



Review of delta smelt and longfin smelt monitoring program at Contra Costa and Pittsburg Power Plants.

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Executive Summary

We conducted a review and assessment of potential for delta smelt and longfin smelt take at the Contra Costa and Pittsburg power plants (collectively “power plants”). This included a summarization of available Interagency Ecological Program (IEP) monitoring data to document when fish occur near the power plants. Results from analysis of Water Year 2008 (November 2007 – October 2008) sampling indicate that:

- Delta smelt and longfin smelt of various life stages are present essentially throughout the year in the vicinity of the power plants. In particular, juveniles of both species are present during months of heaviest pumping activity. Thus both species are vulnerable to entrainment and impingement at the power plants.
- Entrainment and impingement sampling under the Mirant monitoring plan primarily occurs during periods when the power plants are not generating power. While this sampling regime may be desirable for coordination with IEP monitoring, it compromises take assessment at the Mirant facilities.
- Bootstrap re-sampling and expansion of available entrainment data indicates that 150,000 delta smelt ($\pm 60,000$ at 90% confidence intervals) were likely taken at the power plants in Water Year 2008.
- Bootstrap re-sampling and expansion of available entrainment data indicates that 64,000 longfin smelt ($\pm 17,000$ at 90% confidence intervals) were likely taken at the power plants in Water Year 2008.
- Bootstrap re-sampling and expansion of available impingement data indicates that an additional 36 delta smelt (± 21 at 90% confidence intervals) were likely taken through impingement at the power plants in Water Year 2008. No longfin smelt were detected in the 104 hours of impingement sampling conducted in Water Year 2008.
- An increase in the volume and frequency of monitoring is needed to obtain accurate estimates of delta and longfin smelt entrainment at the power plants. In particular, entrainment monitoring should be increased during periods of maximum pumping activity.
- Because impingement monitoring only detects larger fish that can not pass through the power plant traveling screens, and entrainment monitoring only measures smaller fish that can pass through the screens, reliance on either sampling method alone (impingement or entrainment) is inadequate to estimate take accurately.

Collectively, these findings strongly suggest that revisions to the monitoring program at the Mirant power plants are necessary in order to accurately estimate (and ultimately minimize)

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delta smelt and longfin smelt losses to pumping associated with the power plants and to meet the monitoring requirements of the California Endangered Species Act.

INTRODUCTION

Mirant Delta LLC operates two power-generating plants (collectively “power plants”) in Contra Costa County, California - the Pittsburg Power Plant (“PPP”) and Contra Costa Power Plant (“CCPP”) (Figure 1). During operation, the power plants use once-through cooling systems that take large volumes of Sacramento-San Joaquin Delta water from the adjacent channel and then discharge the heated water back into the channel during operation. Power plant operations result in the take of numerous native aquatic organisms, including the threatened and federally protected delta smelt (*Hypomesus transpacificus*) and longfin smelt (*Spirinchus thaleichthys*), a candidate for state listing. The power plants are located in essential habitat, and both species can be found throughout the year at the locations from which the power plants draw water. Concern that losses of at-risk fishes at the power plants may have a significant impact on their survival and recovery has led to the implementation of monitoring efforts at the two facilities.

Recent power plant monitoring has documented take in both species, but sampling in 2008 was relatively sparse and no take estimates were provided with sampling reports. The relative paucity of sampling data and the absence of take estimates suggests the current monitoring framework may be inadequate. Here, we estimate losses of delta smelt and longfin smelt that result from operation of the power plants, focusing on losses that can be inferred from available monitoring data. We also identify improvements that can be made to the current monitoring program in order to more accurately assess power plant activities that impact delta and longfin smelt.

Delta smelt and longfin smelt populations within the Sacramento San Joaquin Delta appear to have declined dramatically over the past decade. Index values suggest that current population sizes of each species may be just a small percentage of that in the late 1990s. Although this decline has most likely been forced by multiple environmental changes (Baxter et al 2007), power plant locations and the associated likelihood that delta and longfin smelt take occurs continuously during power generation may have contributed significantly to the decline. Although thermal discharge from the power plants probably causes direct effects such as stress and mortality and indirect effects such as altered habitat quality, food supply, and disease and predation risk (Luksiene et al. 2000; Itzkowitz et al. 1983; Parker 1979), our analysis focuses on delta and longfin smelt losses resulting from impingement and entrainment.

Both power plants utilize traveling screens on their water intakes to prevent large objects from entering cooling systems. These screens have a mesh size of 3/8 inches (9.5 mm). While screens may successfully exclude fish and other aquatic organisms, some fish may also be trapped (impinged) against the screen, or be pulled through the screen (entrained) into power plant cooling systems. Impingement occurs when fish are too large to pass through the mesh of the screen and the intake velocity exceeds their ability to move away (Steinbeck

et al. 2007). Particularly fragile fish may degrade and pass through the screen, or will otherwise be injured or weakened by impingement. Because of their size and disposition, impinged delta smelt are assumed to suffer 100% mortality (California Energy Commission 2008). While there is little information on longfin smelt impingement effects, we assume 100% mortality for this study.

