The Distribution and Abundance of Larval and Adult Longfin Smelt in San Francisco Bay Tributaries

Year 1: Pilot Study

Prepared by:

James Hobbs, Christina Parker, Jon Cook and Micah Bisson
Department of Wildlife, Fish and Conservation Biology
University of California-Davis

Prepared for:

California Department of Water Resources
3500 Industrial Blvd.
West Sacramento, Ca. 95691

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The IEP Longfin Smelt Project Work Team

INTRODUCTION

The longfin smelt (*Spirinchus thaleichthys)* was once one of the most abundant fishes in San Francisco Bay and Humboldt Bay and even supported a commercial bait fishery until the early 1970's (Moyle 2002). Like several pelagic fishes of the upper San Francisco Estuary, the longfin smelt experienced a marked decline since 2001, which contributed to its listing as "threatened" under the State Endangered Species Act [1](Baxter 2009; Sommer et al. 2007; CESA; Fish and Game Code §2050). Many factors have been associated with this "pelagic organism decline" (POD) including increased freshwater diversions, decreased low-salinity habitat, reduced prey abundance, and frequent toxic algal blooms. All of these impacts occur within larval habitats of the longfin smelt to various degrees (Armor et al. 2005; Feyrer et al. 2007b; Lehman et al. 2008; Sommer et al. 2007; Kimmerer et al. 2009). Despite the long-term decline in abundance of longfin smelt, the species has continued to exhibit a relatively strong abundance trend with freshwater outflow, as indexed by the spring mean position of X2. The mechanism driving this relationship remains a key uncertainty in understanding the response of estuarine biota, including the longfin smelt, to management of freshwater flows.

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 the SFE (Merz et al 2014; Hobbs et al. 2010). Juvenile and adult Longfin Smelt are sensitive to warm water conditions (>18°C) in the summer-early fall, and can be found evading warm waters by either residing in deep, cool, bay channel habitats or, exiting the SFE and residing in coastal marine habitats (Rosenfield and Baxter 2007). Our current knowledge regarding spawning habitat is based on observations of catch by IEP surveys long-term

[1] On March 4, 2009 the Fish and Game Commission (Commission) made a final determination that the listing of longfin smelt as a threatened species was warranted. The Commission has initiated a rulemaking process to officially add longfin smelt to the California Endangered Species Act (CESA) list of threatened species found in the California Code of Regulations (CCR), Title 14, section 670.5(b)(2). At the completion of this rulemaking process, the longfin smelt's status will officially change from candidate to threatened.

monitoring surveys in Suisun Bay and the confluence of the Sacramento and San Joaquin River, and UC Davis surveys in Suisun Marsh. Mature individuals have been observed in the Delta near the confluence of the Sacramento and San Joaquin rivers starting in December extending through March (Rosenfield and Baxter 2007). Spawning is thought 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 in Suisun Bay and other Bay tributaries to spawn, particularly during wet years (Grimaldo et al. 2014). Recently, maturing adults have been discovered in the Alviso Marsh located in Lower South Bay from December through March (Hobbs unpublished data). However; offspring from spawning in the Alviso Marsh has not been found.

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, understanding the spatial distribution of spawning and successful recruit may elucidate the underlying mechanism driving the longfin smelt abundance-X2 relationship, as higher freshwater flows could enhance spawning and survival of longfin smelt utilizing tributaries to San Pablo Bay and South Bay. In this study, the geographic distribution of maturing adults and larvae is being investigated by extending monitoring surveys into bay tributaries to San Pablo Bay including the Napa River and adjacent marsh, Sonoma Creek, the Petaluma River, and adjacent marsh and Coyote Creek and Alviso Marsh in Lower South Bay. This report covers the pilot year of a 5-year study investigating the role of tributaries to Longfin Smelt recruitment.

STUDY DESIGN & METHODS

Beginning in January of 2015, the pilot study was launched in the major tributaries to San Pablo Bay and Lower South Bay (Figure 1). Study sites included the Napa River and the adjacent sloughs of the marsh habitats, Sonoma Creek (Figure 2), The Petaluma River and adjacent sloughs including San Antonio Creek, which flows in from the west side of the Petaluma wildlife refuge (Figure 1). In Lower South Bay, Coyote Creek, Artesian Slough and Alviso Slough, areas connected to freshwater flows from local streams and wastewater effluent were samples (Figure 3). Six bi-weekly surveys were conducted in each tributary system starting in early January 2015 and concluding the last week in March (Table 1). Stations within each tributary and survey were stratified across salinity zones, from freshwater; 1-3ppt, 4-6ppt, 7-9ppt and greater than 10ppt to encompass the ranges of salinity, larval longfin smelt may occupy. In addition, fixed sites in sloughs were sampled. Often, freshwater sites were not found in many of the tributary sites. At a minimum a single tow was conducted in the identified salinity zones per survey, and when possible multiple tows were conducted within the salinity zones.

Adult longfin smelt were sampled using a standard four-seam otter trawl with a 1.5-m depth- 4.3-m width 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. Trawls were towed for 5 minutes at ~3mph in small sloughs (<3-m deep and <70-m wide) and for 10 minutes in larger sloughs (>3-m deep and >70-m wide). Trawls were always oriented into the tidal current, and volume sampled was approximated with a General Oceanics flow meter deployed from the bow of the boat. All fish were identified to species, counted and the first thirty individuals measured for standard length. Larger invertebrates (clams, shrimps, snails) were identified to species and counted and smaller invertebrates (amphipods, isopods, mysid shrimp) were given a rank abundance from 1 to 5. For this report catch per unit of effort (CPUE) was quantified by dividing the counts of each species by the number of minutes of trawling.

Larval longfin smelt were sampling using the DFW "Smelt Larval Survey" sled, a cone shaped net 3.35-m in length with a mouth area of $0.37m^2$. The net is mounted on a weighted tow net steel frame with skids. The net consisted of 505µm Nitex mesh netting with a cylindrical front section with a canvas mouth and a funnel shaped rear section with a canvas throat attaced to a cod-end jar. A General Oceanics flow meter was mounted across the mouth of the net, located in the center of the mouth of the net. The volume sampled by the net was estimated using the following equation.

$$v_{m3} = (Number\ of\ rotations) \times (K\ Factor) \times (net\ area\ m^2\ )$$

Where, the K-factor = 0.026 and the net area = 0.37.

The net was towed against the direction of the current, using a stepped oblique approach, dividing the water column depth into 5 equal sections and towing for 2 minutes in each depth zone. Depths in most slough habitats was typically less than 3-m, resulting in only two depth sections. Tows were conducted at 1-1.5mph for 10 minutes. At times, geographic position was held constant when tidal flows exceeded the capacity for the sled to stay below the surface. Flow meter revolutions were monitored to target ~20,000 revolutions per tow (*our average was 20,087*). The contents of the net were washed down by spraying the outside of the net with a wash down pump. All contents were preserved in 10% buffered formalin on board and returned to the lab. Water quality was measured at the surface and ~1-m from the bottom and the beginning and end of each tow when depths were greater than 2.5-m, otherwise only surface water quality was measured. Water quality parameters included temperature °C, salinity-ppt, conductivity-µs, dissolved oxygen-mg/L and % saturation and secchi depth-cm. To evaluate longfin smelt larval catch with water quality condition the average of surface, bottom and beginning and ending water quality variables were used.

Priority samples (*when available, minimum of 1 tow in each salinity zone and tributary*) were delivered to Tenera Environmental for sorting and larval fish identification. Standard lab procedure for Tenera required splitting of plankton samples, when the total volume exceeded 1-L and the total number of larvae counted exceeded 200 individuals. All samples split by Tenera were brought back to UC Davis and the remainder of the sample was sorted and larval fish were removed to further identify any larval longfin smelt in the sample.

UCD Procedures.

RESULTS

From January 3rd to March 22nd, we conducted 146 tows with the SLS sled among 4 major bay tributaries, and a total of 18 tidal sloughs and creeks (Tables 1-6). A total of 33 larval longfin smelt, ranging from 6.5 to 12.2 mm TL, were encountered during the first year of this survey, only 3 of which had yolk-sacs intact. During survey 1, salinities were generally lower in the San Pablo Bay tributaries, ranging from 1.7 to 8.7ppt compared to South Bay tributaries. Temperatures among all tributaries were seasonally low ranging from 6.8 to 11.1°C, with the exception of station ART-1, which was consistently warmer due to the proximity to wastewater effluent. DO conditions were generally well within normal range for winter in the SFW (Table 1) Larval longfin smelt were found in the Napa River above the Hwy 12 overpass and in the river adjacent to Fagan Slough in the 1-3ppt salinity zone, and in Napa Slough in the 7-9ppt salinity zone (Figure 2). A single individual was also found in the Petaluma River near the Hwy 101 overpass in the 1-3 salinity zone (Table 1). No larval longfin smelt were found in any stations within the Lower South Bay during all 6 surveys (Tables 1-6). In survey 2, salinity in the Napa River and marsh was higher, ranging from 10.1-14.3ppt, than the previous survey in the Napa River and was greater than salinity in Sonoma Creek and the Petaluma River. Temperature was also higher in the Napa River during survey 2 (Table 2). Larval longfin smelt were found at 2 stations within the Petaluma River in the 4-6 and 7-9ppt salinity zones (Figure 2). During survey 3, Salinity at all tributary sites was lower than the previous surveys as a small winter storm passed through Northern California days before survey 3. Temperatures were generally warmer amongst sites in the San Pablo Bay tributaries than previous surveys, with temperatures ranging from 11.9 to 14.2 °C. DO in South Bay was lower than previous surveys ranging from 4.9 to 5.8 mg/L (Table 3). Larval longfin smelt were found in the Petaluma River at two stations in the 4-6ppt zone, in the Napa River, near downtown Napa in the 4-6ppt and 7-9ppt salinity zones, and at two stations in Sonoma Creek in the 7-9ppt salinity zone (Figure 4). During survey 4, only two larval longfin smelt were found in the Petaluma River at a single station in the 1-3ppt zone (Figure 5). Water temperatures continued to increase among all bay tributaries, while salinity variability among tributaries increased as sites further upstream were sampled with lower salinity (Table 4) During survey 5, sampling effort was increased and longfin smelt larvae were found at three stations in the Napa River between downtown Napa and the Hwy 12 overpass in the 1-3ppt, 4-6ppt and the 7-9ppt, and at a single station in the Petaluma River in the 1-3ppt zone (Table 5). Water temperatures in San Pablo Bay tributaries were warmer, ranging from 12.6 to 15.8°C, with temperatures in Lower South Bay exceeding 20°C (Table 5). In survey 6, no larval longfin smelt were found (Figure 6). Water temperatures in all San Pablo Bay tributaries exceeded 16 °C and salinities ranged from 3.2 to 10.9ppt, with the upper reaches of each tributary exceeding 6ppt. Along with elevated temperatures, DO concentrations were lower among all bay tributaries, ranging from 5.7 to 8.7 mg/L in San Pablo Bay tributaries and 4.5 to 9.2 mg/L in Lower South Bay tributaries. (Table 6).

