relative to the heavier ^{18}O isotope, thus a well-established relationship between water temperature and otolith ^{16}O:^{18}O has been established (Devereux I 1967). Oxygen isotope ratios could be used to reconstruct the temperature history of Longfin Smelt and the corresponding derived temperatures during the hypothesized ocean phase could be compared to Bay temperatures. This alone may not infer ocean residency; however combined with trace and minor element ratios associated with upwelled waters could, in combination provide evidence for ocean residency.

Lastly, the variability of strontium isotope ratios $^{87}Sr:^{86}Sr$ during the potential ocean phase could also be used in combination with the above methods to infer ocean residency. In our research with Longfin Smelt and other migratory species such as Chinook salmon and Steelhead in the central valley, we have observed that fish that make ocean migrations, such as Chinook salmon, exhibit much less variability of strontium isotope ratios $^{87}Sr:^{86}Sr$ compared to species such as YOY Longfin Smelt or striped bass which rear in San Francisco Bay or make frequent movements into different salinity environments. Thus, variability of the strontium isotope ratios in conjunction with other element and isotope ratios could be used in combination to infer ocean residency.

While we may not be able to collect Longfin Smelt in the nearshore ocean, we may be able to acquire samples from the NOAA Midwater Trawl Surveys. We would also examine otoliths of a similar species, the night smelt (*Spirinchus starksi*), Surf Smelt (*Hypomesus presiosis*) which are commonly captured off of Bodega Bay. Examining these otoliths from species known to reside in the ocean could be used as a proxy validation of the suite of element and isotope ratios to infer ocean residency. Given the availability, Longfin Smelt could be held in raw seawater at the Bodega Marine Laboratory (BML), where ample fish culture facilities exists, and a long-term monitoring of trace and minor elements is conducted in the nearshore environment in front of the marine lab. The flow-through seawater system at BML draws water from the nearshore environment and all environmental conditions could be maintained to mimic nearshore ocean rearing. The latter possibility of laboratory rearing will be further developed during Years 2-5 of the project if deemed worthwhile by the Longfin Smelt PWT and Technical Team.

Task 4: Effects of environmental variables on Longfin Smelt behavior and catch (Principal Investigators: Data analyses: Dave Fullerton (SWC) and Chuck Hanson (Hanson Environmental, Inc.); Follow-up field sampling: Randy Baxter (DFW); Other PIs to be determined (e.g. if SmeltCam is used)).

The initial effort (Year 1) would involve an exploratory review of existing data sets to determine whether Longfin Smelt catch varies substantially with several environmental variables. Specifically, we would look at the relative catch in concurrent Bay Study MWT and otter trawls, reflecting upper and lower water column catch, respectively. The general approach will be to look at individual surveys and ratios (e.g. Bay MWT/otter) to examine whether there is evidence that total catch or position in the water column varies based on diel, tidal, seasonal, and water transparency changes. The data may be stratified by salinity class and time periods (e.g. pre- and post-POD) to provide some degree of standardization. The initial approach would be graphical, but basic statistical models will be applied as appropriate.

Depending on the results of the exploratory analyses and guidance from the proposed IEP Project Work Team, field studies may be conducted to provide higher resolution data on fish behavior in relation to the environmental variables of interest. However, experimental sampling within the Bay-Delta estuary at night includes a number of logistic and safety concerns. Given these concerns it is recommended that experimental sampling during the day and at night for Longfin Smelt be conducted as part of the proposed suite of studies included in this proposal; however, it is recommended that initiation of the experimental sampling should be delayed until at least the fall of 2015 (Year 2 of the studies). The one-year delay in initiating these studies provides an opportunity to develop a stronger experimental design and experimental sampling protocol, and to estimate and obtain approval for take of ESA fishes, as well as time to plan for the safe implementation of this sampling effort, while minimizing the potential for impacts of the experimental sampling on DFW staff and other fishery sampling programs.

