Summer 2014

Demise of the Delta Smelt Population

October 2014

Photo source: B. Moose Peterson/USFWS Digital Library

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Introduction

Last year we provided a prognosis of what would happen to the Delta smelt, a federal and state listed endangered species, as a consequence of poor summer habitat conditions during the second summer of the present multiyear drought. That report "Summer 2013" warned of grave consequences to the smelt population from low summer Delta outflow and high Delta exports. The subsequent 2013 Fall Midwater Trawl index matched the lowest index on record from 2009, the third year of the 2007-2009 drought.

In this third and most undoubtedly the worst year of the present multiyear drought (and the worst since 1977) habitat conditions have been very poor and the Delta smelt population is now much closer to extinction with the lowest summer index on record. Drastic measures including relaxation of critical year Delta water quality standards were taken to provide badly needed water to farmers and cities, which resulted in uncharacteristically poor Delta habitat conditions in spring and summer. The prognosis for this year regrettably is far worse than last year's. The one saving grace this year was the dependable late winter and early spring snows and rains to the Central Valley and Sierras that provided a respite from the drought and helped the native fish and subsequent summer water supplies. But like last year there was limited subsequent water saving and very low outflow to the Bay after early spring. Adding insult to injury, critically dry year water standards were relaxed and unrestricted water transfers were allowed through the Delta under the relaxed standards, leading to the historically poor habitat conditions and the record low summer smelt abundance indices.

Could this disaster have been avoided or ameliorated? Yes, by providing slightly higher Delta outflows and reducing albeit already low, summer, critically dry year level Delta exports. After reading this report the reader will have to decide if the small amount of extra water that was squeezed through the Delta for export this summer (including water transfers from north to south) was really worth it given the consequences to Delta water quality and ecological health, as well as the increased risk of Delta smelt extinction.

Events Leading Up to 2014

This year's problems actually started back in water year 2011 when after a wet winter-spring a record 6.5 million-acre-ft of water was exported from the Delta. The combination of an above-normal water year in 2010 and a wet water year in 2011 had led to a modest improvement in the Delta smelt population as reflected in the Fall Midwater Trawl Survey Index (Figure 1). Though the lingering wet year conditions allowed the major reservoirs to refill in spring 2012, the effects of the high 2011 exports and the beginning of drought were soon felt. The reservoirs were drawn down sharply in 2012 to meet heavy water demands of the first of three years of drought (Figure 2). As a consequence, the reservoirs did not refill in the winter spring of 2013 leading to further depressed reservoir after the heavy demands for water in 2013. As a consequence, reservoir levels were less the 50% of capacity at the beginning of 2014, and there was very limited supply for the third year of drought.

