Physical and Biological Drivers of Longfin Smelt Vertical Distribution

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Introduction and Background

Longfin smelt (*Spirinchus thaleichthys*) is a small pelagic fish found in estuaries and coastal waters along the Pacific Coast of North America. In the Upper San Francisco Estuary (SFE), longfin smelt populations declined in abundance following a crash in lower trophic level food production associated with the overbite clam invasion of 1987 (Thomson et al. 2010; Rosenfield and Baxter 2011). Longfin smelt abundance has declined further during an era known as the Pelagic Organism Decline (POD), which is defined as a period (2002 to present) where populations of other key pelagic fishes in the upper estuary also declined and have remained suppressed at record low abundances (Sommer et al. 2007). In 2009, longfin smelt was listed as a threatened species under the California Endangered Species Act (CDFW 2009). In 2012, longfin smelt was warranted for listing under the Federal Endangered Species Act (ESA) but precluded from formal listing at this time due to the need to address higher priority listing actions.

Longfin smelt exhibits an anadromous life history strategy, although there are some landlocked populations. Rearing and growth takes place in estuarine and coastal habitats for 2-3 years before longfin smelt spawn in upstream portions of estuaries. In the SFE, most spawning takes place in brackish or freshwater during winter from December to March. Longfin smelt feed on copepods as larvae and primarily on mysids as juveniles and adults. Many studies have highlighted a positive relationship between the abundance of age longfin smelt and freshwater flow (Stevens and Miller 1983; Jassby et al. 1995; Kimmerer 2002) but the mechanisms underlying that relationship remains unclear (Kimmerer et al. 2009).

There are several monitoring programs that sample longfin smelt throughout their life history in the San Francisco Estuary (Table 1) but only one of those monitoring programs (Smelt Larval Survey) was designed with the intent to target longfin smelt abundance and distribution. Although many of these programs collect various life stages of longfin smelt in time and space, are useful for describing relative changes in abundance, these programs may not fully capture the abundance, distribution, and habitat use of longfin smelt (Rosenfield and Baxter 2011). Additionally, gear efficiency studies for longfin smelt have not been conducted for the monitoring programs so interpretation of relative annual abundances may not fully capture

observational error that can arise from water quality, total fish abundance, changes in habitat use, and other factors. Management actions (D-1641, SWP and CVP Export Reductions, etc) for longfin smelt should be based on the most robust understanding of their distribution, abundance, and survival rates.

Recent evidence suggests that variability in longfin smelt vertical distribution may affect the interpretation of data on the spatial distribution and abundance of longfin smelt collected in long-term monitoring programs (Rosenfield and Baxter 2011). Specifically, the ratio of longfin smelt catches in midwater versus demersal habitats has decreased through time in some regions of the SFE (Fig. 1). As both water clarity and station depth increased, the ratio has shifted to smaller values. These analyses suggest that longfin smelt catches in the surface trawls (where catches are abundant in the otter trawls) are lower because a) the net does not sample the same fraction of the water column as it did historically (i.e., the fish are deeper than the habitat sampled by the net), b) longfin smelt are avoiding the net in clearer waters, or c) that longfin smelt has shifted its vertical distribution towards deeper water below the coverage of the Midwater Trawl where turbidity is sufficient to avoid predation and food is more abundant.

The purpose of this study is to investigate if longfin smelt shift their vertical distribution under different environmental and biological conditions. Using smelt cam technology, this study will sample fixed sample depths throughout continuous tidal cycles to ascertain if longfin smelt are positioning in the water column with respect to light (turbidity and day vs night), food, or salinity stratification. This study is designed to understand the mechanisms underlying vertical distribution and to resolve why catches in surface trawls and otter trawls may be affected by environmental conditions and/or monitoring methods. Further, this study should help resolve why longfin smelt catches vary in surface and demersal habitats, which can help to inform about potential biases in the long-term monitoring programs.