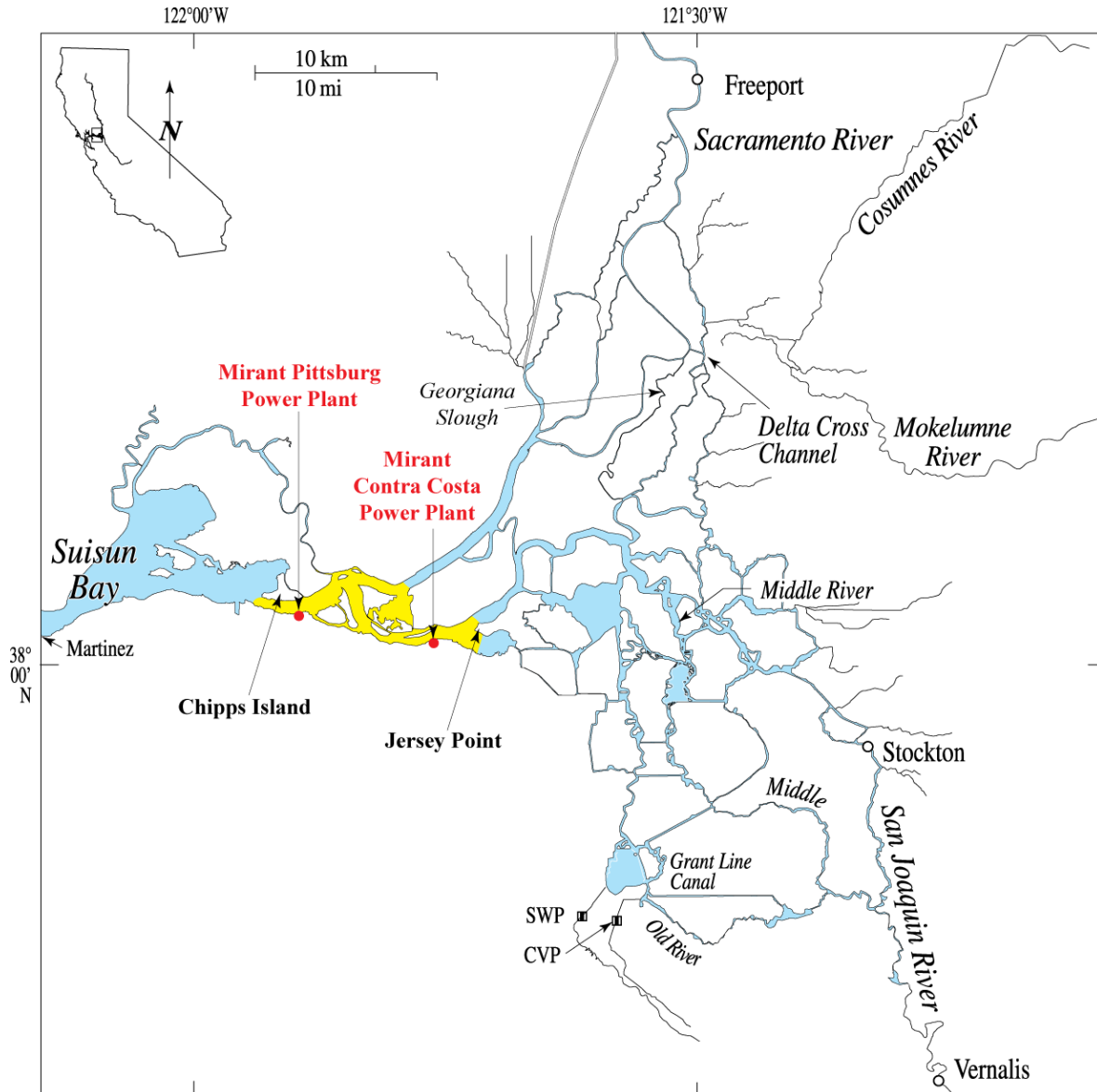


Figure 1. Map of the Sacramento-San Joaquin Delta showing the location of the Mirant facilities. The summary of IEP data used survey stations within the area colored yellow on the map.

Entrainment occurs when fish or other aquatic organisms pass through the intake screens and enter power plant cooling systems. Following review of more than 35 studies on entrainment mortality, the United States Environmental Protection Agency concluded it is appropriate to assume 100% mortality of entrained organisms (EPA 2004), and analyses of water diversion



effects on delta smelt have treated entrainment as equivalent to mortality (e.g., Kimmerer 2008). Therefore one can assume mortality for both delta smelt and longfin smelt when entrainment occurs.

Whether a fish will be impinged on a screen or will pass through the screen and be entrained in the diversion depends on fish body depth, length, orientation to screen, as well as fragility of the fish. Delta smelt are typically 5 to 25 mm total length (TL) as larvae, and may reach 50 mm fork length (FL) or more during juvenile life stage and 80 mm FL during adult stage with a few reaching 130 mm FL (Bennett 2005; Moyle 2002). Within the Sacramento San Joaquin Delta, longfin smelt larvae have been documented as 4.2 to 19 mm TL, juveniles as 20 to 53 mm FL and adults up to 101 mm FL (Baxter 1999), although adults may reach 150 mm TL (Miller and Lea 1972). Fish with a body depth equal to or greater than the 9.5 mm mesh size of the screens at the power plant are susceptible to impingement. Smaller fish encountering the screen at certain orientations may also be impinged rather than entrained. No studies have been conducted to evaluate the maximum size of smelt which actually pass through the power plants traveling screens; but a study by Young and Cech (1997) indicates that delta smelt less than 65.5mm FL have a body depth less than 9.5 mm. This suggests that all larvae, juveniles and a portion of adult delta smelt are susceptible to entrainment. Comparable research has not been performed for longfin smelt, but similarities in body shape between the two species suggest a comparable body length to depth relationship.

Ongoing monitoring at the power plants

Starting in 2006, Mirant planned to coordinate entrainment and impingement monitoring activities at the power plants with Interagency Ecological Program (IEP) surveys (Mirant 2006). Kodiak trawl, summer tow-net, fall mid-water trawl, and 20mm surveys are conducted by IEP to monitor the distribution and relative abundance of delta smelt and longfin smelt (as well as other fishes) throughout the Delta. Power plant sampling is coordinated with IEP sampling to allow Mirant data to be considered in a broader context of Delta and longfin smelt presence and vulnerability near the power plants. Several IEP survey stations are located near the power plants (Figure 1). According to Mirant (2006), monitoring activities are designed “to estimate the abundance and composition of all entrained fishes (species and life stages)” and “to inform the ongoing incidental take authorization process for Delta Plant activities.”

Impingement samples are taken throughout the year, whereas entrainment samples are taken only from March through July. This disparity is based upon the assumption that juvenile smelt are present near the plants only from March through July, and that adult delta and longfin smelt will be detected through impingement monitoring. Entrainment sampling is conducted using 1,600- μm and 160- μm mesh nets. On days when entrainment sampling is performed, three replicates of 193.9 m³ of water are filtered by the nets. On days when impingement sampling is performed, the 3/8-inch traveling screens are checked before and after a known volume of water (from 137,000–310,000 m³) is pumped. Any delta smelt or longfin smelt collected from entrainment or impingement sampling are counted and measured.



In order to evaluate the design and effectiveness of the IEP monitoring plan we examined IEP trawl and survey data on the number of delta smelt and longfin smelt found near the power plants, and analyzed results from the entrainment and impingement monitoring conducted under the IEP monitoring plan. In addition, we used alternative sampling design scenarios, and the entrainment and impingement data to explore variance in take estimates. We then compared the body lengths of individual delta and longfin smelt collected during the 2008 monitoring period to assess patterns of fish size selection in the impingement and entrainment sampling.

METHODS

Summary of IEP Data

The IEP spring Kodiak trawl and 20 mm survey data (available 1995-2008) were downloaded from the California Department of Fish and Game (DFG) Bay-Delta FTP server (<ftp://ftp.delta.dfg.ca.gov/>). Data for the summer tow-net and fall mid-water trawl surveys (available 1995-2004) were downloaded from the Bay Delta and Tributaries (BDAT) project site (<http://bdat.ca.gov/index.html>). The analysis was limited to survey results for delta smelt and longfin smelt at survey stations adjacent to the power plants. Those survey stations, located in the waters between Jersey Point and Chipps Island, include stations: 801, 520, 513, 508, 804 (Kodiak trawl); 703, 804, 801, 513, 520, 508, 802 (summer tow-net); 804, 806, 802, 703, 701, 513, 508, 509 (fall mid-water trawl); and 801, 804, 703, 513, 520, 508, 802 (20 mm). Catch and length data for each species were summarized by month for the period from January 1995 to the most recent sample data. We used 60 mm FL as the delineation between juveniles and adults of both species.