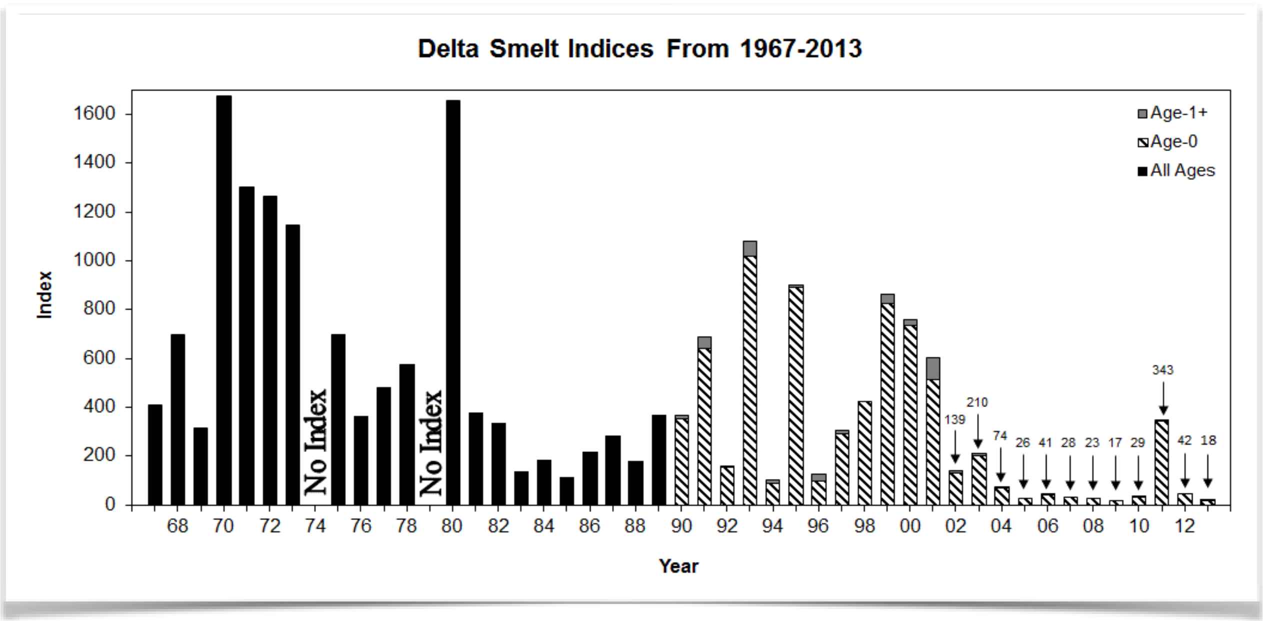


Figure 1. Delta smelt Fall Midwater Trawl Index (1967-2013). (Source: CDFW)

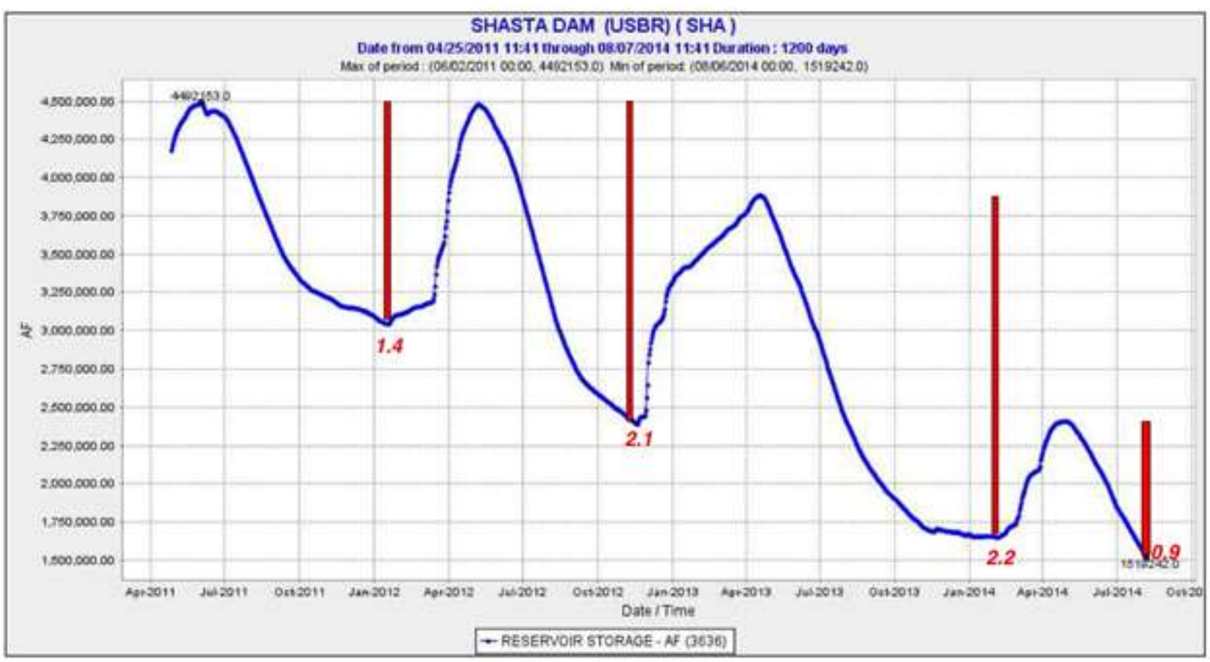


Figure 2. Water storage in Shasta Reservoir during the past three years. (Source: CDEC)

Geographic Features

Many of the geographic and water control features referenced in this report are depicted in Figure 3.