Although the exact details of a field effort remain to be determined, we provide some information about a possible sampling scenario that might be considered. The likely approach would be sampling during the fall months (September-December to coincide with FMWT sampling or other times as appropriate in refining the study design and study plan development) at designated locations using the Bay Study MWT and otter trawls deployed by the RV Longfin during the day and during the night. In addition, the study may include a geographic component such as: one or more stations in the lower Sacramento River near Sherman Island; one or more stations in Suisun Bay channel; one or more stations in San Pablo Bay, and; one or more stations in central San Francisco Bay. Stations would be selected to test a range of turbidity levels. Also, the trawls may be deployed at multiple depths at each station to assess variation in vertical distribution of smelt within the water column. Consideration will also be given to using a net design that would allow fish collection only at prescribed depths. An alternative sampling design that would be applicable for surveys in San Pablo and San Francisco bays, where the greatest majority of Longfin Smelt occur, may be the use of the Smelt-Cam (Feyrer *et al*. 2013) to assess changes in vertical distribution, while reducing the need to collect and harm Longfin Smelt. These additional potential field studies would be designed to be initiated in year 2 or later of the research program.

Task 5: Project management and reporting
UC Davis: James Hobbs.
DFW: Bob Fujimura and Randy Baxter

Overall contract and invoice management for Longfin Smelt distribution and abundance investigations conducted by UC Davis and DFW will be conducted by UC Davis and DFW project personnel associated with each task. Administrative support will be supplied by the Wildlife, Fish and Conservation department at UC Davis. The lead investigator will manage the operations of field and laboratory work. The lead investigator will be responsible for the management and training of staff and student assistants for the study and provide periodic performance evaluations according to University of California policy. The lead investigator will also be responsible for the safety of staff in the field.

Project management of the SLS sampling extension into Napa River (Task 2a) is the responsibility of Bob Fujimura. Coordination of this sampling with UC Davis for gear comparison will be the responsibility of Randy Baxter, and will be accomplished in part through the creation of a Longfin Smelt PWT and Longfin Smelt Technical Team. Randy Baxter will also be responsible for reporting on the density and abundance of Longfin Smelt larvae in Napa River in relation to the upper Estuary.

Project management of Longfin Smelt vertical migration investigations would be the responsibility of the State Water Contractors (Dave Fullerton, Chuck Hanson) and DFW (Randy Baxter). Contract management and management oversight of the initial analytical investigations will be coordinated between the principal parties based on specific tasks and responsibilities. Initial analytical efforts and reporting will be the responsibility of Chuck Hanson. If analyses determine that Longfin Smelt catch appears to be related to one or more of the factors listed and the variation is substantial enough to influence abundance indices, then additional field sampling will be planned and conducted with Randy Baxter as the responsible party of DFW personnel and logistics coordination; Dave Fullerton, Randy Baxter and Chuck Hanson for study design, data analysis and reporting.

The proposed IEP Longfin Smelt Project Work Team and Longfin Smelt Technical Team will provide guidance and assistance for all of the proposed studies, review of analyses and results, and assist in identifying refinements or additions to the proposed scope of investigations.

Data analyses

Research Questions 1 (Bay tributary spawning) and 2 (Differences between wet and dry years).

If adult Longfin Smelt are detected in tributary sampling, then the catch-per-unit of effort (CPUE) from the otter trawl catch at different Bay tributaries (and potentially other Bay Study locations) will be compared using general linear modeling, with environmental variables as covariates, such as salinity, temperature, turbidity etc (Question 1). In addition, variables such as freshwater outflow from the Delta or water year type will be assessed to address Question 2. The analysis may also use occupancy modeling because catch is likely to be low and the CPUE data not normally distributed. Occupancy modeling can take frequency of occurrence "occupancy" and environmental variables into consideration simultaneously using a maximum likelihood approach. Statistical significance can be assessed by an iterative Markov-Chain Monte Carlo simulation of the raw data to provide for a more robust assessment of certainty regarding the presence or occupancy and environmental drivers associated with occupancy.

Research Question #3 (Contributions of Bay tributaries to overall population).

Larval data will be summarized based on density (e.g. #/1,000 m^3) within the range of lengths effectively captured by both gears (derived from parallel sampling with DFW SLS and determination of size-specific collection efficiency of the two sampling nets) and compared to SLS samples in upstream areas adjusting for differences in habitat area or volume among sampling sites. Initial comparisons will be based on ANOVA among the different geographical locations and study years. Absolute abundance estimates will be generated based on the volume of each geographic area (Newman 2008). Additional analyses of population abundance based on salinity ranges will also be considered to provide a measure of the potential relative contribution of different geographic areas to the larval population. Because the proposed sampling program will be coordinated with DFW SLS surveys, density data can be translated into estimated larvae present in Suisun Bay and the confluence area (i.e., make direct comparisons of habitat volume and area weighted density) and assess the proportional contribution to the larval abundance. Regional volume estimates are available based on hydrologic models (Newman 2008; and from current modeling work). The contribution of Bay tributaries

Research Questions #3 (contribution of tributaries and regions to juvenile and adult age classes), #4 (unique geochemical signals of tributaries), and #5 (regional contributions to juvenile and adult age classes).