Sample Size Analysis of Power Plant Monitoring Data

Entrainment

Power plant pumping and monitoring data from November 2007 through October 2008 were provided by California Department of Fish and Game and Mirant Delta, LLC. These data allowed us to assess the adequacy of current sampling using bootstrap re-sampling and expansion of available data following the methods described in Manly (1992). In bootstrapping, statistics are estimated by repeatedly sub-sampling (re-sampling) with replacement data from an available dataset. Delta smelt and longfin smelt entrainment sampling occurred at the power plants from March 2008 through July 2008 (five months). By re-sampling from this dataset we were able to estimate total entrainment under alternative sampling scenarios. In effect, we asked how many entrainment samples would be necessary in order to obtain a reliable estimate of annual or monthly delta smelt and longfin smelt take at the two facilities.

Because multiple entrainment samples were taken in most months, we calculated a monthly per-sample catch for each power plant. Five months of sampling for each plant produced a total of 10 entrainment catch values for analysis (Table 1). These values were then pooled into one 'pilot' dataset so that returns from both plants could be analyzed together. The pilot dataset was then bootstrap re-sampled 100 times for each alternative entrainment sampling scenario. The size of the bootstrap sample was determined by the scenario (e.g., five samples



per month gives a bootstrap sample size of 60 for one year). The resulting catch values were expanded to estimate the entrainment catch if all water pumped in WY 2008 had been sampled. This total annual entrainment was estimated by multiplying catch values per volume of water by the total water volume pumped in 2008. Following expansion, means and 90% confidence intervals of the 100 bootstrap samples were calculated for each alternative entrainment sampling scenario.

Table 1. Available monthly per-sample catch data used for bootstrap re-sampling analysis. Entrainment catch is reported as average fish catch per sample and month (CCPP and PPP treated as separate sampling events). Impingement catch is reported as average fish catch per 250,000 m³ water sample and month (again treating CCPP and PPP as separate sampling events).

samples	Entrainment		Impingement	
	delta smelt	longfin smelt	delta smelt	longfin smelt
1	0	1	0	0
2	0	0.666666667	0	0
3	1.5	0	0	0
4	0	0	0.857349405	0
5	0	0	0.816523296	0
6	0	1	0	0
7	0	0.666666667	0	0
8	2	0	0.402685039	0
9	4.5	0	0	0
10	0	0	0	0
11			0	0
12			0	0
13			0	0
14			0	0
15			0	0
16			0	0
17			0	0
18			0	0
19			0	0
20			0	0
21			0	0
22			0	0
23			0	0
24			0	0

The above analysis addressed the ability of alternative sampling efforts to accurately estimate *annual* entrainment. Comparing sampling efforts for estimating *monthly* entrainment required a separate analysis. To do this, we repeated the above analysis but limited the expanded estimate to a single month (August 2008). Here larger bootstrap sample sizes were used in order to identify an adequate sampling frequency for a monthly entrainment estimate in a month having particularly large pumping volumes.

We also evaluated within-month variation in abundance near the power plants. Because August is a month when delta smelt are assumed to be relatively rare in the vicinity of the power plants, we repeated the monthly analysis using sequential reductions of delta smelt



abundance. This was carried out by reducing the catch values in the pilot dataset by 50%, 25%, and 10%, respectively, prior to bootstrap re-sampling.

We did not repeat similar within-month analyses for longfin smelt, because challenges related to single-month entrainment sampling during high pumping activity were effectively illustrated with the delta smelt example. Other than their total entrainment losses, similar patterns with regard to necessary sampling effort and estimate variance can reasonably be expected for longfin smelt.

Impingement

We also assessed the ability of alternative sampling efforts to accurately estimate annual impingement of delta smelt. Longfin smelt impingement was not similarly analyzed, because no longfin smelt were caught in the impingement samples reported by Mirant Delta, LLC. Delta smelt impingement monitoring occurred at the power plants from November 2007 through October 2008. As in the entrainment analysis, we pooled monthly per-sample catch data from each power plant into a pilot dataset. Given 12 months of sampling for each plant, this produced a total of 24 impingement catch values (Table 1). The analysis proceeded as described above for the annual entrainment analysis (monthly analysis was not performed for impingement).

Delta Smelt Length Frequency Analysis

In order to assess potential size selectivity for entrainment and impingement sampling methods, we (1) compared lengths of delta smelt captured by sampling method and power plant using analysis of variance (ANOVA), and (2) compared delta smelt length frequencies between IEP sampling programs and power plant entrainment and impingement sampling using chi-square analysis. Because summer tow-net and fall mid-water trawl survey data were not available after 2004 on the BDAT project site, we only used the 2008 Kodiak and 20 mm data for this analysis.

RESULTS

Summary of IEP Data

Catch data indicates delta smelt of all life stages are present throughout the year near the Delta Plants (Figure 2). Though relative abundance varies from month to month, delta smelt have been captured near the power plants every month of the year. Longfin smelt are less abundant than delta smelt, but IEP sampling illustrates these species also occur in the vicinity of the Delta Plants throughout the year (Figure 3). The sampling data indicates juvenile longfin smelt (<60 mm) are most abundant between March and August, while adults are present during fall and winter months. Insufficient longfin smelt catch in the Kodiak trawl precluded analysis from this sampling method.