Conceptual Model and Goals

Our conceptual model explaining the divergent patterns in longfin smelt catch in otter trawl and midwater trawl samples from the CDFW Bay Study at site 325 is that longfin smelt are not evenly distributed vertically in the water column. The conceptual model posits that longfin

smelt are distributed near the bottom of the water column (Fig. 2). This results in larger catches in the otter trawl samples than the midwater trawl samples because the otter trawl is positioned along the bottom of the water column for the entire duration of a tow, while the midwater trawl is pulled obliquely through the water column and is therefore positioned near the bottom of the water column for only a short duration of a tow. Therefore, the otter trawl collects more longfin smelt than the midwater trawl because it is towed for a longer duration through longfin smelt habitat (i.e, turbid water) than is the midwater trawl. Thus, the primary objective of this study is to determine the vertical distribution of longfin smelt. This will be done by sampling for longfin smelt at fixed depth strata to confirm or refute the conceptual model that longfin smelt are distributed near the bottom of the water column (Fig. 3). The secondary objective of this study is to determine how variability in vertical distribution influences observations and inferences from the CDFW Bay Study in order to improve Study.

If our conceptual model that longfin smelt are not evenly distributed vertically in the water column is confirmed, the observed patterns may be due to a wide range of related environmental processes and cues that ultimately control the vertical distribution, including life stage, tidal currents, salinity and turbidity gradients, ambient light, diel cycle, or food abundance. Thus, we will need to sample under sufficiently diverse environmental conditions (particularly, tidal and diel cycles, hydrologic conditions) to distinguish among all of the various factors that may control vertical distribution. Therefore, we are proposing a 2-year study (Table 1) with intensive field sampling during approximately 2-4 weeks each year to address three key questions:

- (1) Are longfin smelt evenly distributed vertically in the water column?
- (2) Does longfin smelt vertical distribution respond to environmental cues, including gradients in tidal currents, turbidity, salinity and ambient light, diel cycle or food abundance?
- (3) Do longfin smelt need to achieve a threshold age or size before they respond to environmental cues for vertical distribution?

Study Design and Sampling Protocols

This 2-year study will include three individual elements, 1 pilot effort and 2 separate field efforts examining vertical distribution of longfin smelt (Table 1). The purpose of the pilot effort will be to refine sampling logistics and obtain preliminary information on the efficacy of non-lethal sampling methods for longfin smelt using the SmeltCam (Feyrer et al. 2013). The SmeltCam is an open-ended underwater video camera codend that automatically collects information on the number and species of fishes that pass freely through a trawled net without handling. The SmeltCam has previously been successfully applied in a study of the vertical and lateral distribution of delta smelt over tidal cycles in the upper San Francisco Estuary (Feyrer et al. 2013). The pilot study will determine the efficacy of the SmeltCam for similar non-lethal studies of longfin smelt. Specifically, we will test the ability to identify and distinguish longfin smelt from other fishes using images obtained with the SmeltCam. We will also be evaluating other study logistics during the pilot effort, including optimal tow length durations, coordinated sampling of fish with other physical and biological parameters, and the collection of some preliminary data to use in a power analysis to refine estimates of samples sizes required for the assessment of vertical distribution, and potentially detection probabilities.

The first vertical distribution study will take place within approximately a few months of the pilot study and the second will take place the following calendar year. Vertical distribution studies will be conducted in San Pablo Bay at site 325 of the CDFW Bay Study (Fig. 4). This site was chosen because it is where divergent patterns in catch in otter trawl and midwater trawl samples from the CDFW Bay Study are strongest The site is also located in a key deep (12.3 m), main center channel location of San Pablo Bay where strong tidal currents generate vertical structure in physical habitat features important to elucidating vertical distribution of longfin smelt (Fig. 6). A single fixed site in these studies is sufficient because tidal currents can move water and fish habitat approximately 10 miles past the site, allowing us to effectively sample the equivalent of about 20 miles of longitudinal habitat.

The general design of the vertical distribution studies will be to sample physical and biological parameters approximately every 2 hours for 48 consecutive hours in order to obtain

consistent data over a full range of tidal and diurnal cycles. All sampling will be conducted aboard the USGS R/V Turning Tide. Physical measurements will be made with a vertical acoustic Doppler current profiler (V-ADCP) and a YSI EXO sonde. The V-ADCP will be used to measure vertical flow structure and the YSI EXO will be used to obtain vertical profiles of water temperature, turbidity, conductivity, dissolved oxygen concentration, FDOM (surrogate for dissolved organic carbon), pH, Chlorophyll a fluorescence (surrogate for phytoplankton biomass) and Phycocyanin (surrogate for blue-green algal biomass). A submersible low light autoradiometer will be used to measure ambient light. At each sampling interval, physical condition measurements will be made first and examined in real time in order to determine the most appropriate vertical spatial structure for sampling fish. Based upon the tidally-averaged depth of site 325 (12.3 m) and the vertical dimension of the mouth of the midwater trawl (3.6 m), fish density could potentially be measured at 3 or 4 independent depth strata, depending upon tidal stage. Prevailing physical conditions as measured by the V-ADCP and the YESI EXO Sonde will determine if the vertical distribution structure of the fish sampling should be adjusted relative to the maximum number of independent depth strata available to be sampled.