Chemical signatures from the study tributaries will be assessed from water samples and fish otoliths using a suite of multivariate ordination statistical tools, canonical cluster analysis and discriminant function analysis. Water quality parameters such as water temperature, electrical conductivity, and salinity will be included as co-variates in the models to determine the cause of unique chemical signatures of Bay tributaries. The otolith chemistry of recruited juvenile and adult fish collected in DFW Bay Study and FMWT sampling and those collected as part of the proposed surveys could then be examined to determine the proportional contribution of different spawning and rearing areas and regions to the juvenile and adult populations. A maximum likelihood mixed stock model (Hobbs *et al*. 2007) will initially be used to determine the natal source.

Research Question #6 (Ocean Residency).

Chemical signatures from the Bay and nearshore ocean will be assessed from water samples and fish otoliths collected in the Bay by the SF Bay Study, and UCD, and from nearshore samplings by NOAA Fisheries Midwater Trawls and lab validations of fish held at the Bodega Marine Laboratory. Similar statistical approaches (notably discriminant function analysis) will be employed as in questions 3-5.

Research Questions #7 (vertical migration with tidal cycle) and #8 (effect of water clarity on FMWT, BMWT, and OT).

Using existing data, graphical and basic statistical analyses will be used to address Questions 7 and 8 (influence of time of day, tidal cycle, and water transparency on Longfin Smelt catch). The exact approach to analyses of new field survey data depends on the results of the exploratory data analyses, plus the methods developed by the study team. However, the analytical approach of Feyrer *et al*. (2013), in which models predicting the effect of water quality variables on Delta Smelt catch were compared, offers a suggestion of how osmerid data collected during fall could be statistically evaluated.

Estimated Take

This study will rely heavily on samples collected from existing IEP sampling programs (FMWT, Bay Study, Smelt Larval Survey) and existing take. Additional take would occur as a result of SF Bay tributary sampling. Take for UC Davis San Francisco Bay tributary sampling will be covered under the individual permits for the lead investigator (Hobbs) for SF Bay tributary sampling. The current Memorandum of Understanding between the California Department of Fish and Wildlife and U.C. Davis will be amended to include lethal sampling of a subsample of pre-spawning adult Longfin Smelt to assess reproductive condition and collect otoliths for geochemistry analysis.

Estimated additional ESA take for the expansion to the DFW Smelt Larval Survey is as follows:

Longfin Smelt: larvae – 9,000, juveniles – 20, adults -2.

UCD
Estimated Longfin Smelt take based on 3 years of preliminary study:

Coyote Creek -100 adults, juveniles 1000
Napa River – 100 adults, juveniles 2000, Larvae 9000
Sonoma Creek– 100 adults, juveniles 2000, Larvae 9000
Petaluma River -10 adults, 100 juveniles, 100 larvae
Alameda Creek - 20 adults, 200 juveniles, 500 larvae

Salmonids and sturgeon: No take is requested.

Delta Smelt: larvae – 10, adults –2. Existing Delta Smelt take coverage for SLS [derived from NBA sampling and very high] is sufficient to cover this new work.

UCD
USFWS Permit to J. Hobbs 5/31/13-5/30/2017 for the Napa River TE97450A-0 50 Adults 150 larvae/juveniles per year

No take for Delta Smelt will be requested for Sonoma, Petaluma, Alameda, Coyote Creek. Take for Delta Smelt may be required for (this is currently be ascertained by looking at existing data from the Suisun Marsh project).

Timeline

The current proposal focuses on the first year, when key methods will be established and analyses will be conducted to modify the approach as necessary. However, the anticipated timeline for the full study is relatively long (5+ years) because: 1) a key part of the design is to compare results for wet and dry years, which occur at unpredictable frequencies; and 2) understanding the sources of Longfin Smelt recruitment will be most effective if there is sampling at the larval stage (to determine the initial production areas), followed by analyses of sub-adults and adults from the same cohort 1-2 years later (to determine which fish recruited to the population). The proposed timeline is provided as Table 1.