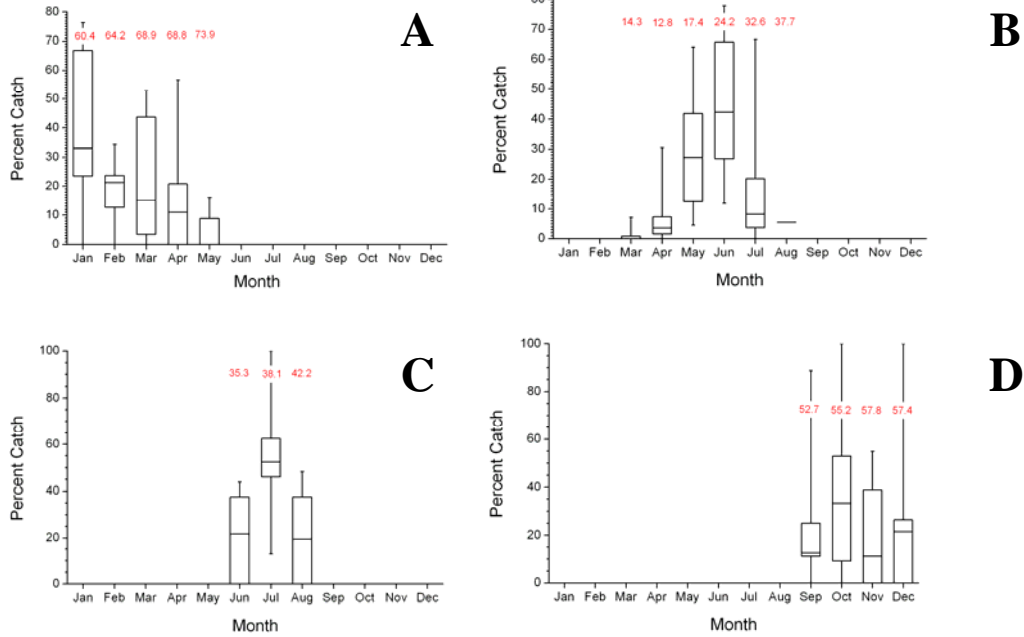


Figure 2. Delta smelt percent catch by month in IEP surveys from stations between Jersey Point and Chipps Island. Values in red indicate monthly average fish length (mm). Each box and whisker plot shows median, upper and lower quartile, maximum, and minimum. (A) Kodiak trawl survey (2002-2008). (B) 20 mm survey (1995-2008). (C) Summer tow-net survey (1995-2004). (D) Fall mid-water trawl survey (1995-2004).

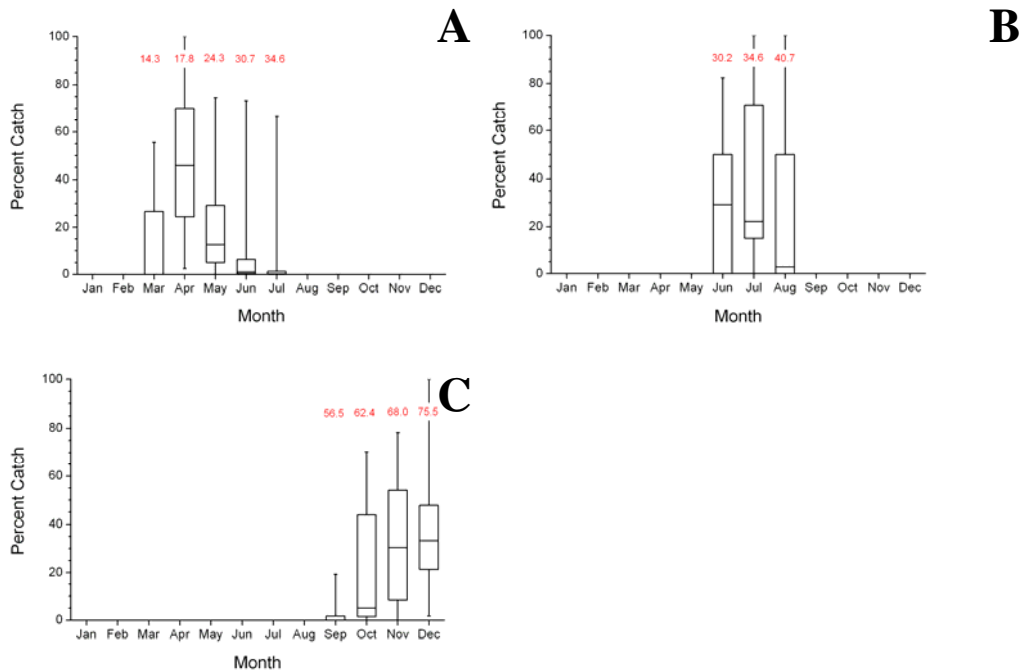


Figure 3. Longfin smelt percent catch by month in IEP surveys from stations between Jersey Point and Chipps Island. Values in red indicate average monthly fish length (in mm). Each box and whisker plot shows median, upper and lower quartile, maximum, and minimum. (A) 20 mm survey (1995-2008). (B) Summer tow-net survey (1995-2004). (C) Fall mid-water trawl survey (1995-2004).

In summary, IEP data from the spring Kodiak trawl, summer tow-net, fall mid-water trawl, and 20mm surveys collectively shows juvenile and adult delta smelt and longfin smelt occur essentially year-round in the vicinity of the power plants (Figure 4).

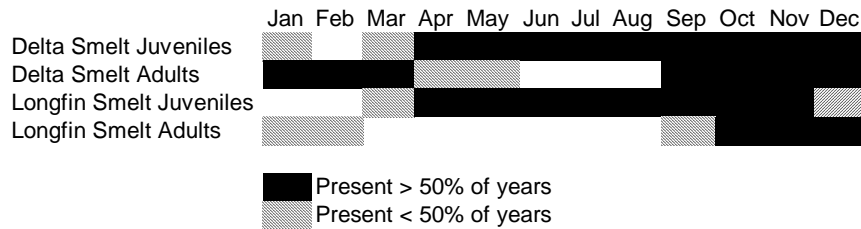


Figure 4. Monthly presence of delta smelt and longfin smelt caught at survey stations between Jersey Point and Chipps Island during CDFG surveys, including date from spring Kodiak trawl, 20 mm survey, summer tow-net survey, and fall mid-water trawl, between 1995-2008. For both smelt species, individuals smaller than 60 mm are considered juveniles, while adults are ≥ 60 mm.

Summary of Pumping and Sampling Operations

From 2007–2008, entrainment and impingement monitoring at the power plants primarily occurred during non-generation periods, when water was pumped through the plants solely for monitoring purposes (Figure 5). Only four of ten entrainment samples occurred during electricity generation flows. The remaining six samples did not appear to correspond with water pumping events. In fact, no record of water pumping (generation or non-generation) was reported for the six days when these entrainment samples were taken. As with entrainment monitoring at the facilities, it appears that as few as three impingement sampling events occurred during pumping for active power generation.

For both entrainment and impingement monitoring at the power plants, sampling efforts were not proportional to pumping activities. The percent of monthly flow sampled for impingement at the power plants varied across the year, but on average, impingement monitoring sampled 18.4% of the average total volume pumped each month (Figure 6). In months when pumping activity increased, impingement sampling was typically less than 10% of total volume pumped. Moreover, with a mean monthly sampling rate of just 0.01%, the percentage of flow sampled for entrainment monitoring was more than 1,000 times lower than the percentage of flow sampled for impingement (Figure 7).