Fish will be sampled using a midwater trawl with the same dimensions as the one that is used for the CDFW Bay Study. All fish sampling will be conducted with a midwater trawl because, unlike an otter trawl, it facilitates sampling at fixed depth strata (Feyrer et al. 2013). The midwater trawl used by the CDFW Bay Study has a mouth opening of 3.7 m (width) × 3.7 m (height) with mesh graduated in nine sections from 20.3 cm stretch mesh at the mouth to 1.3 cm stretch mesh at the codend. The CDFW protocol is to tow the midwater trawl obliquely through that water column for 12 minutes against the current. For this study, we anticipate also towing the midwater trawl for 12 minutes against the current obliquely through the water column to obtain a sample representative of what would be collected by the CDFW Bay Study. This is in addition to towing the midwater trawl for 12 minutes against the current at fixed depth strata to evaluate vertical distribution. Thus, if water depth permits sampling 4 independent depth strata, a total of 5 separate tows will be conducted during each 2-hour sampling interval (4 tows conducted at individual depth strata and one tow conducted

obliquely through the water column). Conducting the additional oblique tow at each sampling interval will contribute to directly addressing the secondary objective of this study, which is to determine how variability in vertical distribution influences observations and inferences from the CDFW Bay Study in order to improve interpretations of longfin smelt spatial structure and abundance generated from the CDFW Bay Study.

Food abundance will be measured at each depth strata in which fish are sampled by measuring densities of macrozooplanton (mysids and amphipods) and mesozooplankton (all stages of copepods) using the methods of Kimmerer et al. (1998). Macrozooplankton will be sampled with 60-cm, 0.5mm-mesh, opening-closing Bongo nets affixed with flow meters. Mesozooplankton will be sampled with a 100-I min⁻¹ submersible pump equipped with a noncollapsable intake hose with the discharge filtered through 35-µm mesh net into a container of known volume.

Data analyses will involve examining the available data using a variety of summarization and statistical approaches to address the three key research questions. The basic approach to the data analysis will consist of two stages: (a) data exploration, which includes generating summary statistics and graphical representations of the data, and (b) model building and the development of statistical tests. The 33 years (1980-2012) of data collected in the CDFW Bay Study at site 325 indicate that longfin smelt catches are zero-inflated and non-normally distributed (Fig. 7). Thus, in order to appropriately test hypotheses we may ultimately fit log linear Poisson models which control for overdispersion (the quasi-Poisson and negative binomial), or models allowing for excess zeroes (the zero inflated negative binomial) which control for overdispersion and excess zeroes with the Poisson distribution (Martin et al. 2005). Model fitting will likely be done using the statistical computing environment R, version 2.15.1, along with the R package 'pscl' (Jackman 2012). To make between model comparisons, we may calculate AIC values, AIC = $2*k - 2*\log(\text{Likelihood})$, where k = the number of parameters. AIC simultaneously quantifies goodness of fit, as defined by the likelihood of the data, and model complexity (as measured by k), and models with the smallest AIC values are considered preferable.

A preliminary power analysis was conducted with the historical (1980-2012) CDFW Bay