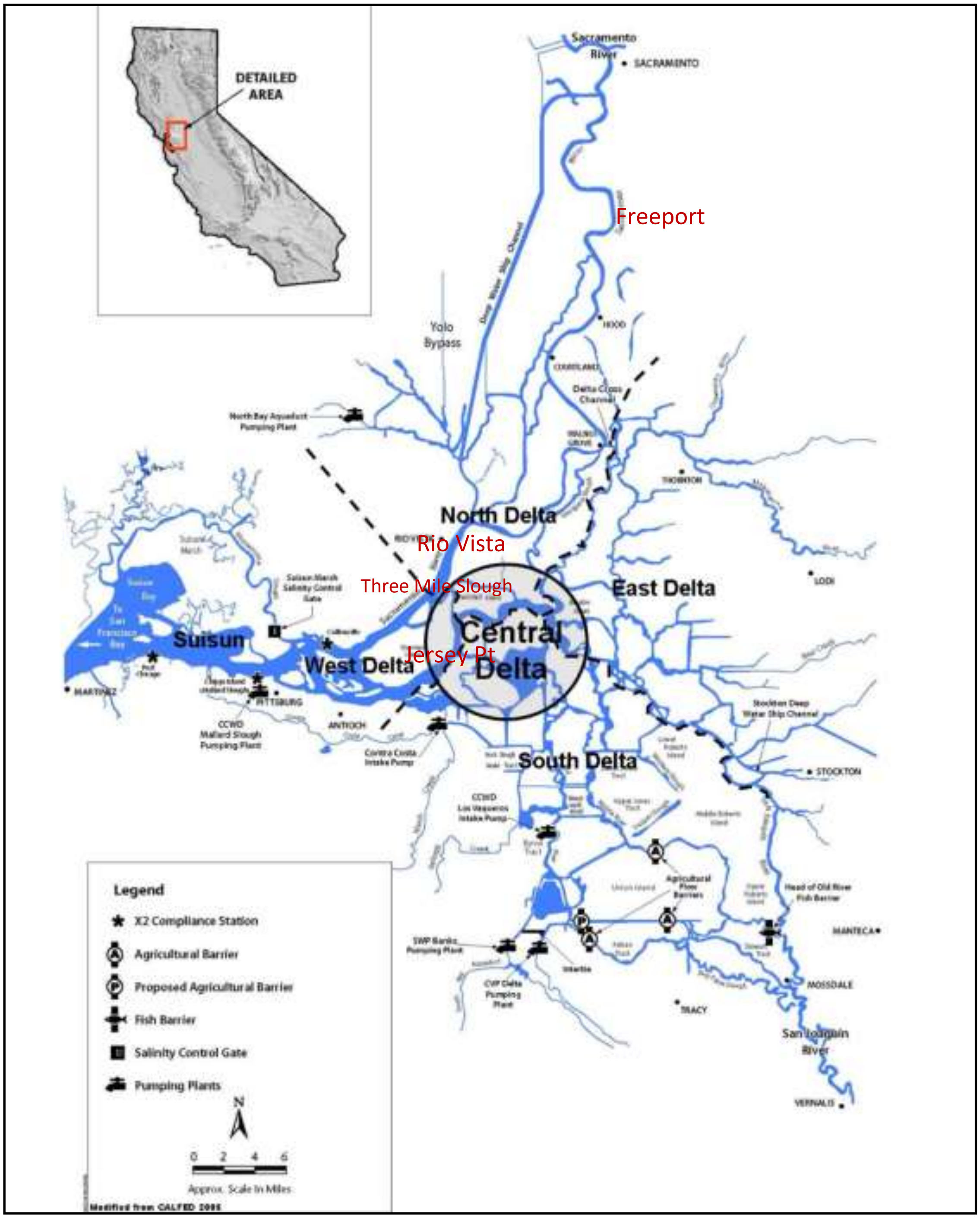


Figure 3. Map of Delta and key locations mentioned in report (in red).

Glossary

Delta Outflow: The amount of water leaving the Delta tidally averaged over the day is defined as Delta Outflow. Various methods are used to estimate outflow magnitude including the Net Delta Outflow Index (NDOI) and North Delta Outflow (NDO), which are estimated outflow based on estimated inflows and net Delta consumptive use, or the sum of net measured outflow from the Sacramento River at Rio Vista, the San Joaquin River at Jersey Point, and the net flow through Three Mile Slough and False River, respectively. Delta outflow is also an estimate of the outflow from the Delta to San Francisco Bay. Delta outflow is the primary driver of the salinity distribution in the Bay and Delta, and is thus critically important to the ecology of the Bay and Delta.