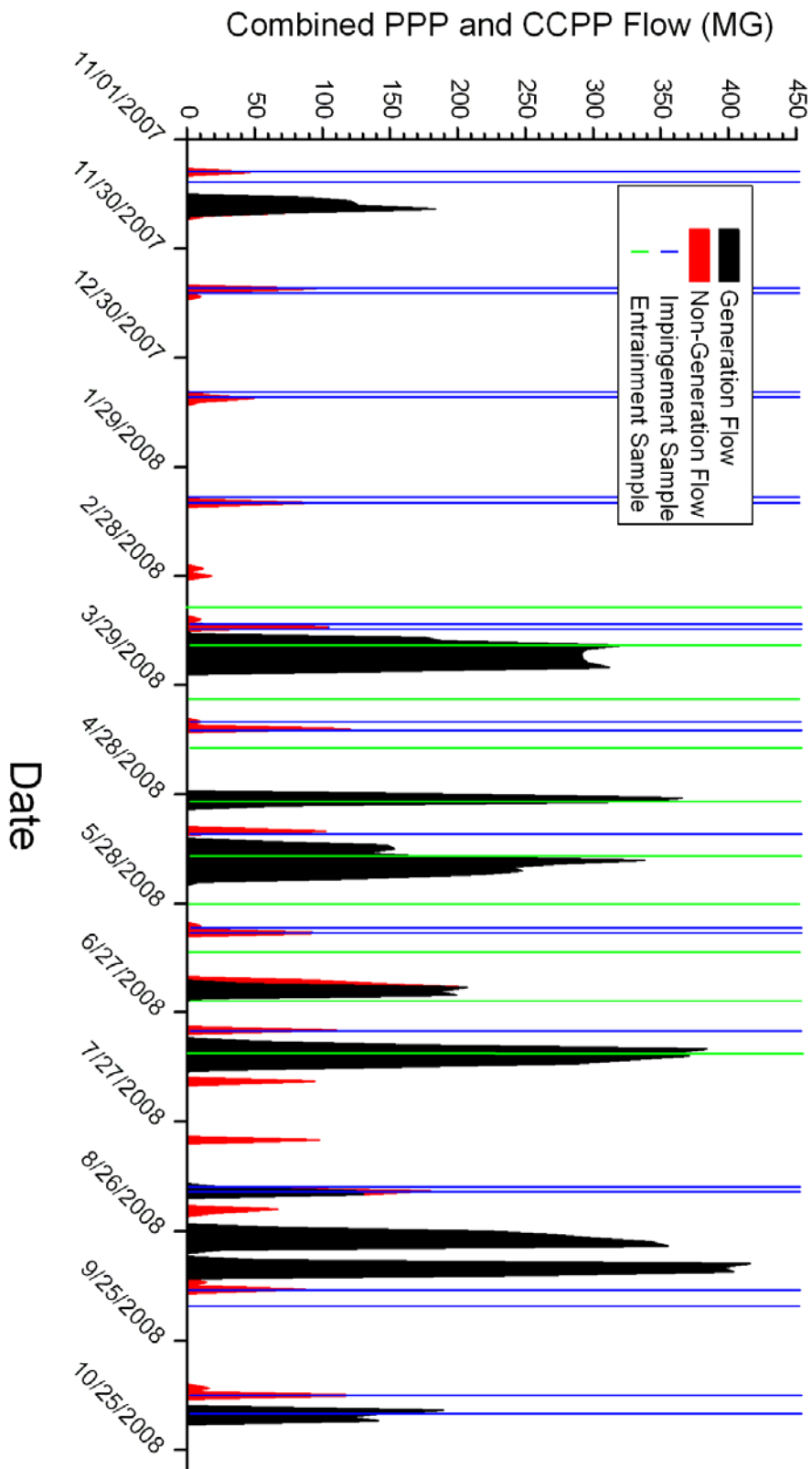


Figure 5. Flow through Delta Plants, Pittsburg (PPP) and Contra Costa (CCPP), during electricity generation and non-generation periods and relative timing of impingement and entrainment sampling events

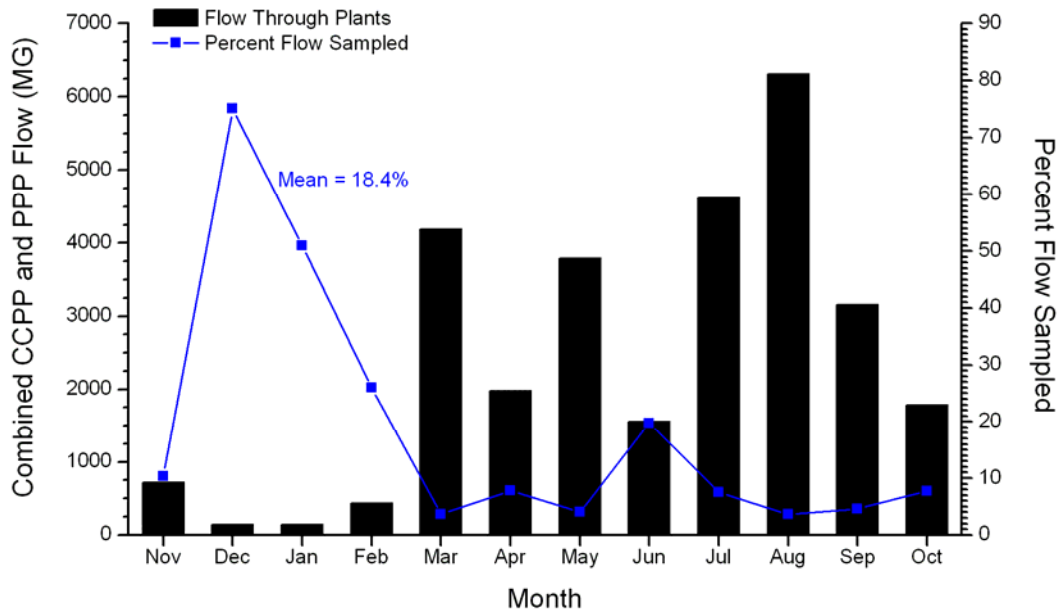


Figure 6. Combined total monthly flow pumped through the Delta Plants, Contra Costa (CCPP) and Pittsburg (PPP), and monthly percentage of flow sampled for impingement.