The extremely high proportion of zero catches precluded an in-depth statistical treatment of the CPUE data across bay tributaries and salinity zones, therefore we present means of CPUE by categorical variables; tributary, salinity zone and survey and with smoothed plots of CPUE continuous variables; salinity, temperature, secchi and depths to describe general trends. CPUE tended to be higher in the Napa and Petaluma Rivers; mean CPUE was 3.1 ± 6.0 σ in the Napa River, 2.7 ± 5.7 σ in the Petaluma and 1.0 ± 3.0 σ in Sonoma Creek (Figure 10), while CPUE tended to be higher in the higher salinity zones; no catch in freshwater and the mean CPUE in the 1-3ppt was 2.4 ± 4.4 σ, in 4-6ppt was 2.5 ± 5.5 σ, in 7-9ppt was 4.2 ± 7.1 σ (Figure 11). Across surveys, CPUE tended to be highest during survey 3; mean CPUE for survey 1 was 3.2 ± 7.3 σ, for survey 2, 2.2 ± 5.3 σ for survey 3 6.3 ± 6.8 σ, survey 4 0.1 ± 0.5 σ, survey 5 1.7 ± 4.0 σ and no larval longfin smelt were found in survey 6 (Figure 12). Longfin smelt CPUE did not show a significant trend across salinities from 1 to 9ppt and no larvae where found above 10ppt (Figure 12), while CPUE also did not vary across the temperatures observed from 9-14 °C, with no larvae found above 15 °C (Figure 13). CPUE tended to be higher at shallow depths 6-10ft, but did not show any trend with cecchi depths encountered from 20-80cm (Figure 14)

During the 6 surveys in 2015, we conducted 198 otter trawls and captured 59 longfin smelt ranging from 23mm to 111mm standard length. The majority of longfin smelt were classified as Age 1+ using the length-at-month age criteria for longfin smelt; only 3 individual were classified as YOY and only a single individual was classified as age 2+. The three YOY individuals were collected in the Napa River at stations NAP-2 and NAP-5 during survey 5, and ranged in lengths from 23-28mm SL. A total of 43 adult longfin smelt were collected in 94 otter trawl stations (23 % of trawls) in the Coyote Creek tributary (mean CPUE 0.08 ± 0.19 σ), and were found in all 6 surveys conducted in 2015 (Table 7). Adult longfin smelt were found at 14 of the 22 fixed stations including 4 tidally restored salt ponds (Ponds A6, A17, A19 and A21) and sloughs sampled and mean CPUE was similar between restoration ponds and sloughs (Figure 15). A total of 2 adult longfin smelt were captured among 39 otter trawl stations (10% of trawls) in the Napa River (mean CPUE 0.02 ± 0.079 σ). One adult was found at station NAP-1 during survey 6 in the 1-3ppt salinity zone, while the second adult was captured at NAPS-2 in survey 1 (Table 7). Three YOY were collected in the otter trawls during survey 5 at stations NAP-2 and NAP-5 (Figure 16). A total of 11 adult longfin smelt were captured among 41 otter trawl stations (17% of trawls) in the Petaluma River (mean CPUE 0.03 ± 0.084 σ) in survey 3-5 (Table 7. Adults were encountered as station PET-1 and PET-4 in survey 3; PET-7,8 and 9 in survey 4, and PET-5 and 7 during survey 5 (Figure16).

DISCUSSION.

The pilot "Smelt Larval Survey-Bay Tributaries" in 2015 discovered for the first time, evidence of bay tributary spawning of longfin smelt. Larval stage longfin smelt were encountered during 5 of the 6 bi-weekly surveys conducted from the first week in January through the end of March, in the Napa River and marsh, Sonoma Creek and the Petaluma River. In addition, adult longfin smelt were encountered in the same areas larvae were encountered providing further support that longfin smelt are utilizing these bay tributaries for spawning. Longfin smelt are thought to stage in San Pablo Bay during the fall months once water temperatures decrease to around 18 °C (*R. Baxter personal communication*), and spawn around the confluence of the Sacramento and San Joaquin Rivers and Delta in fresh or very low salinity waters. The ultimate cues for the movement of longfin smelt from staging areas to spawning habitats is not known for certain, but is likely a function of freshwater flows and temperature. Longfin smelt staging in San Pablo Bay, may be cued to move up the Napa, Petaluma River and Sonoma Creek when winter rains result in small flow pulses coming from these tributaries. Moreover, due to the lack of water storage on these tributaries, storm events would cause flow pulses from these areas before a flow pulse from the Sacramento or San Joaquin Rivers, thus it is possible, longfin smelt in spawning condition would utilize the San Pablo Bay tributaries prior to the spawning pulse at the Sacramento-San Joaquin confluence. However; in 2015 longfin smelt larvae collected during survey 1 in the bay tributaries were similar in length (6-9mm TL) to the DFW SLS survey during the same week. Therefore, we did not see evidence of earlier spawning in bay tributaries in 2015.

Larval longfin smelt densities in bay tributaries were generally much lower than those found in Suisun Bay by the California Department of Fish and Wildlife (DFW) during 2015 (http://www.dfg.ca.gov/delta/data/sls/CPUE_Map.asp). Bay tributaries densities ranged from 1-30 fish per 1,000 cubic meters sampled, while densities in Suisun Bay often exceeded 130 fish per 1,000 cubic meters sampled. Gear efficiency is not a likely explanation for the differences in densities as we used the same net as the DFW surveys and followed all DFW sampling protocols. Thus, larval densities and subsequent total spawning efforts in the bay tributaries were lower than near the confluence and Suisun Bay in 2015. Relative survival also appeared to be less in bay tributaries than Suisun Bay as densities declined rapidly in the San Pablo Bay tributaries and no larvae greater than 12mm TL was encountered during our surveys with the SLS net. We did encounter 3 juveniles in our otter trawl surveys in the Napa River during survey 5, thus some larvae may have survived, however subsequent s surveys have not found juvenile longfin smelt since this survey. Larval longfin smelt were encountered in relatively high salinities, with the highest densities occurring in 7-9ppt. Grimaldo et al. (2014) found high densities of larval longfin smelt in Suisun Bay tidal marshes at similar salinities and concluded that longfin smelt may spawn and successfully rear at these salinity ranges. However; there is considerable uncertainty regarding survival of larval longfin smelt at different ranges of salinity. In laboratory trials, larval longfin smelt were shown to have lower hatching success, first feeding success and survival in salinities greater than 4ppt (Hobbs et al. 2013). Laboratory trials were conducted with NaCl, and results were questioned. Follow up studies using Instant Ocean ® (having a multi-mineral content) showed better overall rearing conditions, but full experimental trials were not conducted due to funding limitations (G. Tigan person communication). Using otolith micro-chemistry, Hobbs et al (2010) found evidence for natal rearing in salinities greater than 4ppt in adult longfin smelt collected near Chipps Island during the spawning season in 2007 and 2008, thus it is likely larvae can survive these conditions. However, a greater proportion of adult longfin smelt rearing in brackish waters was associated with the Pelagic Organism Decline, thus survival and ultimate recruitment success and year-class strength may be lower when longfin smelt rely solely on brackish nursery habitats (Hobbs et al . 2010).

Adult longfin smelt CPUE was approximately 4 times greater in Lower South Bay tributaries than in San Pablo Bay tributaries in 2015. This was consistent with otter trawl surveys conducted from 2010-2014 in the Alviso Marsh area of Lower South Bay (Hobbs unpublished data) where adult longfin smelt have been consistently found utilizing newly restored salt ponds in the range of 1-30 fish per otter trawl between December and March. Despite the relative high abundance of adult longfin smelt in the Alviso Marsh during the spawning season, no larvae we found in 2015. Additional larval fish sampling in the Alviso Marsh during the 2012 and 2013 resulted in zero larval longfin smelt catches. The Lower South

Bay tributaries receives much less freshwater flows from the local tributaries (Guadalupe River and Coyote Creek) which average only 1-5 cubic feet per second (CFS) flows with short pulse flows in the range of 1,500 CFS following storms than the Sacramento and San Joaquin Rivers which can often exceed 50 – 100,000 CFS in winter and the Napa River which can contribute 100-1000 CFS. The greatest, consistent input of freshwater flow into the Lower South Bay occurs in Artesian Slough, the location of the San Jose-Santa Clara Wastewater effluent, which provides ~ 70-90 million gallons of tertiary treated freshwater daily. Salinity was consistently high (8-20ppt) in Coyote Creek during 2015 and only single storm event created freshwater condition in the upper-most reach of Coyote Creek in the Alviso Marsh where longfin smelt adults occurred. Longfin smelt found in the Coyote Creek tributary may not spawn in the Lower South Bay. We cannot rule out that these fish migrate to the Delta to spawn. However; collections of adult longfin smelt from 2010 to 2014 revealed a few adult fish in spawning condition; one female extruded ripe eggs when captured and a second milted when handled (Hobbs personal observations). In addition many fish appear to be developing gonads while residing in the Alviso Marsh during the winter (Hobbs unpublished data). During the 1982-83 El Nino, the San Francisco Bay study conducted larval fish surveys in the South Bay, and found post-larval longfin smelt, and length-frequency distributions by station suggested larvae were coming from the Coyote Creek tributary (Baxter 1999). Thus, if freshwater flows are high, successful rearing could occur in the Lower South Bay.

Longfin smelt abundance indices in the DFW Fall Midwater Trawl have shown significant linear increases with high freshwater outflow from the Sacramento-San Joaquin River and with the spring time mean position of X2 (where bottom salinity averages 2ppt) (Kimmerer 2002b; Baxter 2009). The mechanism underlying this relationship has remained elusive, despite numerous studies (Kimmerer et al. 2009, 2002a,b). Spawning and successful rearing in San Pablo Bay and other tributaries to the SFE may be associated with the abundance-X2 relationship. High freshwater flows from the Sacramento-San Joaquin River and an X2 position in San Pablo Bay and even as far west as Central Bay could facilitate successful recruitment of young spawned within bay tributaries, adding to the abundance of fish. In 2015 we saw generally low numbers of adults and larvae in San Pablo Bay tributaries, but high numbers of adults in Lower South Bay. Thus data were inconclusive for this mechanism, but a high flow year would be required to adequately address this hypothesis. Alternatively, high outflow may facilitate better nursery habitat conditions within San Pablo Bay and the large marsh habitats in the Napa River system. In 2015, a critical drought year, we found generally poor recruitment success of young longfin smelt in the San Pablo Bay tributaries, which would be consistent with this mechanisms, but again we would require a high flow year to begin to address these questions.

CONCLUSION

In this first "pilot" study year of a five year study to explore the distribution and abundance of larval and adult longfin smelt in SFE bay tributaries, we successfully deployed the DFW "Smelt Larval Survey" gear and found longfin smelt larvae far upstream the Napa, Petaluma River and Sonoma Creek in a critically dry year. In addition adult longfin smelt found in the general area provided further evidence that longfin smelt will move up into bay tributaries to spawn.

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Table 1. Survey 1dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek.

Survey	Date	Time	Tributary	Station ID	Temp	Secchi	Salinity	EC	DO	CPUE
1	1/3/2015	9:11	NAP	FAG-1	7.4	21	4.8	5688	9.9	0
1	1/3/2015	11:33	SON	SON-1	6.8	22	2.0	1930	10.6	0
1	1/3/2015	12:14	SON	SON-2	7.1		4.2	5121	10.0	0
1	1/4/2015	8:40	ART	ART-1	18.0	77	2.1	3357	6.9	0
1	1/4/2015	9:09	ART	ART-2	10.1	33	14.7	17318	8.2	0
1	1/4/2015	10:25	COY	A19-1.1	9.2	20	17.7	20085	7.9	0
1	1/4/2015	14:20	COY	A19-1.2	10.3	-	19.2	22226	8.9	0
1	1/4/2015	10:00	COY	Coy-1 E.1	9.0	-	17.6	19833	8.1	0
1	1/4/2015	13:55	COY	Coy-1 E.2	10.0	-	19.4	22298	8.5	0
1	1/4/2015	9:30	COY	Coy-1 W.1	8.9	-	17.7	19944	8.3	0
1	1/4/2015	13:35	COY	Coy-1 W.2	9.4	-	21.2	23839	7.8	0
1	1/9/2015	10:27	PET	PET-1	6.9	26	1.7	2748	8.9	5.21
1	1/9/2015	11:22	PET	PET-2	7.8	26	2.2	3647	8.3	0
1	1/9/2015	12:07	PET	PET-3	8.3	23	2.6	4281	8.5	0
1	1/9/2015	15:30	PET	PET-4	8.4	19	6.5	9902	8.3	0
1	1/9/2015	13:15	PET	PET-5	8.3	18	4.7	7345	7.9	0
1	1/9/2015	14:19	PET	SAN-1	8.4	18	6.4	9808	8.4	0
1	1/11/2015	10:46	NAP	MUD-1	10.4	37	8.3	10341	7.9	0
1	1/11/2015	11:34	NAP	NAP-2	10.7	35	8.7	10822	8.5	6.10
1	1/11/2015	10:10	NAP	NAPR-1	10.4	48	6.6	8252	8.7	26.87
1	1/11/2015	12:02	NAP	POND-5	11.1	25	8.8	11135	7.4	0
1	1/11/2015	9:45	NAP	STEM-1	10.0	43	6.2	7776	8.0	0
1	1/11/2015	13:30	NAP	NAP-1	10.5	80	0.5	1034	9.9	9.94

Table 2. Survey 2 dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ALV = Alviso Slough; ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek..