Delta Inflow: The amount of water entering the Delta primarily from the Sacramento and San Joaquin Rivers and local Delta tributaries is defined as Delta Inflow. In summer most of the Delta Inflow comes from the Sacramento River and its major storage reservoirs on the upper Sacramento River (i.e., Shasta Reservoir), Feather River (Oroville Reservoir and Bullards Bar Reservoir), and American River (Folsom Reservoir). Inflow from the San Joaquin River can be high in winter especially in wetter years, but is generally low in summer (less than 10% of Sacramento River inflow).

X2: X2 is the location in the Bay-Delta salinity gradient expressed as distance in kilometers from the Golden Gate Bridge to the location where bottom salinity is 2 parts per thousand (ppt). X2 moves seasonally with freshwater inputs. It also moves up and down the estuary with the tides – generally a distance in summer of about six miles (or about 10 kilometers).

Low Salinity Zone or LSZ: the LSZ is defined as the Bay-Delta area in which salinity is between 0.5 and 6 ppt, including the X2 location near the center of the LSZ. By local convention, the LSZ is also expressed in terms of distance in kilometers from the Golden Gate Bridge. The LSZ is an important area of an estuary because it is often where the freshwater inflow and high salinity bottom water from the Bay mix. For species like salmon the LSZ is important for acclimating from freshwater to ocean salinity conditions. For others like smelt, the LSZ has salinities similar to their blood plasma concentrations, thus requiring less energy to maintain their blood plasma concentrations. The LSZ is also characterized as the Null Zone or Entrapment Zone where many pelagic organisms and suspended sediments tend to accumulate, making it one of the most productive zones of an estuary. The young of many marine, estuarine, and freshwater fish depend on this high productivity zone of the estuary.

South Delta Exports: Water is exported from the southern Delta at the Tracy (federal Central Valley Project) and Banks (State Water Project) pumping plants. Water is also exported at two smaller Contra Costa Water District pumping plants (see Figure 3).

Delta Hydrology in 2014

The 2014 drought is a consequence of record low rainfall, snowpack, and reservoir levels through the end of January 2014. Being the third year of a multiyear drought made conditions all the worse. But like most drought years, storms in late winter and spring usually bring some relief and 2014 was no different. Three storm periods from February to early April brought moderate flows into the reservoirs and Valley streams, as can be seen in Figure 1. Delta inflow at Freeport in the Sacramento River in the North Delta rose to over 20,000 cfs during the storms. Reservoir inflow reached near 50,000 cfs and storage nearly doubled, although achieving only 50 percent of normal for spring. Snowpack accumulations were however critically low. South Delta exports were able to increase during the storm runoff.