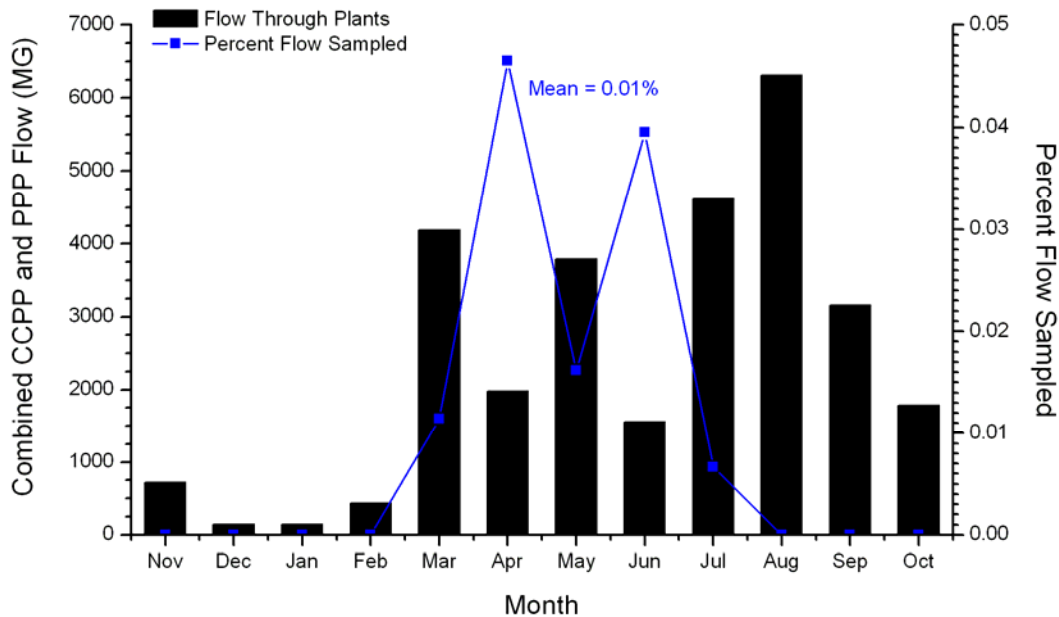


Figure 7. Combined total monthly flow pumped through the Delta Plants, Contra Costa (CCPP) and Pittsburg (PPP), and monthly percentage of flow sampled for entrainment.

Sample Size Analysis of Delta Plants Monitoring Data

Average annual estimates of delta smelt entrainment using water year 2008 operating levels and bootstrap re-sampling and expansion were consistently near 150,000 individuals. Not surprisingly, 90% confidence intervals were very large reflecting low sampling frequencies (Figure 8). Average annual estimates of longfin smelt entrainment for the same period were more than 60,000 fish. Confidence intervals associated with longfin smelt entrainment estimates show less variability relative to delta smelt (Figure 9).

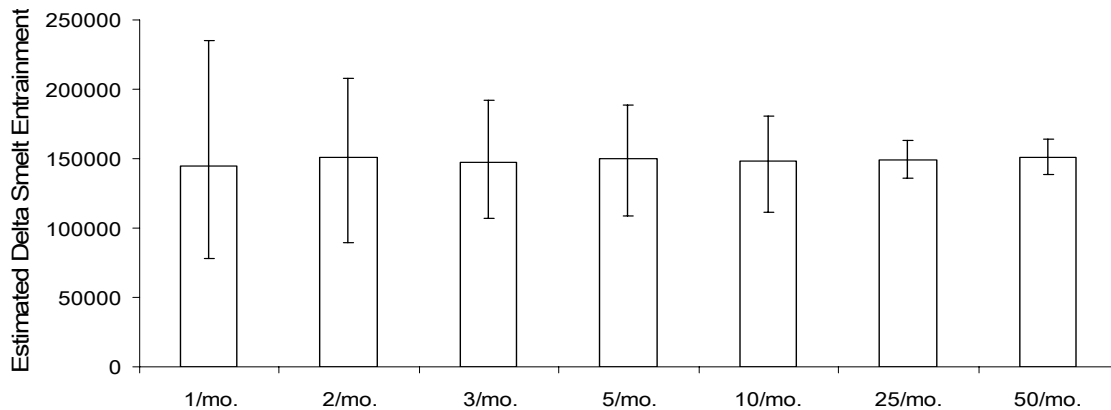


Figure 8. Expanded bootstrap re-sampling estimates of annual delta smelt entrainment at the power plants using Water Year 2008 pumping volumes and alternative sampling frequencies. Column heights are means and error bars show 90% confidence intervals for different monthly sampling frequencies (1-50 times per month).

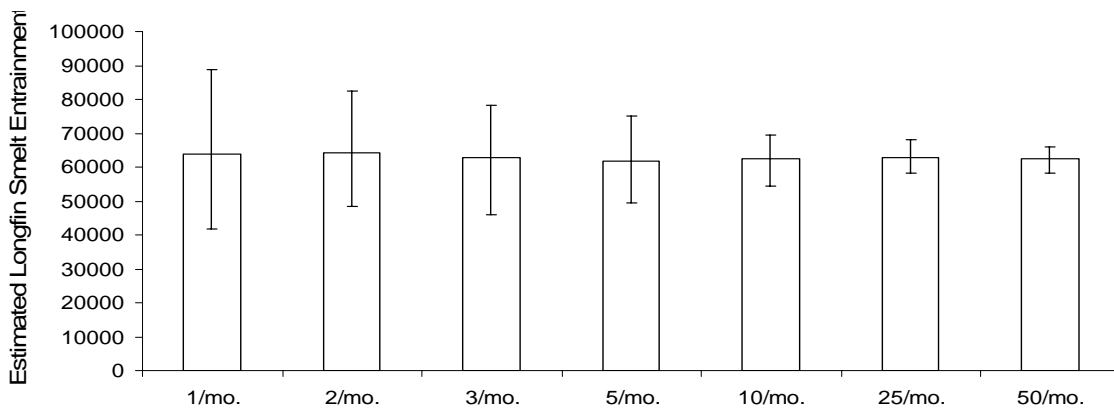


Figure 9. Expanded bootstrap re-sampling estimates of annual longfin smelt entrainment at the power plants using Water Year 2008 pumping volumes and alternative sampling frequencies. Column heights are means and error bars show 90% confidence intervals for various monthly sampling frequencies (1-50 times per month).

Bootstrap re-sampling estimates of monthly delta smelt entrainment indicate that heavier pumping rates require more intensive sampling efforts to characterize take accurately. This also holds true for scenarios with reduced delta smelt abundance (Figure 10).