Survey	Date	Time	Tributary	Station #	Temp	Secchi	Salinity	EC	DO	CPUE
2	1/24/2015	8:23	ALV	ALV-1	12.1	35	16.6	20398	10.4	0
2	1/24/2015	9:22	ALV	ALV-3	12.2	18	19.9	24087	7.1	0
2	1/25/2015	9:02	ART	ART-1	19.7	110	2.0	2804	5.1	0
2	1/25/2015	9:33	ART	ART-2	18.1	56	5.7	8691	9.4	0
2	1/25/2015	10:27	ART	ART-3	17.0	22	7.7	11256	7.1	0
2	1/24/2015	11:52	COY	COY-2	14.5	28	13.2	17558	9.1	0
2	1/25/2015	12:38	COY	UCOY-2	12.8	45	8.3	10972	7.6	0
2	1/26/2015	11:40	NAP	FAG-1	11.3	35	13.2	16207	7.1	0
2	1/26/2015	10:55	NAP	NAPS-1	11.1	25	14.3	17354	7.0	0
2	1/26/2015	10:32	NAP	NAPS-2	10.8	32	10.5	12910	7.1	0
2	1/26/2015	11:59	NAP	NAPR-1	11.8	35	10.0	68155	7.1	0
2	1/26/2015	10:16	NAP	NAPS-4	10.6	25	10.1	12412	6.9	0
2	1/26/2015	12:21	NAP	STEM-1	10.9	22	10.1	12513	7.3	0
2	1/22/2015	8:52	PET	PET-1	10.9	29	2.7	3682	8.0	0
2	1/22/2015	12:00	PET	PET-2	11.7	23	5.2	6925	7.5	9.15
2	1/22/2015	11:17	PET	PET-5	12.0	22	7.2	9395	8.5	17.36
2	1/22/2015	10:25	PET	PET-6	10.9	26	8.8	1959	8.4	0
2	1/26/2015	9:18	SON	SON-1	10.6	18	7.8	9701	7.6	0
2	1/26/2015	9:42	SON	SON-2	10.4	20	4.8	6159	7.2	0

Table 3. Survey 3 dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek..

Survey	Date	Time	Tributary	Station #	Temp	Secchi	Salinity	EC	DO	CPUE
3	2/7/2015	9:10	ART	ART-1	19.4	100	4.5	5743	5.7	0
3	2/7/2015	10:00	ART	ART-2	18.3	45	6.2	9459	5.8	0
3	2/7/2015	10:39	ART	ART-3	17.3	25	6.0	10698	5.1	0
3	2/7/2015	11:17	ART	ART-4	16.6	30	6.6	9733	4.9	0
3	2/7/2015	12:00	COY	UCOY-1	16.1	18	0.4	1741	5.3	0
3	2/7/2015	12:29	COY	UCOY-2	16.7	25	5.5	8101	4.9	0
3	2/4/2015	8:06	NAP	NAP-1	11.9	70	2.1	2883	8.4	0
3	2/4/2015	9:04	NAP	NAP-2	12.5	65	5.3	7130	7.8	13.84
3	2/4/2015	9:43	NAP	NAP-3	13.4	60	6.7	9039	7.9	5.74
3	2/4/2015	10:30	NAP	NAP-4	13.8	48	9.2	12295	7.3	7.62
3	2/5/2015	8:09	PET	PET-1	12.4	45	3.8	5178	8.0	21.15
3	2/5/2015	8:54	PET	PET-2	12.5	45	4.6	6315	8.1	0
3	2/5/2015	9:43	PET	PET-3	13.0	40	6.4	8528	7.9	6.75
3	2/5/2015	10:26	PET	PET-4	13.5	45	8.8	11721	7.0	0
3	2/4/2015	12:58	SON	SON-1	13.8	25	5.4	7483	7.6	0
3	2/4/2015	13:58	SON	SON-2	14.2	30	7.1	9825	7.4	9.02
3	2/4/2015	14:35	SON	SON-3	13.6	40	9.2	12188	7.7	0
3	2/4/2015	15:15	SON	SON-4	13.7	30	9.3	6727	7.7	10.86

Table 4. Survey 4 dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ALV = Alviso Slough; ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek..

Survey	Date	Time	Tributary	Station #	Temp	Secchi	Salinity	EC	DO	CPUE
4	2/21/2015	15:48	ALV	ALV 1	17.6	30	18.3	24965	6.9	0
4	2/21/2015	10:15	ALV	ALV 3	16.5	30	15.9	21252	13.4	0
4	2/22/2015	9:00	ART	ART 1	19.7	70	4.8	7582	8.0	0
4	2/22/2015	9:49	ART	ART 2	19.3	44	6.9	10722	8.5	0
4	2/22/2015	10:40	ART	ART 3	19.3	40	7.6	10659	8.4	0
4	2/22/2015	13:39	COY	A19 1	17.0	20	14.0	19477	6.7	0
4	2/21/2015	13:11	COY	A21 4	16.9	23	17.7	24169	7.2	0
4	2/21/2015	12:20	COY	COY 2	17.2	22	17.0	23365	6.9	0
4	2/21/2015	11:22	COY	COY-4	16.0	18	20.8	27438	6.8	0
4	2/22/2015	11:35	COY	UCOY 1	15.8	28	8.0	11320	6.2	0
4	2/14/2015	7:45	NAP	NAP-1	13.2	45	0.3	442	7.3	0
4	2/14/2015	8:55	NAP	NAP-2	14.3	40	2.6	3902	6.5	0
4	2/14/2015	10:00	NAP	NAP-3	15.2	32	6.0	8531	5.9	0
4	2/14/2015	11:01	NAP	NAP-4	16.3	45	7.7	11137	5.7	0
4	2/14/2015	13:00	NAP	NAPS-1	17.6	30	9.2	13455	6.0	0
4	2/14/2015	13:20	NAP	NAPS-2	16.8	20	8.5	12346	5.9	0
4	2/14/2015	13:44	NAP	NAPS-3	17.3	28	7.8	12686	5.5	0
4	2/13/2015	7:42	PET	PET-1	13.2	20	0.7	1000	5.4	0
4	2/13/2015	8:28	PET	PET-2	13.4	25	2.3	3264	5.8	1.82
4	2/13/2015	9:25	PET	PET-3	13.8	20	4.9	6731	5.3	0
4	2/13/2015	10:15	PET	PET-4	14.7	25	8.6	9014	5.6	0
4	2/13/2015	11:14	PET	PET-5	15.6	35	13.5	18318	5.9	0
4	2/15/2015	8:06	SON	SON-1	14.5	22	2.0	3069	6.1	0
4	2/15/2015	9:30	SON	SON-2	15.3	26	3.3	4858	6.0	0
4	2/15/2015	10:35	SON	SON-3	16.5	40	5.2	7711	6.4	0
4	2/15/2015	11:27	SON	SON-4	17.6	30	11.9	16957	6.5	0

Table 5. Survey 5dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ALV = Alviso Slough; ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek..

Survey	Date	Time	Tributary	Station #	Temp	Secchi	Salinity	EC	DO	CPUE
5	3/7/2015	8:43	ALV	ALV 1	16.0	34	13.1	17962	10.0	0
5	3/7/2015	10:05	ALV	ALV3	16.0	31	16.7	22275	9.7	0
5	3/8/2015	9:05	ART	ART1	21.0	70	2.1	3595	8.6	0
5	3/8/2015	9:51	ART	ART2	20.1	49	5.5	8698	9.8	0
5	3/8/2015	10:38	ART	ART3	19.5	36	6.2	9673	9.1	0
5	3/8/2015	13:15	COY	A19 4	18.2	32	10.2	14897	9.0	0
5	3/7/2015	12:40	COY	A21 1	16.9	20	16.9	23141	10.2	0
5	3/7/2015	11:59	COY	COY2	16.8	30	16.2	17892	10.8	0
5	3/8/2015	11:26	COY	UCOY1	16.0	30	5.6	8174	7.9	0
5	3/8/2015	12:25	COY	UCOY2	18.0	30	8.6	12754	9.1	0
5	3/5/2015	7:48	NAPA	NAP1	13.0	80	0.6	948	11.8	0
5	3/5/2015	8:27	NAPA	NAP2	13.7	45	1.4	2149	11.1	10.03
5	3/5/2015	9:07	NAPA	NAP3	14.2	40	2.3	3374	11.6	0
5	3/5/2015	10:20	NAPA	NAP4	14.6	35	3.5	5146	10.8	5.06
5	3/5/2015	11:06	NAPA	NAP5	15.1	35	6.3	8869	10.2	0
5	3/5/2015	11:45	NAPA	NAP6	14.9	45	8.0	11127	10.3	11.90
5	3/5/2015	13:02	NAPA	NAP7	14.8	45	10.7	14539	10.3	0
5	3/5/2015	13:44	NAPA	NAP8	15.8	40	9.7	13503	10.6	0
5	3/6/2015	7:48	PET	PET1	13.5	30	2.7	3782	9.3	12.73
5	3/6/2015	8:34	PET	PET2	13.3	36	3.0	4235	9.5	0
5	3/6/2015	9:50	PET	PET3	13.9	36	4.2	5952	9.6	0
5	3/6/2015	10:49	PET	PET4	14.7	31	6.2	8673	10.2	0
5	3/6/2015	12:05	PET	PET5	14.9	25	8.0	11178	10.1	0
5	3/6/2015	12:28	PET	PET6	14.8	31	9.6	13158	9.7	0
5	3/6/2015	13:13	PET	PET7	14.9	26	11.4	15385	9.6	0
5	3/6/2015	13:52	PET	PET8	15.0	41	13.5	18071	9.8	0
5	3/4/2015	8:25	SON	SON1	12.4	24	4.1	5696	9.8	0
5	3/4/2015	9:09	SON	SON2	13.3	20	3.7	5096	9.3	0
5	3/4/2015	9:50	SON	SON3	13.9	20	4.0	5695	9.8	0
5	3/4/2015	10:30	SON	SON4	14.2	20	6.7	9386	10.6	0
5	3/4/2015	11:30	SON	SON5	14.3	25	6.3	8799	9.7	0
5	3/4/2015	12:04	SON	SON6	14.3	22	8.6	11787	9.8	0
5	3/4/2015	12:51	SON	SON7	13.3	35	13.0	16686	10.0	0
5	3/4/2015	13:28	SON	SON8	12.6	40	15.1	18867	11.0	0

Table 6. Survey 6 dates, tributaries and salinities zones sampled for larval longfin smelt in 2015 by UCD. Data are mean CPUE (1000m^2). Horizontal dash lines represent no sample collections. ALV = Alviso Slough; ART= Artesian Slough; COY = Coyote Creek; NAP=Napa River and marsh; PET =Petaluma River ; SON = Sonoma Creek..