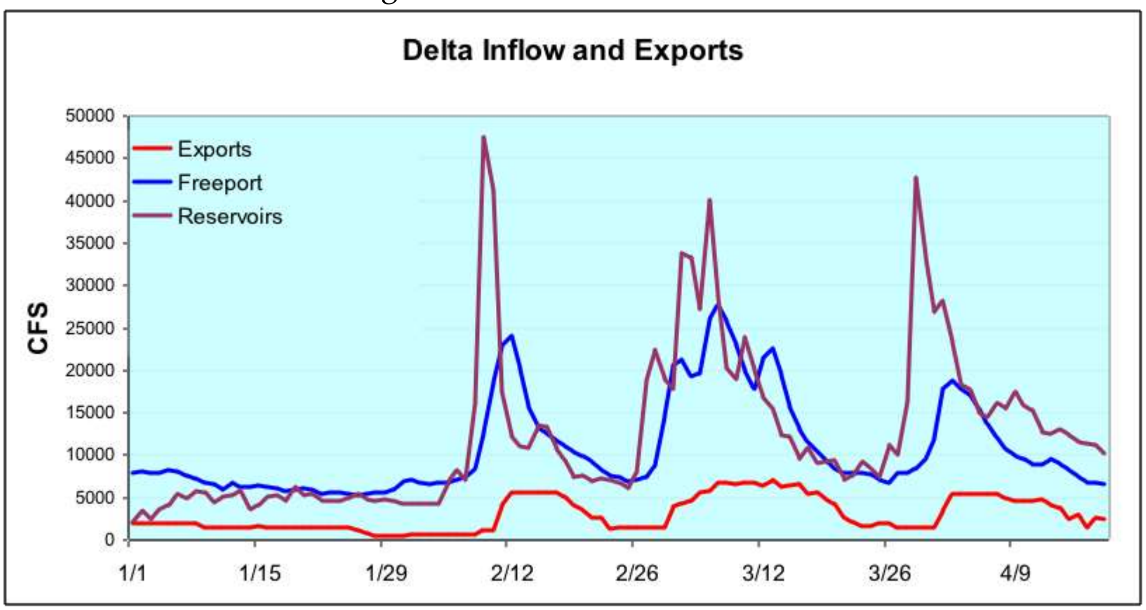


Figure 4. Total Delta exports, Project reservoirs inflow, and Sacramento River Delta inflow 2014. Reservoir inflow is total of four Project reservoirs (Shasta, Oroville, Folsom, and New Melones). Exports are the total of Clifton Court, CCWD, and Tracy pumping plants. Sacramento River at Freeport flows were primarily made up of the flows of the many Sacramento Valley streams that flow undammed into the Delta. Major contributions came from Cow, Cottonwood, Battle, Deer, and Mill creeks and the Yuba and Cosumnes rivers.

Early February rainstorms led to freshwater pouring into the Delta and through the Delta into Suisun Bay and Marsh. The source of water was uncontrolled water from the watershed, with nearly half coming from the unregulated portions of the Yuba River (mainly the South Fork and Deer Creek). Much of the rainfall, which was over 10 inches of precipitation in the Sierra, was captured in Valley Reservoirs. Oroville, Folsom, and Shasta reservoirs each captured up to 20,000-30,000 cfs during the storms, but did not release any of the extra water. The Low Salinity Zone (LSZ) which had been in the Delta moved west into Suisun Bay and Marsh. Delta outflow had been 7000 cfs before the storms, but then reached a peak of 25,000 cfs.

Despite similar storms in March and April, drought conditions soon returned to the Delta. The following sections describe the 2014 patterns for Delta inflow, outflow, and exports.

Delta Inflow

Delta inflow from the Sacramento River for 2014 was far below normal. The three major storm periods interrupted the drought flow levels and mark the record. Large reservoirs on the Sacramento and San Joaquin watersheds retained most of their storm inflows. The low Sacramento River inflows at Freeport in late April and early May (Figure 5) were due to much of the Delta inflow requirements being met by prescribed San Joaquin reservoir releases for salmon and steelhead smolt out-migration to the Bay. Inflows ranging from 7000 to 10,000 cfs in late spring and into summer were from reservoir releases necessary to meet minimum summer Delta water demands including South Delta exports as well as those from thousands of smaller agricultural, municipal, and industrial diversions. Because water allocations from the State and Federal water projects were curtailed due to the drought along with State Board drought restrictions on smaller water rights diversions, these Delta inflows were only about 50% of normal water year levels.