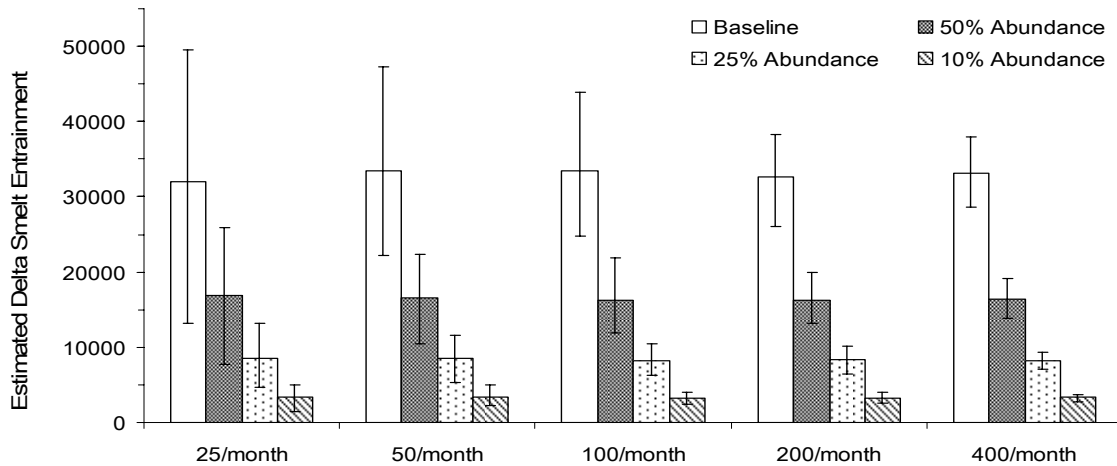


Figure 10. Expanded bootstrap re-sampling estimates of monthly delta smelt entrainment at the power plants using August 2008 pumping volumes and alternative sampling frequencies. Bars with different shading patterns show entrainment estimates re-sampled from sequential reductions of the original pilot dataset (see Methods). Column heights are means, and error bars show 90% confidence intervals for different monthly sampling frequencies (1-400 times per month).

Bootstrap re-sampling and expansion estimated annual impingement losses of delta smelt to be very low, about 40 individuals per year (Figure 11). Variability in impingement estimates was high. No expanded estimates of longfin smelt impingement were possible because longfin smelt were not detected in survey samples.

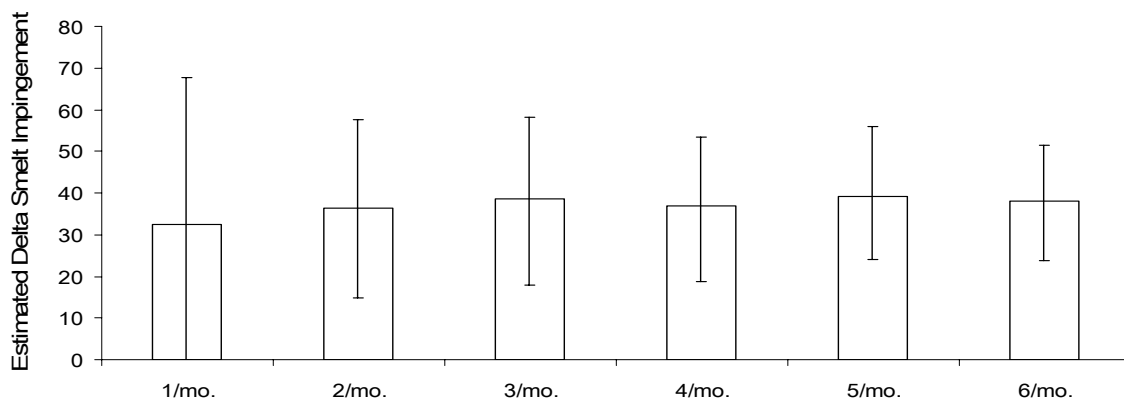


Figure 11. Expanded bootstrap re-sampling estimates of annual delta smelt impingement at power plants using Water Year 2008 pumping volumes and alternative sampling frequencies. Column heights are means; error bars show 90% confidence intervals for various monthly sampling frequencies (1-6 times per month).

Delta Smelt Length Frequency Analysis

Fork lengths of impinged delta smelt at PPP ranged from 22.5 – 70 mm (mean =41.8 mm; SE ± 5.2). No smelt were impinged at CCPP. Fork lengths of entrained delta smelt ranged from 16 to 33 mm (mean = 22.1; SD ± 3.5) (Figure 12). Lengths observed by these two sampling methods were significantly different ($F = 9.9825$; $df = 17, 1$; $P < 0.0057$). Only two longfin smelt were observed (32 and 38 mm FL). Twenty-nine (29) of the 31 observed fish (90%) were smaller than the threshold (65.5 mm) for the 3/8 inch (9.5mm) screen mesh size.

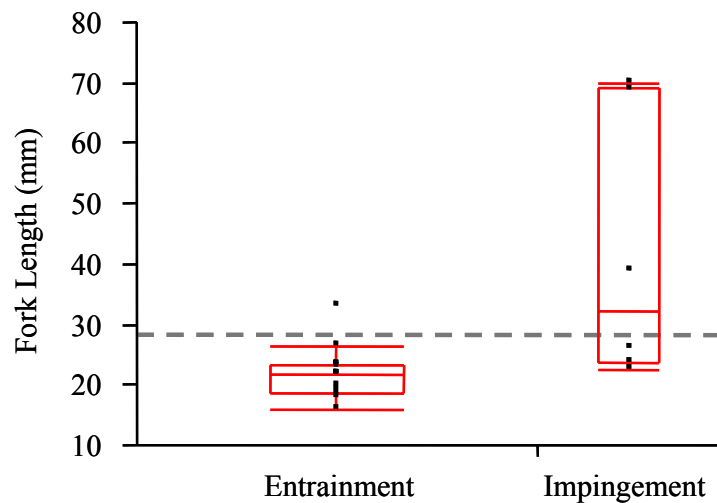


Figure 12. The fork length of delta smelt sampled by impingement and entrainment at the CCPP and PPP during the 2008 sampling period. Broken gray line indicates mean length of all sampled delta smelt.

Comparing observed delta smelt length frequencies shows statistically significant differences in observed fish size ($X^2 = 74.953$; $df = 13$; $P < 0.0001$) between expected values (derived from 2008 IEP program catch data) and pooled 2008 power plant entrainment and impingement sampling. Specifically, delta smelt less than 20 mm in length were under-represented, delta smelt 20 to 30 mm were over-represented, and delta smelt 40 to 65 mm were under-represented (Figure 13).

The size of delta smelt sampled was significantly influenced by Delta Plant location ($F = 11.2402$; $df = 35$; $P = 0.0019$) (Figure 14).