Survey	Date	Time	Tributary	Station #	Temp	Secchi	Salinity	EC	DO	CPUE
6	3/21/2015	15:24	ALV	ALV1	18.9	35	17.8	25304	6.8	0
6	3/21/2015	9:31	ALV	ALV3	18.0	20	15.5	21946	7.0	0
6	3/22/2015	8:53	ART	ART1	21.6	50	3.5	5903	8.1	0
6	3/22/2015	9:44	ART	ART2	20.6	30	7.1	11210	9.2	0
6	3/22/2015	10:30	ART	ART3	20.6	20	7.1	11311	8.2	0
6	3/22/2015	13:45	COY	A19 4	18.8	20	14.3	20821	5.9	0
6	3/21/2015	13:01	COY	A21 1	18.7	25	18.2	25745	6.4	0
6	3/21/2015	12:15	COY	COY2	18.3	25	17.8	25094	6.4	0
6	3/22/2015	11:28	COY	UCOY1	18.0	25	8.6	12739	4.9	0
6	3/22/2015	12:23	COY	UCOY2	18.4	32	12.5	17985	4.5	0
6	3/23/2015	7:59	NAP	NAP1	17.8	38	3.2	5047	8.7	0
6	3/23/2015	8:47	NAP	NAP2	17.9	29	3.8	6058	8.2	0
6	3/23/2015	9:33	NAP	NAP3	18.0	27	5.2	7895	8.1	0
6	3/23/2015	10:22	NAP	NAP4	18.1	38	5.5	8352	6.7	0
6	3/23/2015	11:21	NAP	NAP5	18.0	37	7.3	10873	8.0	0
6	3/23/2015	12:12	NAP	NAP6	18.0	48	8.9	13150	7.8	0
6	3/23/2015	12:57	NAP	NAP7	17.9	46	10.6	15471	7.9	0
6	3/23/2015	13:43	NAP	NAP8	18.2	32	10.9	15875	8.1	0
6	3/24/2015	7:55	PET	PET1	17.8	44	6.1	9280	7.1	0
6	3/24/2015	8:36	PET	PET2	17.7	48	6.2	9417	7.3	0
6	3/24/2015	9:48	PET	PET3	16.9	38	7.6	12091	7.0	0
6	3/24/2015	10:25	PET	PET4	16.9	43	8.4	12128	7.2	0
6	3/25/2015	7:52	SON	SON1	16.2	16	5.8	8336	5.7	0
6	3/25/2015	8:57	SON	SON2	16.0	25	5.6	8160	6.4	0
6	3/25/2015	9:54	SON	SON3	16.7	33	7.4	10352	7.8	0
6	3/25/2015	10:52	SON	SON4	16.9	37	8.3	12076	8.0	0

Table 7. Summary statistics of longfin smelt catch in otter trawls in bay tributaries. COY= Coyote Creek in Lower South Bay, NAP = Napa River, PET = Petaluma River and SON = Sonoma Creek. CPUE calculated as the catch per minute of trawl effort. FO = frequency of occurrence of longfin smelt in trawls among tributaries, reported as the percentage of trawls.

Tributary	Trawls	Catch	CPUE	FO
COY	94	43	0.081	23%
NAP	39	5	0.022	10%
PET	41	11	0.027	17%
SON	24	0	0	0

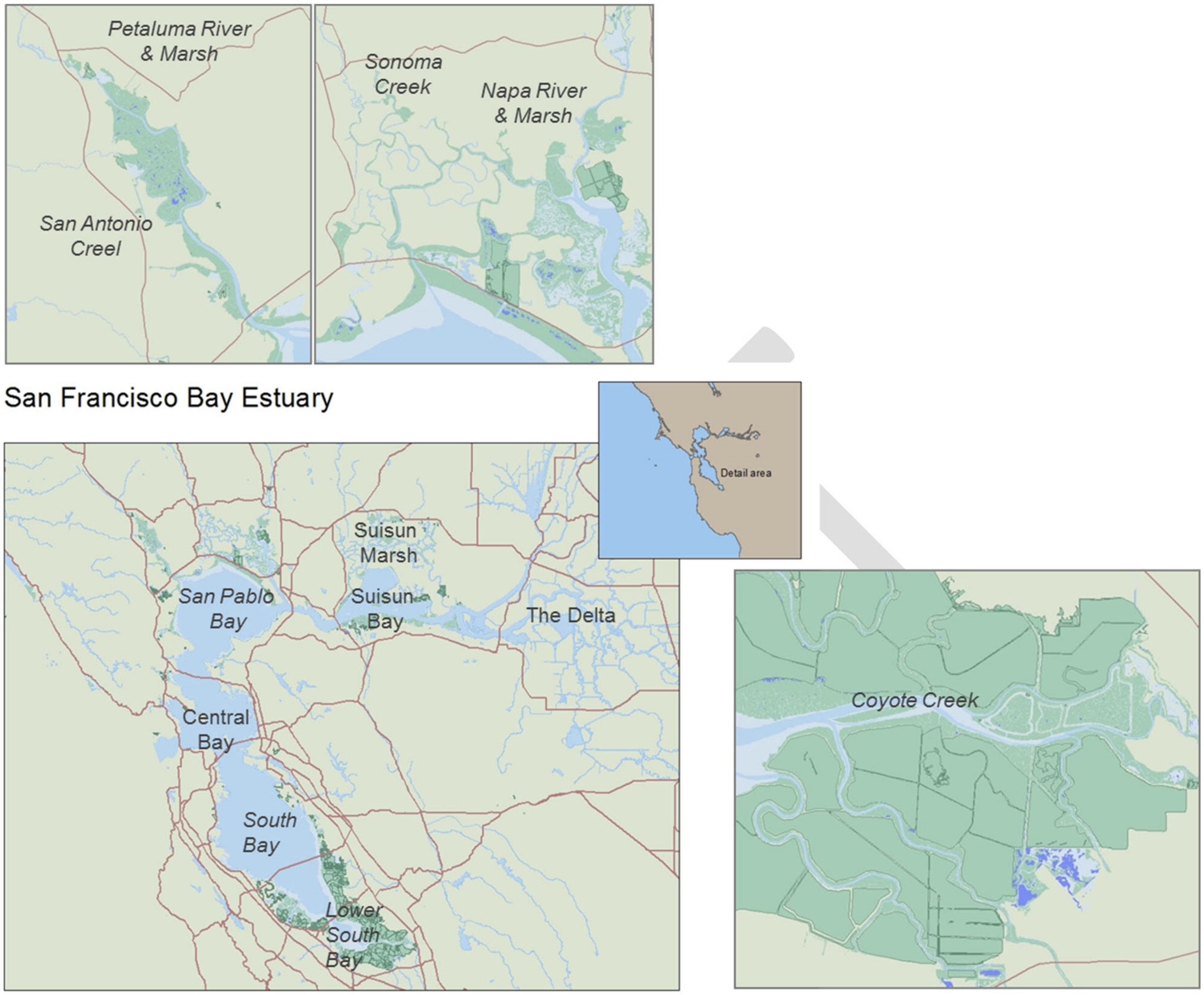

Figure 1. Map of San Francisco Bay Estuary and the Bay tributaries samples in year 1 of the study.

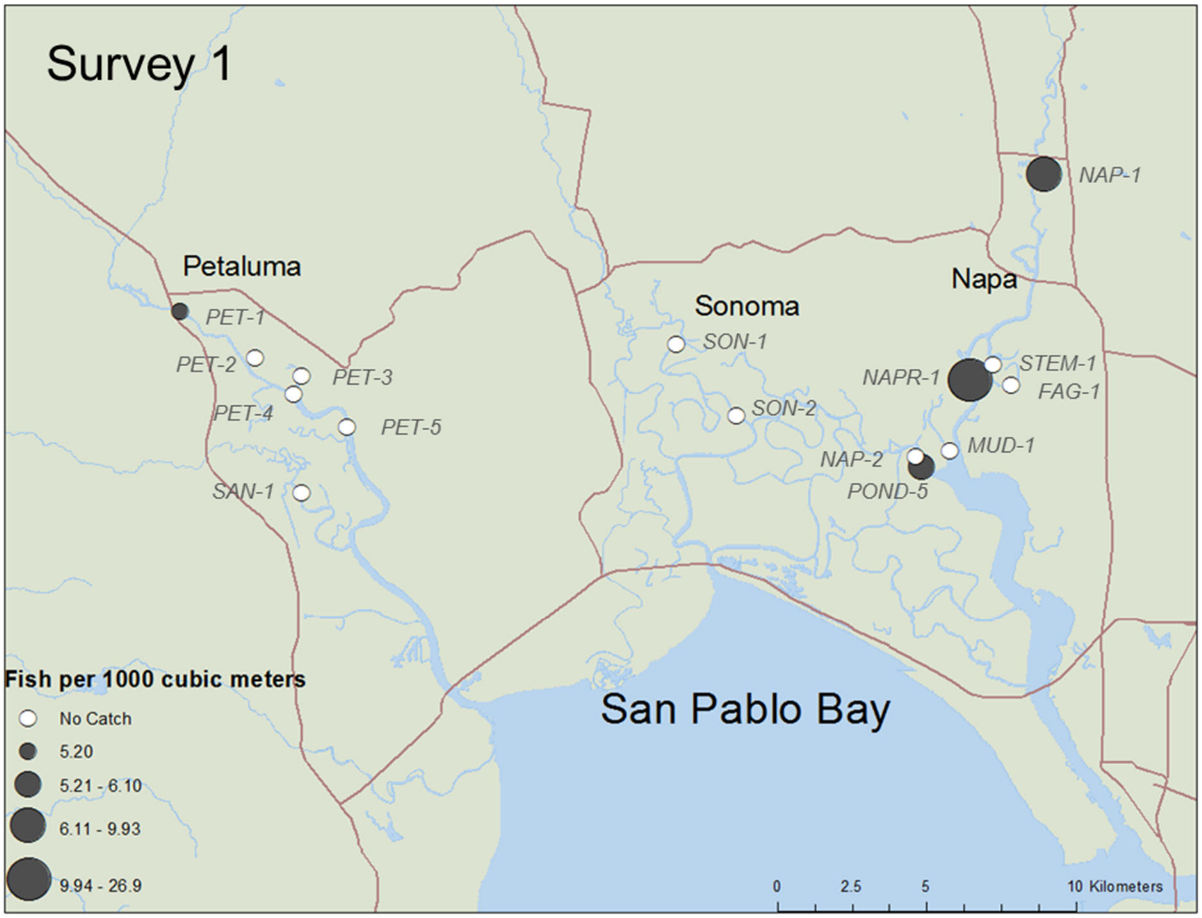

Figure 4. Survey 1, January 3rd to January 11th, 2015. Distribution of larval longfin smelt collected during the UCD “Smelt Larval Survey” in the tributaries to San Pablo Bay. Smelt catch in 1000m^3 .

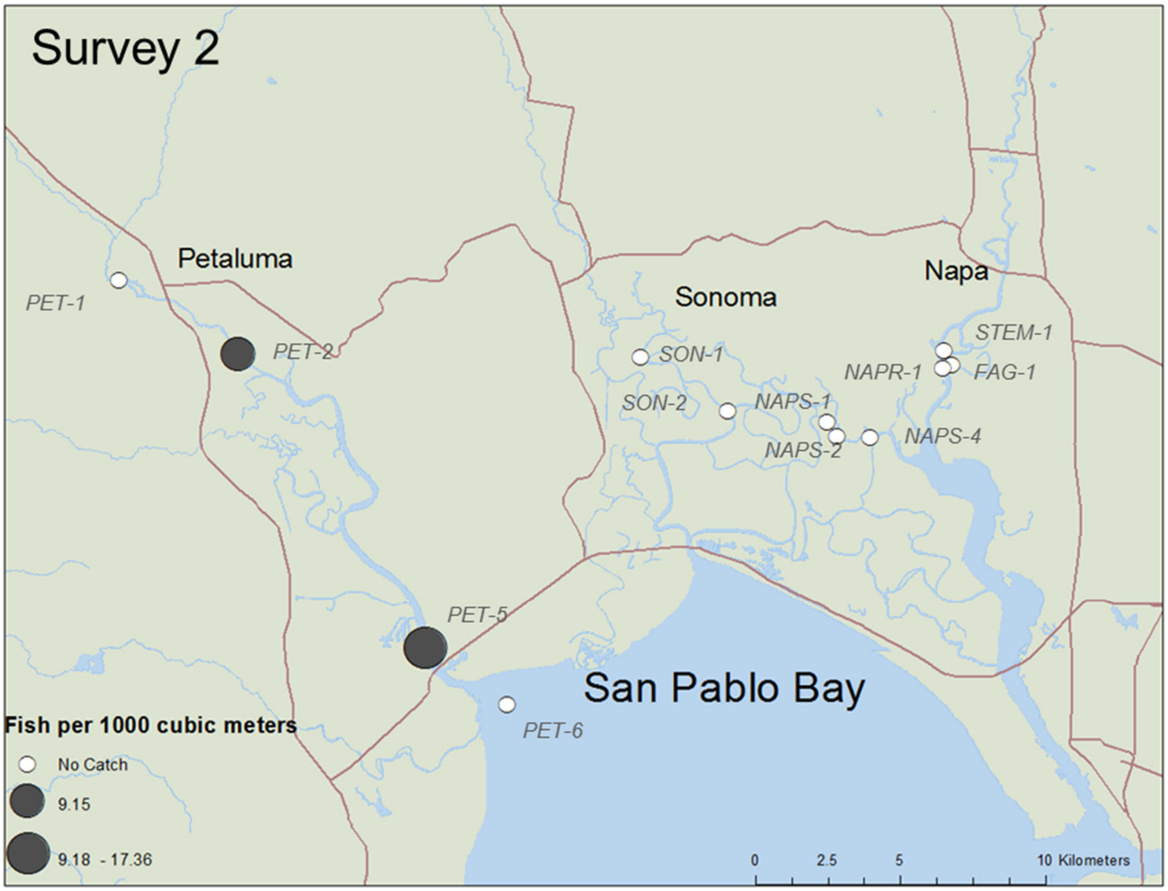

Figure 5. Survey 2, January 22nd to January 24th, 2015. Distribution of larval longfin smelt collected during the UCD "Smelt Larval Survey" in the tributaries to San Pablo Bay. Smelt catch in 1000m^3 .