Study catches of age-0 longfin smelt at site 325 to get a general sense of the sample size required to reject a basic null hypothesis that there is no treatment level effect across 4 independent depth strata on longfin smelt catch per unit effort (CPUE). CPUE in the CDFW Bay Study midwater trawl samples is traditionally calculated as the total number of individuals collected standardized to the total volume of water filtered by the net x10,000. We calculated CPUE of age-0 longfin smelt for samples at site 325 in the month of June across the history of the CDFW Bay Study for use in the power analysis, the standard deviation of which = 10. Based upon the standard deviation of 10, α = 0.05, and potential sample sizes of 24, 48, 96 or 120 replicates, the estimated maximum detectable differences in CPUE units were approximately 12, 8, 6 and 5, respectively (Fig. 8). This can be interpreted as, for example, with 48 replicate samples (the likely number that will be collected in this study as it is currently envisioned) there is a 95% probability of detecting a difference of at least 8 CPUE units between the treatment means. Thus, the null hypothesis that there is no effect of depth would be rejected if there was a difference of at least 8 CPUE units between treatment means. Although generally informative, this power analysis should be considered only as a preliminary, conservative guideline because: (a) it is based on data using oblique tows which may differ in unknown ways from data that will be collected at specific depth strata, (b) it is based on aggregating 33 years of historical data which may or may not represent future conditions for the time period when the study is conducted, (c) the number of depth strata sampled ultimately may differ from 4, and (d) it considered only a test of the null hypothesis that there is no overall effect of depth strata on CPUE and therefore does not consider the potential effects of covariates.

ESA Take Considerations

The field work conducted for this study could potentially result in the take of State- and Federally-listed fish species. The potential take of listed species for this study was estimated using data from the 33 years (1980-2012) of midwater trawl sampling conducted at site 325 in the CDFW Bay Study. In the entire history of sampling at site 325 in the CDFW Bay Study, there have been no green sturgeon, and only a single delta smelt and a single steelhead collected, thus we do not anticipate collecting any of these species during this study. During this time

period there have been 4,355 age-0 longfin smelt, 1,925 age-1+ longfin smelt, and 125 juvenile Chinook salmon (of unknown race) collected at site 325. Thus, we anticipate collecting age-0 and age-1+ longfin smelt (indeed, they are the focus of this study) and also possibly collecting juvenile Chinook salmon during this study.

The occurrence of age-0 longfin smelt, age-1+ longfin smelt, and juvenile Chinook salmon in midwater trawl samples at site 325 is highly seasonal (Figs. 9 and 10). We considered data collected during the month of June to estimate the take of age-0 longfin smelt, age-1+ longfin smelt, and juvenile Chinook salmon for this study. The average number of individuals collected per tow was as follows: juvenile Chinook salmon =1, age-0 longfin smelt = 76, and age-1+ longfin smelt = 5. Extrapolating these average values to the approximately 48 tows that we anticipate conducting in this study results in total estimated take levels as follows: juvenile Chinook salmon = 96, age-0 longfin smelt = 3,648, age-1+ longfin smelt = 288.

The take of individual longfin smelt and juvenile Chinook salmon during this study is not expected to affect the status of either species. It should first be noted that the juvenile Chinook salmon collected during this study are expected to consist primarily of fall- and late-fall run individuals. Although it is possible that individual juvenile spring-run or winter-run Chinook salmon could be collected, it is unlikely based upon outmigration timing. To the extent possible, sampling will be conducted with the SmeltCam affixed to the midwater trawl in order to maximize the opportunity for non-lethal take. Any individual juvenile Chinook salmon collected in nets with traditional cod ends will be gently handled and released back to the water alive. Longfin smelt collected in nets with traditional cod ends will be retained for further examination in the laboratory at a later time. Potential uses for these individual include examining their stomach contents for diet characterization, and examining their otoliths to determine age, growth, natal origin, migration history, as well as numerous other applications. Overall, the results of this study are expected to provide net benefits to the species by improving our understanding of their ecology and habitat use that can guide management decisions and habitat restoration actions.

Budget

The total budget for this study is \$370,680 (see attached USGS and ICF Budget sheets for details). This includes all labor, equipment, and identification services. This budget estimate does not include services provided by Sureworks. Sureworks budget might be available through the existing SFCWA budget. Budget estimates for ICF (\$206,878) and USGS (\$163,802) are provided separately because we assume they will go under different contract vehicles.

Labor	Totals	
ICF International		\$158,705
USGS		\$127,022
staff benefits @%	included	
TOTAL LABOR		\$285,727
OPERATING EXPENSES		
Travel and Per Diem		
ICF		\$8,173
USGS		\$15,089
Boat (Turning Tide) and vehicle rental		\$16,976
Equipment		
ICF		\$17,500
USGS		\$4,715
Subcontractor (BSA)-Identification services		\$22,500
TOTAL OPERATING EXPENSES		\$84,953
SUBTOTAL LABOR + OPERATING EXPENSES		\$370,680
OVERHEAD @ % (Less Equipment)	Included	
GRAND TOTAL		\$370,680

Longfin smelt vertical distribution studies

Deliverables

Deliverables will include at least one manuscript submitted to a peer reviewed journal and, as requested, presentations at conferences and to representatives, designees and staff of Metropolitan Water District.