Feasibility

As noted above, much of the sampling would be based on existing IEP surveys, so other field sampling along the same lines (i.e., Napa River sampling) is highly feasible. The Hobbs research group has been successful with proposed techniques in some south Bay tributaries and in South Bay salt ponds and embayments, so these can be adapted to other tributaries with some advanced reconnaissance. In particular, Hobbs et al. have a long history of sampling in shallow waters of South San Francisco Bay (Coyote Creek and Alviso Slough/Guadalupe River) using otter trawling methods developed in Suisun Marsh's 30+ year monitoring program (Hobbs et al. 2012). In addition, Hobbs et al. have been conducting zooplankton and larval fish sampling in South San Francisco Bay. The Hobbs group already holds a Memorandum of Understanding with DFW for sampling Longfin Smelt in both Coyote Creek and the Napa River and a federal take permit for Delta Smelt in the Napa River. The Hobbs lab would be able to conduct a limited amount of work with existing funds; however those efforts would only cover Coyote Creek bi-monthly and the Napa River for 3 months.

Importantly, the proposed timeline depends on the ability to execute contracts to UC Davis and DFW supplemental field sampling. If the contracts cannot be executed very early in 2014, additional SF Bay tributary sampling may not be possible in winter-spring 2014 and the entire study would be delayed by a year.

Deliverables

The schedule of reporting for each task is provided in Table 1. All reports will be provided to the IEP Longfin Smelt PWT and the Longfin Smelt Technical Teams to be formed in Year 1. As the present study design is primarily a pilot project to assess spawning and rearing of larvae in Bay tributaries during the first year of what is expected to become a longer-term investigation, the primary deliverable from this pilot effort will be a report detailing findings from reconnaissance work and a detailed study plan for the remainder of the study. During Years 2 – 4, annual progress reports detailing sampling activities and preliminary findings will be submitted for Bay tributary sampling and nearshore ocean rearing (UCD), and Napa River sampling (DFW). At the end of Year 4 or in the Winter-Spring of Year 5 (depending on whether final sampling efforts take place in Year 3 or Year 4, final reports for each task will be completed (Table 1).
The Napa River larva sampling effort (Task 2a) will result in data added to the current SLS database, which will be available via DFW's FTP site, and a summary report describing the density and abundance (absolute estimate for the river reach sampled) for the river compared to the upper Estuary for each year of the sampling effort through Year 3. After Year 3 the utility of this work will be re-assessed. Gear comparison results will be used to establish the size range of Longfin Smelt larvae in which both gears are effective, and that range used for comparative abundance reporting. Reports detailing the densities and abundance estimates for Bay tributaries in relation to the Napa River and upper Estuary will be provided to the Longfin Smelt PWT and Technical Team by fall following sampling (fall Year 4).

Assessment of Longfin Smelt vertical migrations will initially involve a detailed analysis of a Bay Study dataset containing paired MWT and OT samples to determine if catches in the MWT are associated with any of the factors listed. This effort will result in a report providing detailed description of the data, data manipulation and analyses conducted, followed by results and an assessment of whether vertical movement appeared to occur and if the magnitude was such that it could influence abundance indices and additional sampling would be necessary to more accurately assess the effect. This report would be submitted to the Longfin Smelt PWT and Technical Teams, and its review and acceptance would initiate discussion of next steps and study design for field sampling. In addition and if necessary, a detailed study plan for field studies to investigate Longfin Smelt vertical migration will also be submitted at the end of Year 1.

Assuming that the study is successful, we anticipate that at least two peer-reviewed scientific papers would be produced by the study. Initial papers are most likely to be based on methodology (e.g. tributary and oceanic otolith signatures; using estimates of absolute abundance to estimate contribution to the larva population), while later publications addressing the contribution of Bay tributaries to the adult population would require several years to develop meaningful results to describe sources of recruitment.

Project Coordination

The study would receive input and guidance from the proposed new IEP Longfin Smelt Project Work Team that would be chaired by a DFW team member. PWTs are open to the public, but we expect that at a minimum, the group would include scientists from DFW, DWR, UC Davis, and State Water Contractor staff involved in the development of the current proposal, as well as other interested agencies and stakeholders. Major changes and additions to the study plan, such as field investigation of Longfin Smelt vertical migration, will require development of new study plans that will be reviewed by IEP Management and Coordinator Teams. Project direction and coordination will be managed by the Longfin Smelt Technical Team that will be convened with at least one representative from DWR, SWC, and DFW.