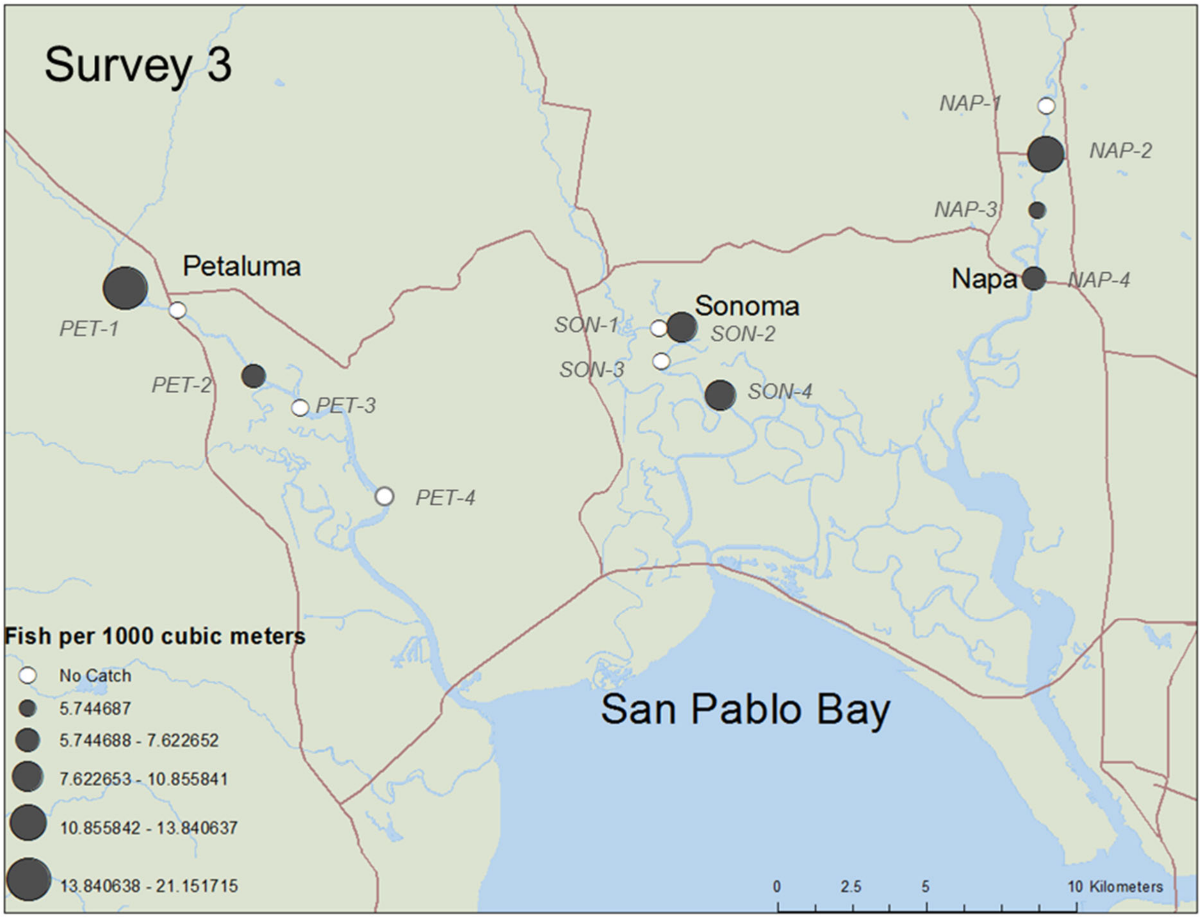

Figure 6. Survey 3, February 4th to February 7th, 2015. Distribution of larval longfin smelt collected during the UCD "Smelt Larval Survey" in the tributaries to San Pablo Bay. Smelt catch in 1000m^3.

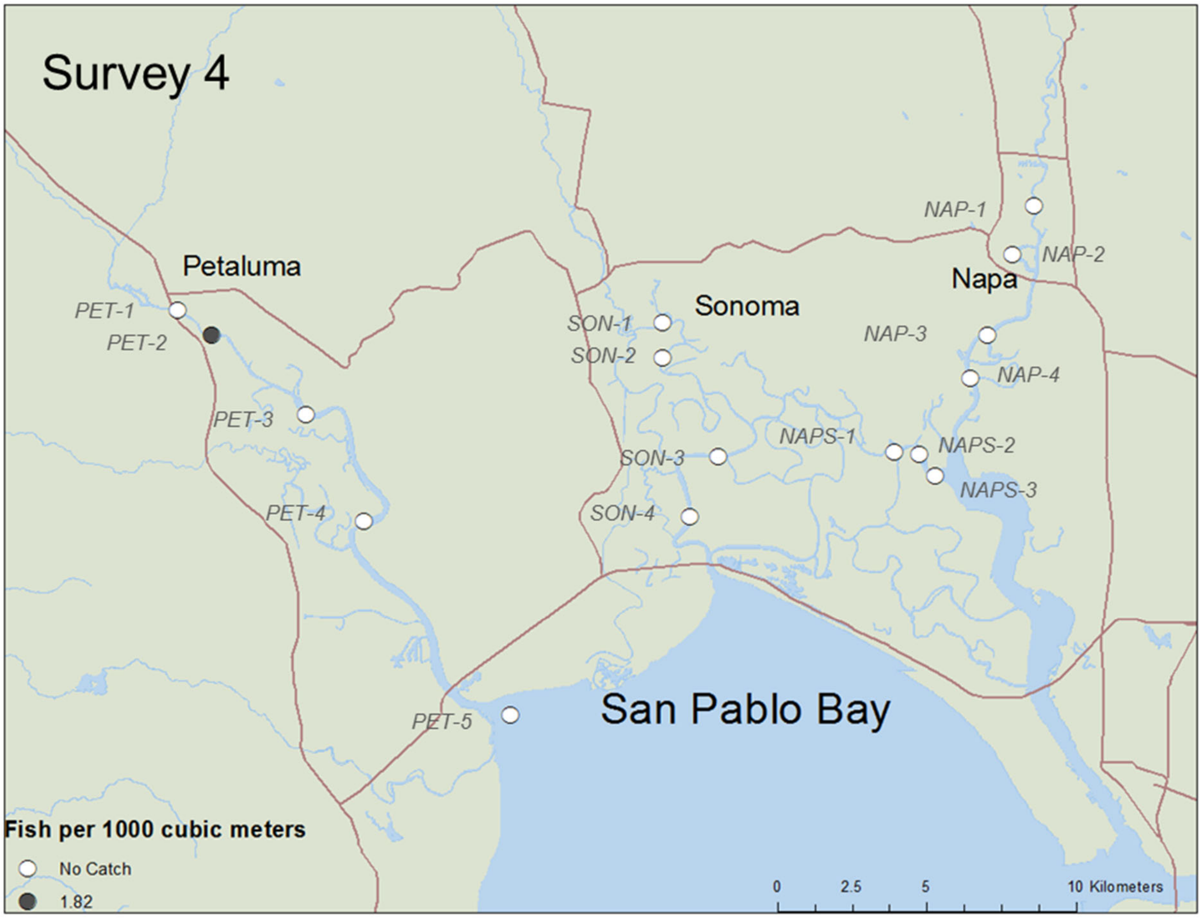

Figure 7. Survey 4, February 13th to February 15th , 2015. Distribution of larval longfin smelt collected during the UCD “Smelt Larval Survey” in the tributaries to San Pablo Bay. Smelt catch in 1000m^3 .

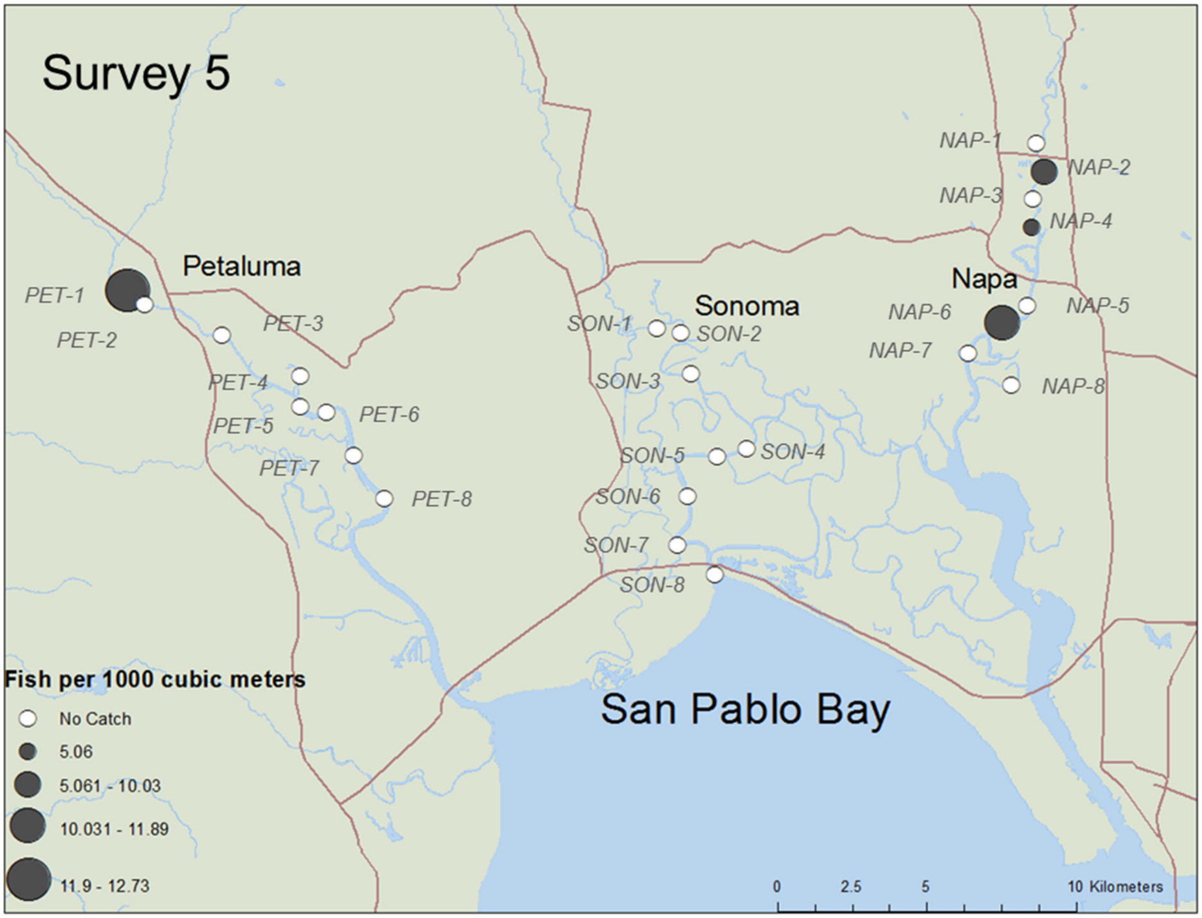

Figure 8. Distribution of larval longfin smelt collected during the UCD "Smelt Larval Survey" in the tributaries to San Pablo Bay during Survey 5, March 4th to March 8th , 2015. Smelt catch in $1000 m^3$.