Literature Cited

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Survey	Life Stage	Duration	Habitat/Gear Type	Location
Fall Midwater Trawl	Age 0, Adult	Sept-Dec	Oblique/ Midwater	San Pablo to
1967-Present			trawl	Delta
Chipps Island Trawl	Age 0, Adult	Jan-Dec	Oblique/Midwater	Chipps Island
1976-Present			trawl	
Bay Study	Age 0, Adult	Jan-Dec	Oblique/Midwater	Estuary wide
1980-Present			Demersal/Otter Trawl	
Smelt Larval Survey	Larvae	Jan-Mar	Oblique tow/Larval net	San Pablo to
2009-Present			(505 μ mesh) on sled	Delta
20 mm Survey	Larvae, post	Mar-July	Oblique tow/ Larval net	San Pablo to
1995-Present	larvae		(1600 μ mesh) on sled	Delta
Townet Survey	Post-larvae,	May-Aug	Oblique tow/Net on	San Pablo to
1959-Present	Juveniles		sled	Delta

Table 1. Fish Monitoring Surveys in the San Francisco Estuary

Table 2. Approximate time frame for study elements.

Calendar year	Element	Approximate timing
2015	Pilot study	Late Spring/early Summer 2015
2015	First vertical distribution study	Late Summer/early Fall 2015
2016	Second vertical distribution study	Summer 2016

Figure 1. Ratio of Midwater Trawl (MW) to Otter Trawl (OT) longfin smelt CPUE from the Bay Survey from 1980 to 2011. The ratio over time has decreased, suggesting there has been a change in detection, catchability, or habitat use of longfin in the MW trawl over time.



Figure 2. Schematic diagram demonstrating the conceptual model explaining the divergent patterns in longfin smelt catch in otter trawl and midwater trawl samples from the CDFW Bay Study at site 325. The conceptual model posits that longfin smelt are distributed near the channel bottom. This results in larger catches in the otter trawl samples than the midwater trawl samples. This is because the otter trawl is positioned along the channel bottom for the entire duration of a tow, while the midwater trawl is pulled obliquely through the water column and is therefore positioned near the channel bottom where longfin smelt are distributed for only a short duration of tow.



Figure 3. Schematic diagram demonstrating the sampling strategy that will be employed to test the conceptual model explaining the divergent patterns in longfin smelt catch in otter trawl and midwater trawl samples from the CDFW Bay Study at site 325. The conceptual model posits that longfin smelt are distributed near the channel bottom. This will be tested by sampling for longfin smelt at up to 4 fixed independent depth strata, and also with an oblique tow for direct comparisons to samples representative of the CDFW Bay Study.



Figure 4. Map of the San Francisco Estuary shown with study sites from the CDFW Bay Study. Site 325, highlighted in red, is the location where the longfin smelt vertical distribution studies will be conducted.





Figure 5. Catch frequency of longfin smelt in the OT and MW by station.

Figure 6. Map showing the bathymetry of San Pablo Bay and that site 325 is located in the deep, main center channel where strong tidal currents generate vertical structure in physical habitat features important for elucidating vertical distribution of longfin smelt. Hotter colors indicate greater depth.



Figure 7. Frequency histograms of the count of age-0 longfin smelt collected per tow across months at CDFW Bay Study site 325, 1980-2012. Note that both the vertical and horizontal axes are truncated and do not show the full range of the data.



Panel variable: Month

Figure 8. Graphical display of the results of a power analysis testing the null hypothesis that there is no overall treatment effect of 4 independent depth strata on age-0 longfin smelt CPUE. The horizontal dashed line is set to $\alpha = 0.05$.



Power Curve for One-way ANOVA

Figure 9. Boxplot representation of the number of longfin smelt collected per tow across months at CDFW Bay Study site 325, 1980-2012.



Figure 10. Boxplot representation of the number of juvenile Chinook salmon collected per tow across months at CDFW Bay Study site 325, 1980-2012.