Budget (for purposes of this presentation the detailed project budget has not been included)

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Principal Investigator and Affiliation:

James Hobbs, Ph.D., ***Research scientist III in the Wildlife Fish and Conservation Biology Department and consulting research affiliate with the Interdisciplinary Center for Inductively Coupled Plasma Mass Spectrometry at UC Davis***.

Dr. Hobbs completed his PhD. in Ecology from the University of California, Davis under the mentorship of Dr. Peter Moyle and was a Sea Grant-CALFED Post-Doctoral Fellow at the University of California, Berkeley under Dr. Lynn Ingram. His research focuses on several elements of fish conservation, restoration and population dynamics. He is a leader in the development of otolith microstructure and microchemistry techniques to understand the population biology and ecology of commercially important and threatened species. Dr. Hobbs has published several articles in peer review literature regarding the application of laser ablation inductively coupled plasma mass spectrometry. Dr. Hobbs has been conducting research in San Francisco Bay for over 15 years focusing on native fish ecology and population biology for conservation and restoration efforts. His recent research focuses on the interdependence of fish life history and healthy habitats, such as the interplay of habitat characteristics of the north Delta and the residency of Delta Smelt in freshwater year round. He is currently leading the monitoring of restored salt ponds in South San Francisco Bay and defining the habitat features that result in the restoration of habitats for native fish, including the Longfin Smelt.

Appendix B

Indices of Longfin Smelt Abundance used in the Model Analyses

Table B1. Indices of age class longfin smelt abundance and standard deviations.

	Age Zero		Age Zero/One		Age One/Two	
	June-July		October-March		November-March	
Year	Index	Sd	Index	Sd	Index	Sd
1980	5.147645	1.540905	2.83565	0.477295	0.671315	0.147691
1981	0.054695	0.011506	0.294994	0.060716	2.028516	0.500702
1982	6.811693	1.338478	15.33047	1.345329	1.789226	0.375208
1983	0.762013	0.223661	1.952064	0.386329	4.703123	0.834940
1984	0.903832	0.288505	1.779105	0.517306	1.008610	0.214744
1985	0.112521	0.031633	0.755896	0.166815	1.544150	0.293123
1986	0.306562	0.027569	0.758722	0.107062	0.850549	0.107033
1987	0.056342	0.013876	0.43984	0.07363	3.128023	0.350311
1988	0.039315	0.010529	0.142759	0.020949	0.999951	0.130288
1989	0.032967	0.006855	0.103985	0.016985	0.522527	0.122224
1990	0.015897	0.004812	0.079563	0.017161	0.246579	0.062757
1991	0.005760	0.001925	0.024622	0.007549	0.147667	0.082057
1992	0.025127	0.007020	0.018699	0.004657	0.051506	0.023044
1993	0.138967	0.039880	0.381778	0.059058	0.377306	0.089155
1994	0.043509	0.011538	0.052570	0.013347	0.756030	0.214500
1995	10.73554	2.403421	1.368429	0.509663	0.158759	0.045147
1996	0.029749	0.007081	0.414955	0.064429	3.440189	0.427180
1997	0.073301	0.013608	0.162279	0.030000	0.567071	0.101007
1998	1.387879	0.420226	1.204877	0.190967	0.611440	0.098984
1999	2.561377	0.471928	0.428749	0.071549	0.917655	0.122052
2000	0.344826	0.072434	1.091874	0.197442	1.297423	0.180564
2001	0.033508	0.009184	0.122097	0.028096	1.427239	0.203511
2002	0.114351	0.027719	0.497593	0.093370	0.695358	0.177047
2003	0.095383	0.037800	0.148043	0.020793	0.719237	0.120373
2004	0.054189	0.012327	0.207661	0.031095	0.586214	0.096707
2005	0.177300	0.048076	0.075951	0.016592	0.498012	0.111741
2006	0.270357	0.083662	0.438508	0.079466	0.457178	0.102388
2007	0.074141	0.026098	0.026090	0.007441	0.185869	0.042095
2008	0.064460	0.014879	0.275455	0.114707	0.479959	0.108918
2009	0.023163	0.006680	0.049674	0.010794	0.292118	0.082641
2010	0.025387	0.010043	0.030204	0.007888	0	0.030100