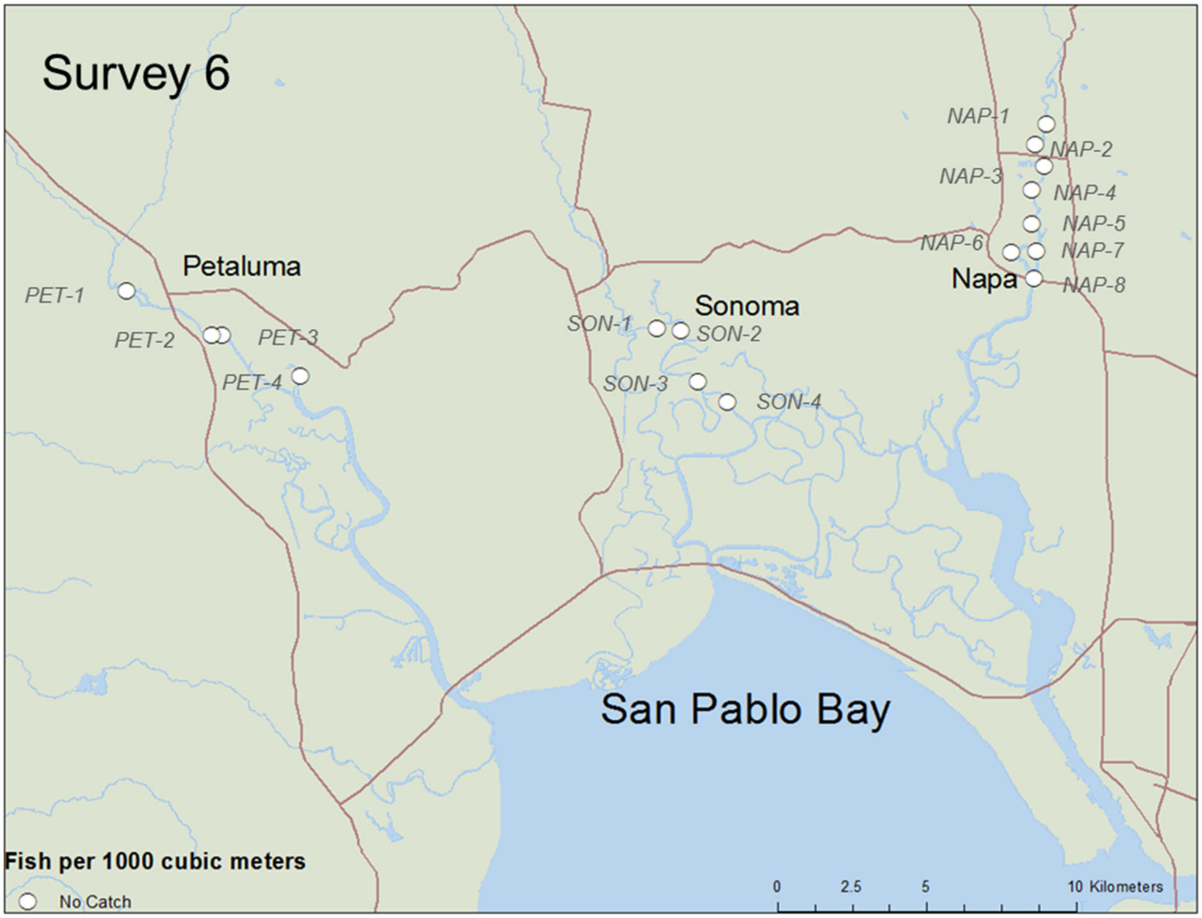

Figure 9. Survey 6, March 21st to March 26th , 2015. Distribution of larval longfin smelt collected during the UCD “Smelt Larval Survey” in the tributaries to San Pablo Bay. Smelt catch in 1000m^3 .

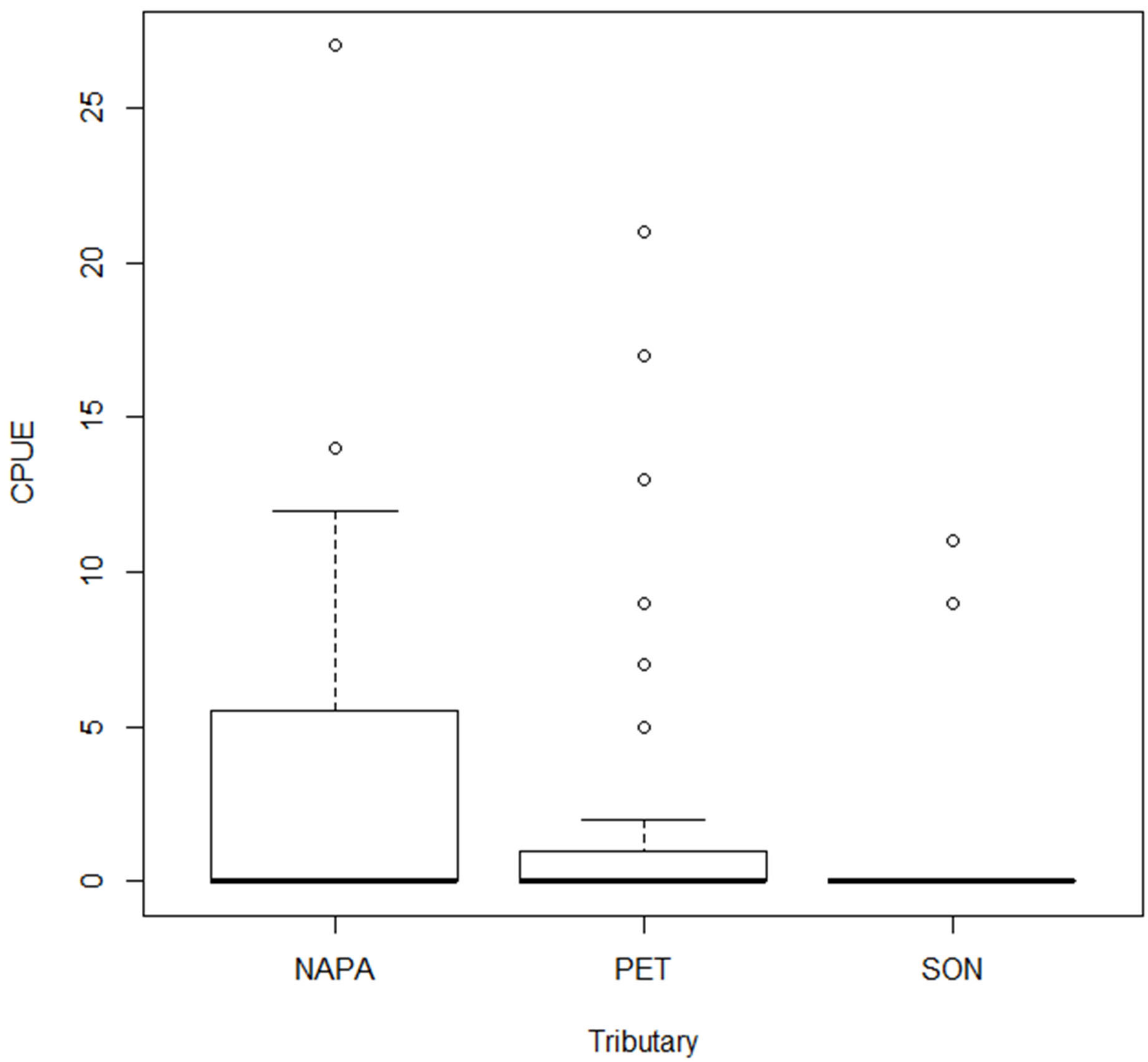

Figure 10. Box-plot of CPUE ($1000m^3$) for the San Pablo Bay tributaries; NAPA=Napa River and marsh, PET=Petaluma River and SON=Sonoma Creek.

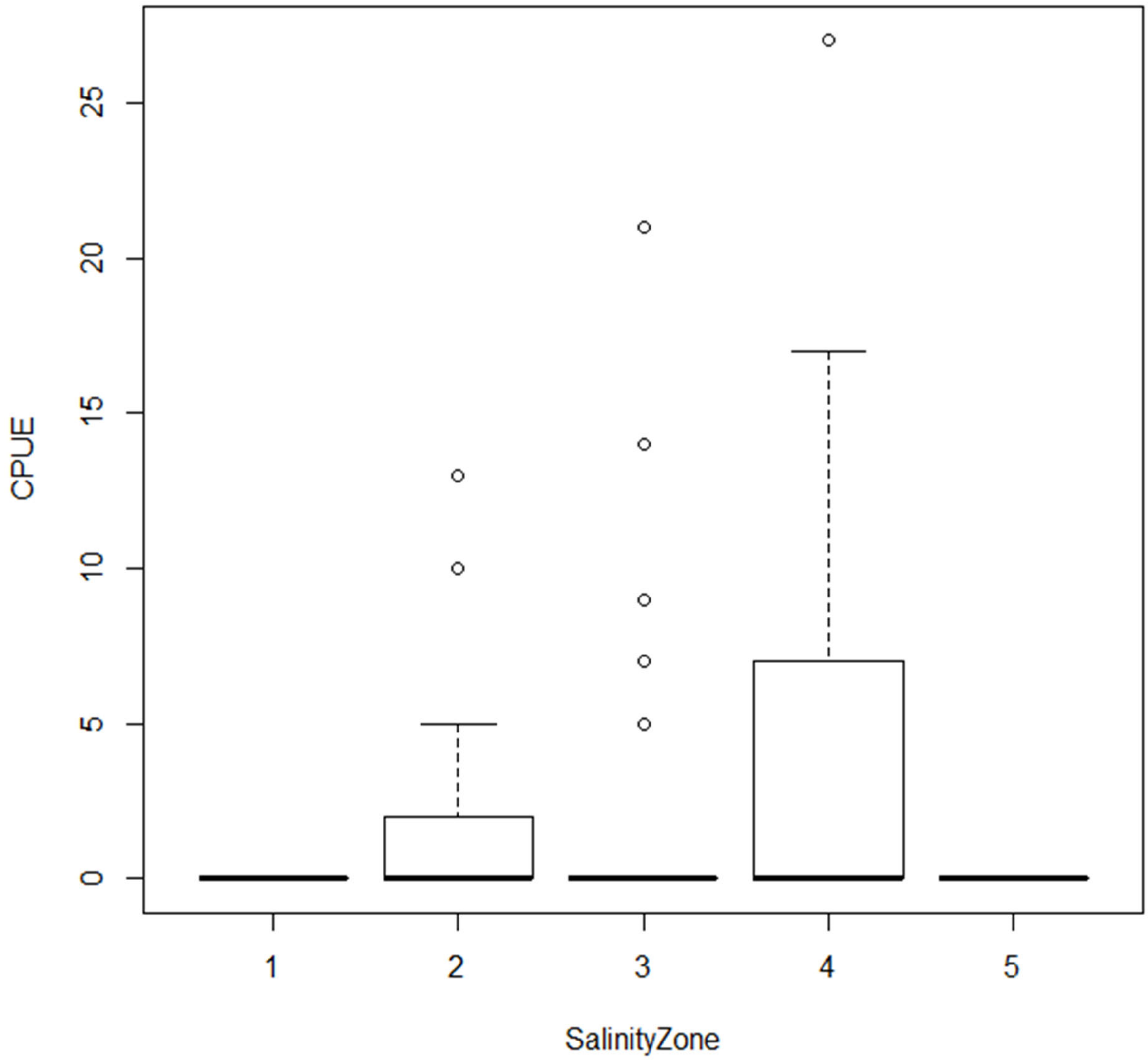

Figure 11. Box-plot of CPUE (1000m^3) for the salinity zones encountered during the surveys; 1 = freshwater, 2 = 1-3ppt, 3 = 4-6ppt;4 = 7-9ppt, and zone 5 = > 10ppt.