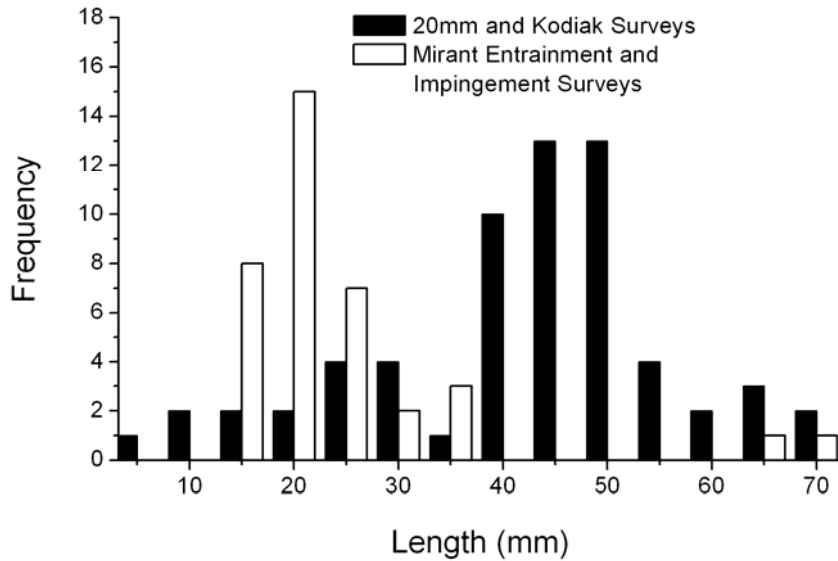


Figure 13. Length Frequencies of delta smelt caught during the 20mm tow-net and Kodiak trawl surveys during 2008 at stations between Chipps Island and Jersey Point and the Entrainment and Impingement surveys at the Mirant power plants during 2008. Summer tow net and fall mid-water trawl data were not available from BDAT in 2008.

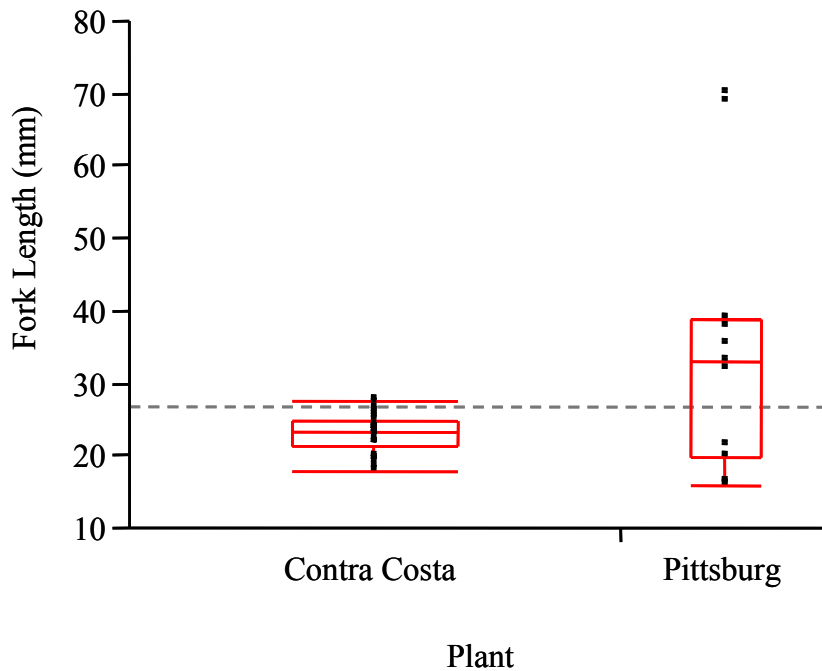


Figure 14. The fork length of delta smelt sampled at the power plants (pooled; impinged and entrained) during the 2008 sampling period. The broken gray line indicates mean length of all sampled delta smelt.

DISCUSSION

The findings presented above show that the frequency of entrainment sampling for the monitoring effort at the Mirant power plants produces annual and monthly take estimates with extremely high variance. Although IEP data demonstrate that delta smelt and longfin smelt are found in areas around the power plants throughout the year, a limited entrainment monitoring effort takes place only from March into July (with one sample in July). Instead of scheduling monitoring to assess take of fish when power plant pumping is greatest, Mirant's monitoring plan schedules monitoring to correspond with the timing of IEP trawl surveys. Pumping activity at the power plants is much greater in August and September, months in which no entrainment monitoring was conducted. In fact, some entrainment sampling appears to have occurred when no water was passing through the plants. Restricting entrainment sampling to such a limited period likely under-represents the take of delta smelt and longfin smelt. In order to more adequately monitor pumping operation impacts, impingement and entrainment sampling need to be more frequent during periods of high pumping.

Based on data from 2007 and 2008, smelt losses from impingement appear to be relatively low. Increased sampling effort would increase the precision of impingement take estimates, but differences would likely have little significance in shaping project operations. The greatest concern with the current impingement-sampling scheme relates to the unknown sizes and number of smelt that are assumed to be impinged, but may in fact be entrained. Entrainment studies at the power plants that were conducted by PG&E from 1978 to 1979 show that juvenile smelt were able to pass through the 3/8 inch (9.5mm) screens and become entrained (PG&E 1981a, 1981b). Unfortunately, no studies have been conducted to evaluate the maximum size of fish that can pass through 3/8 inch (9.5mm) traveling screens. However, fish length frequencies observed during the 2008 sampling period indicate that smaller individuals are less susceptible to impingement, and the smaller size of fish sampled at the CCPP indicates that impingement may under-represent the take of smelt there.

The fact that unknown numbers of both smelt species may pass through the screens undetected by impingement monitoring is particularly significant because impingement monitoring, rather than entrainment monitoring, is conducted year round. The low numbers of impinged smelt that are measured during impingement monitoring may mask numbers of smelt that pass through the screen unmeasured, and then into the power plant pumps. While impingement sampling captures a relatively large proportion of the water actually pumped (nearly 10% in active pumping months), the percent of pumping operations sampled for fish entrainment is extremely low (monthly mean 0.01%). Our analyses illustrate that increasing the frequency (therefore volume) of entrainment sampling is necessary in order to estimate the take of delta smelt and longfin smelt at the power plants. Given that smaller adult and juvenile smelt are subject to entrainment rather than impingement, these smelt size classes are likely under represented by impingement sampling. The year-round presence of both smelt species near the plants

strongly indicates the current entrainment monitoring requires substantial improvements in sampling frequency and duration.

Bootstrap re-sampling and expansion estimates show that the current practice of sampling for entrainment only twice per month for March to July results in annual take estimates that differ from actual take by as much as 40% in 9 out of 10 years. In contrast, entrainment sampling 25 times per month (as part of a properly randomized sampling design) would generate estimates within 10% of the actual take in 9 out of 10 years. Entrainment monitoring designed to estimate monthly take would require higher sampling frequencies in months with high pumping activity and variable smelt abundance. For impingement monitoring, it is debatable whether more precise estimates would be particularly useful in conservation planning. Put another way, whether 20 adult smelt or 60 adult smelt are impinged annually at the power plants may not be considered important to resource managers.

The current scarcity of both smelt species in Delta waters complicates accurate estimation of entrainment and impingement losses at the power plants; however, this problem is greatly exacerbated by shortcomings in the current power plant sampling effort. The combination of large confidence intervals and sampling gear selectivity observed in our analyses suggest the present monitoring plan provides an unreliable assessment of delta smelt and longfin smelt losses at the power plants.

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