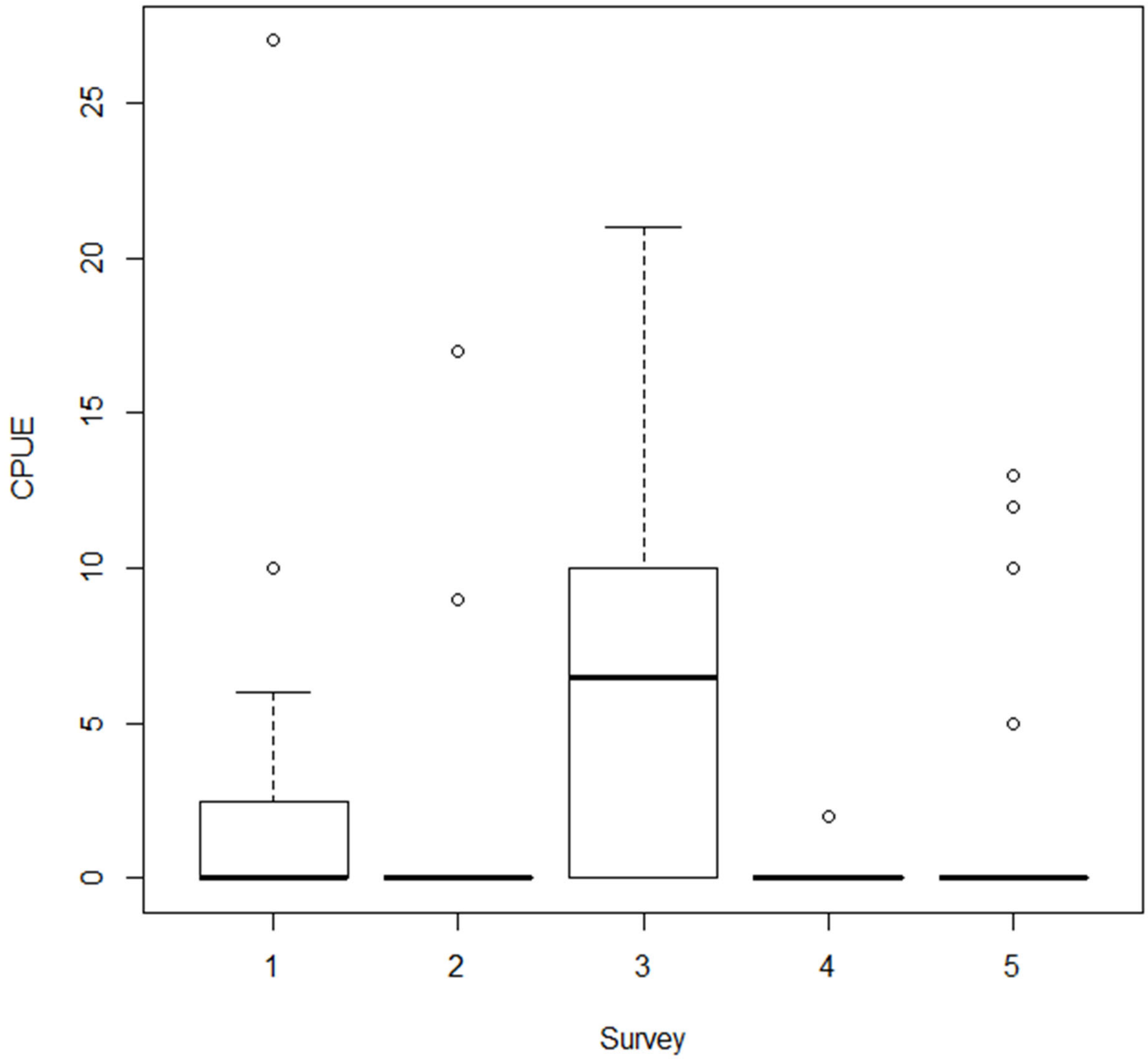

Figure 12. Box-plot of CPUE ($1000m^3$) across the surveys in 2015. Survey 6 is not shown as there were no larval longfin smelt collected in that survey.

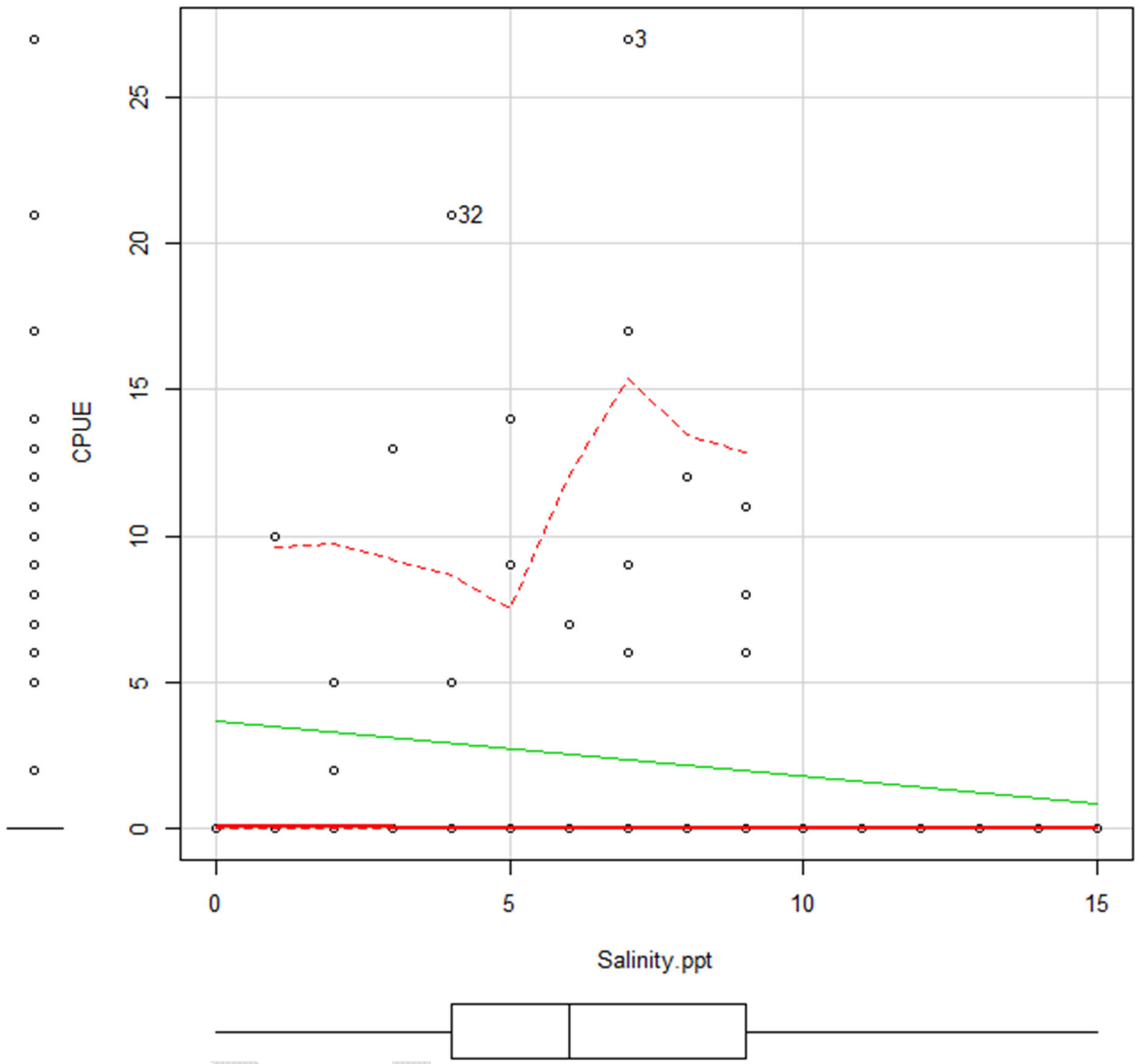

Figure 13. Scatter plot of CPUE (1000m^3) and salinity. Red dotted line depicts a smoothed spline through the data and the green line a linear regression line. Left depicts the CPUE distribution and the box-plot below the median and quartile range of CPUE weighted salinity.

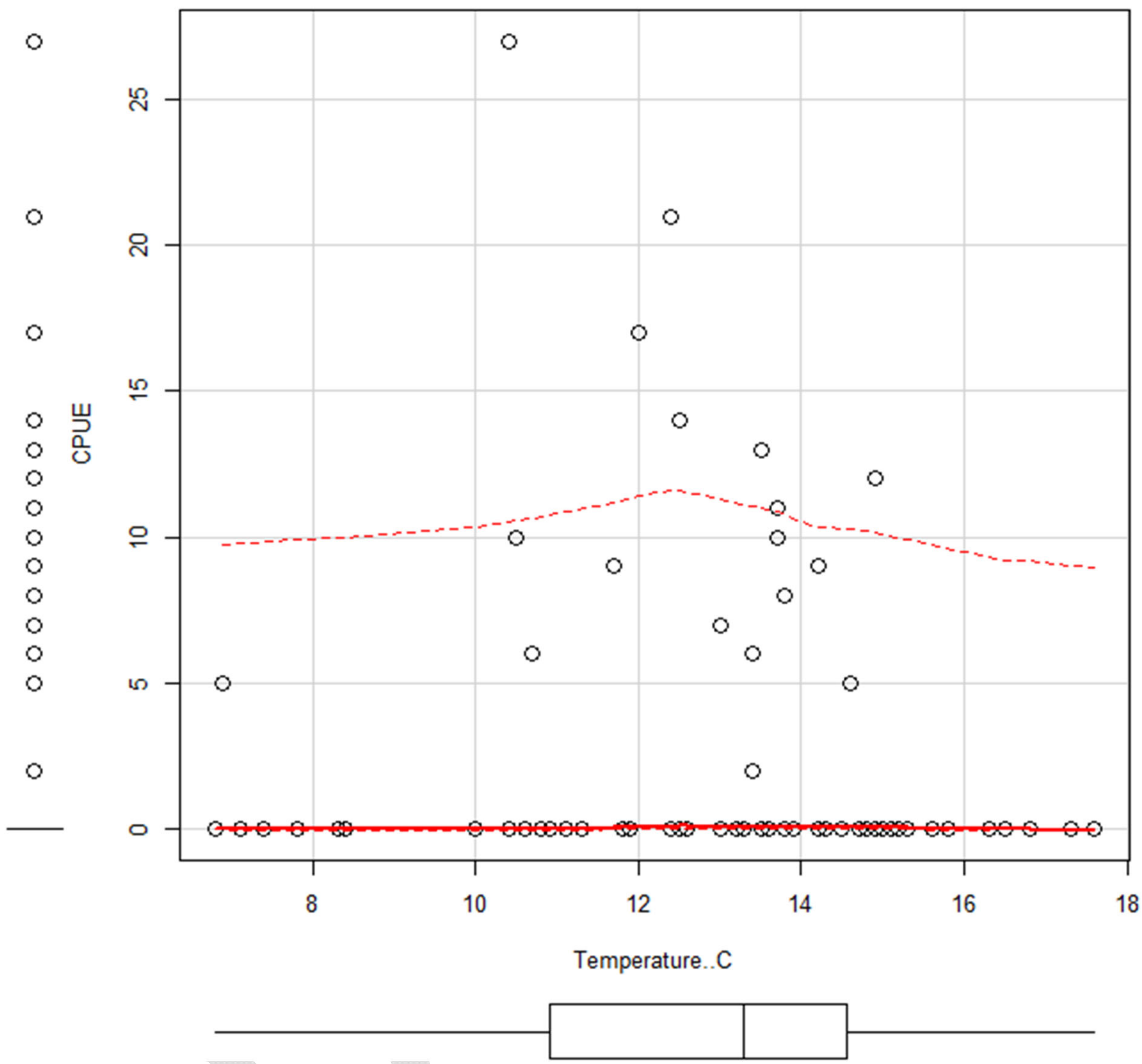

Figure 13. Scatter plot of CPUE (1000m^3) and temperature. Red dotted line depicts a smoothed spline through the data. Left is the distribution of CPUE and bottom a box-plot of CPUE weighted temperature.

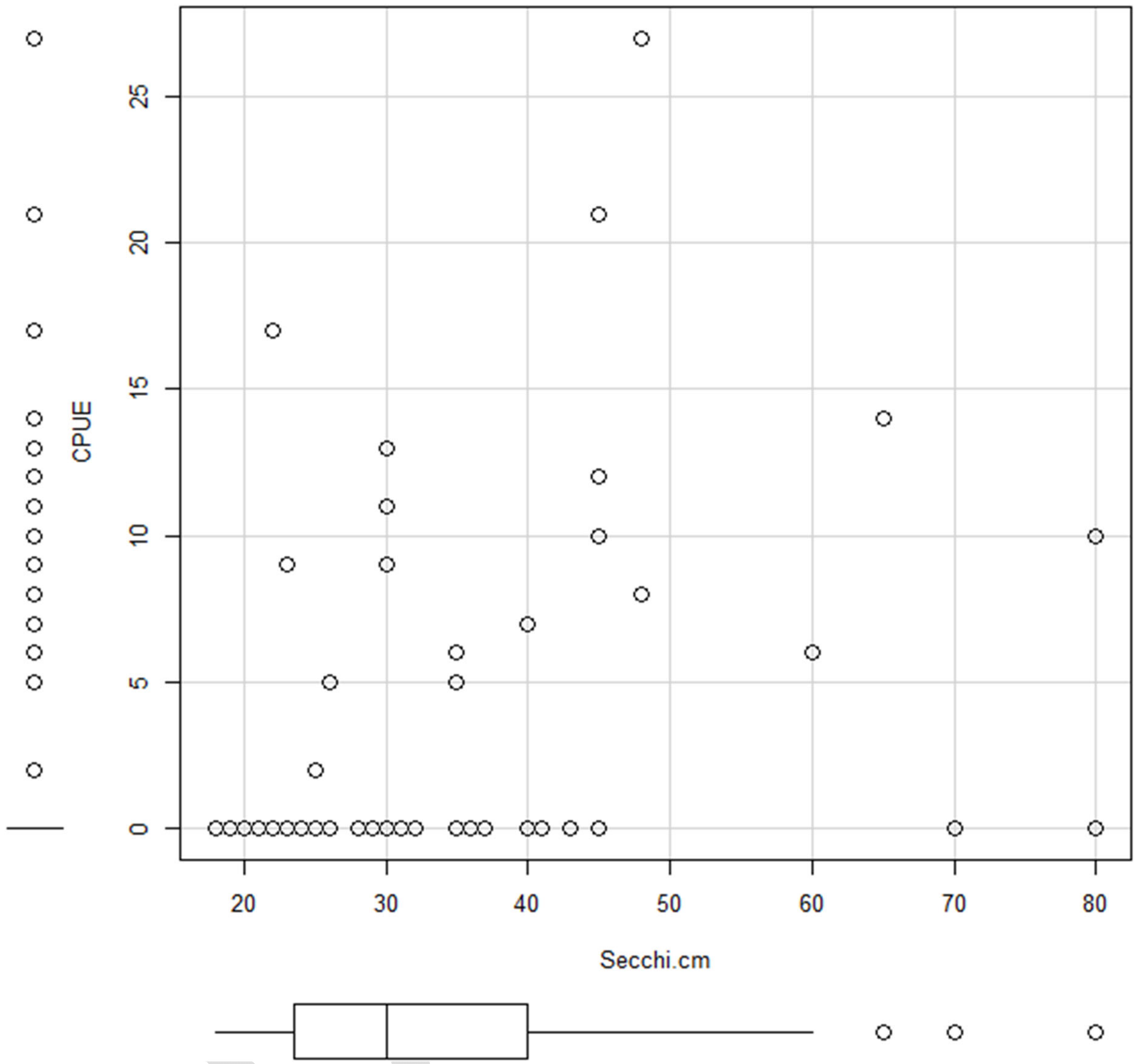

Figure 14. Scatter plot of CPUE ($1000m^3$) and Secchi. Left is the distribution of CPUE and bottom a box-plot of CPUE weighted temperature.

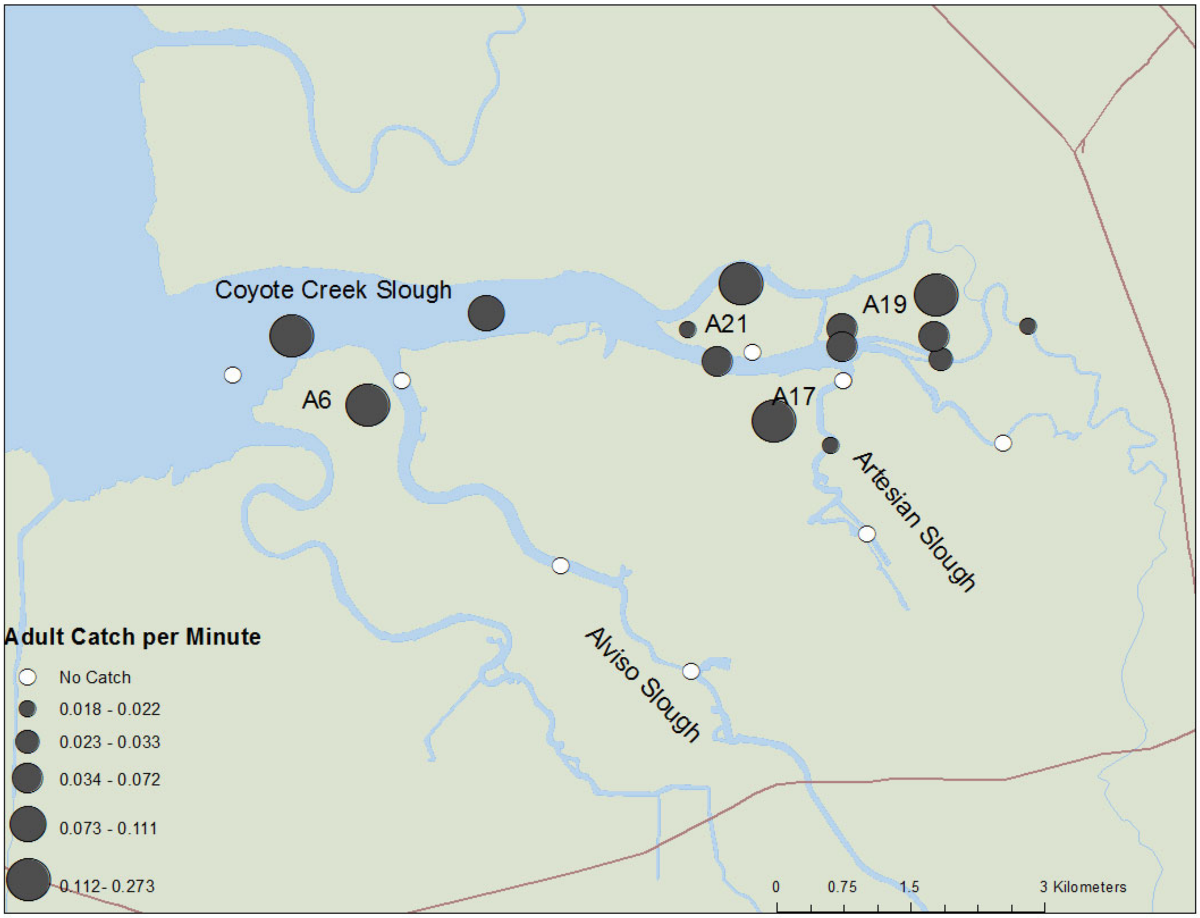

Figure 15. Map of adult CPUE in the Coyote Creek and Alviso Marsh tributary system in Lower South Bay. Bubble plots depict the mean catch per minute of trawling at each station during the 6 surveys in 2015.

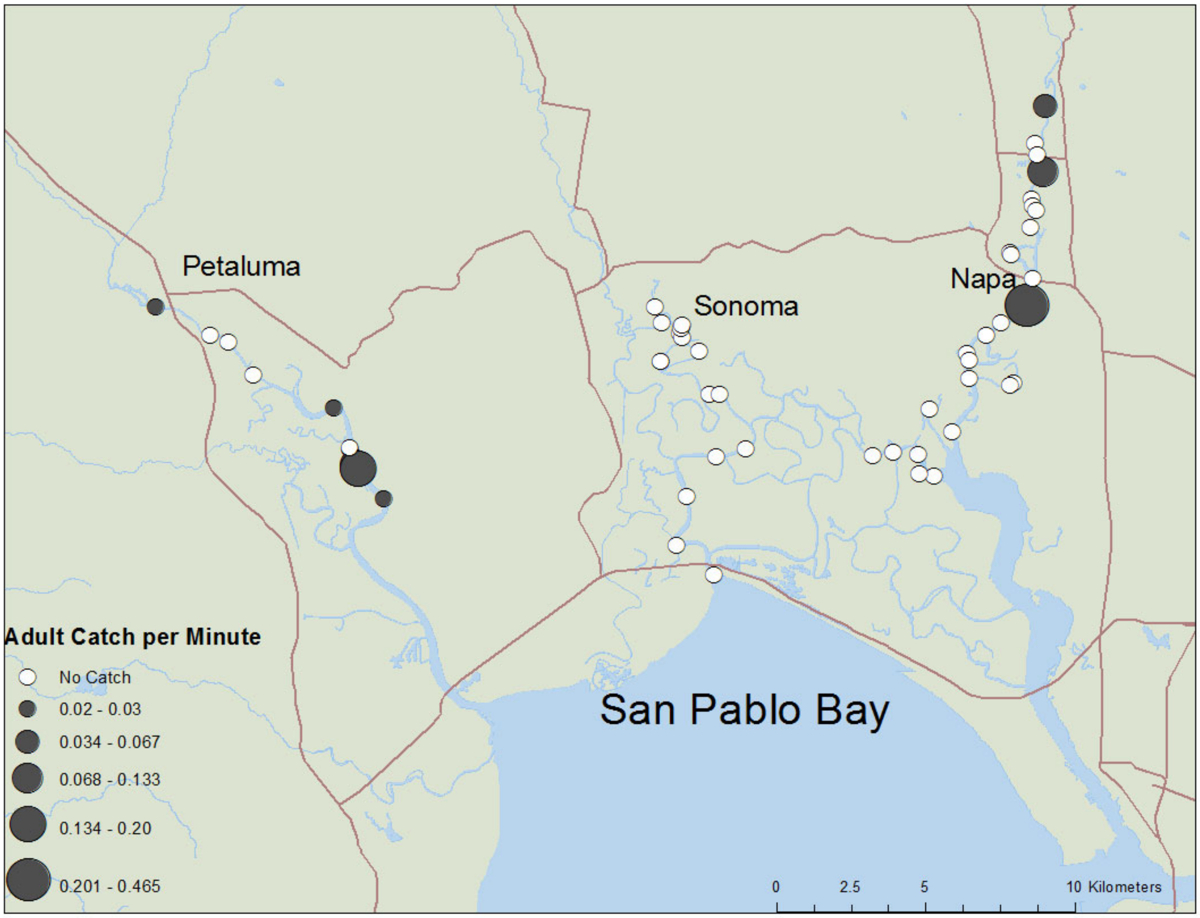

Figure 16. Map of adult CPUE in the San Pablo Bay tributaries. Bubble plots depict the mean catch per minute of trawling at each station during the 6 surveys in 2015.