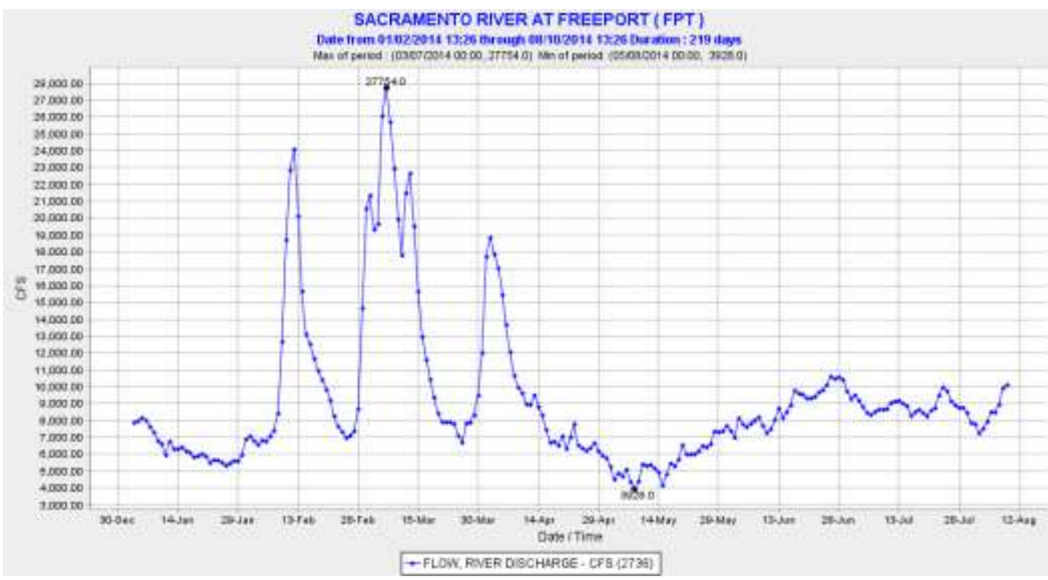


Figure 5. Delta inflow from Sacramento River (measured at Freeport) in 2014. (Source: CDEC)

Delta Exports

Because of the drought, Delta exports were much lower than normal or capacity (11,400 cfs). State exports however did reach modest peaks in February during the storm periods (Figure 6), while taking advantage of the higher Delta storm inflows (see Figure 5). Low spring and early summer exports of 250-750 cfs were prescribed by the State Board because of the drought. Summer State exports above 750 cfs are attributed to allowed water transfers through the Delta. Federal exports had a similar pattern (Figure 7).

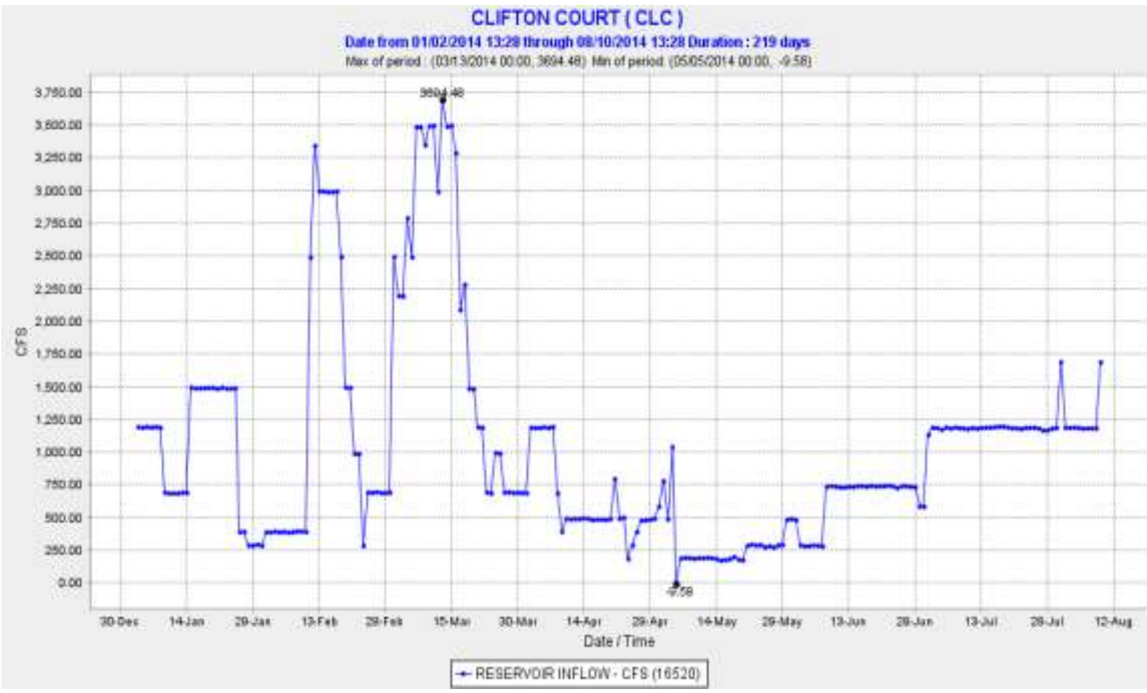


Figure 6. Exports in cfs at State Banks Pumping Plant in 2014. (CDEC)

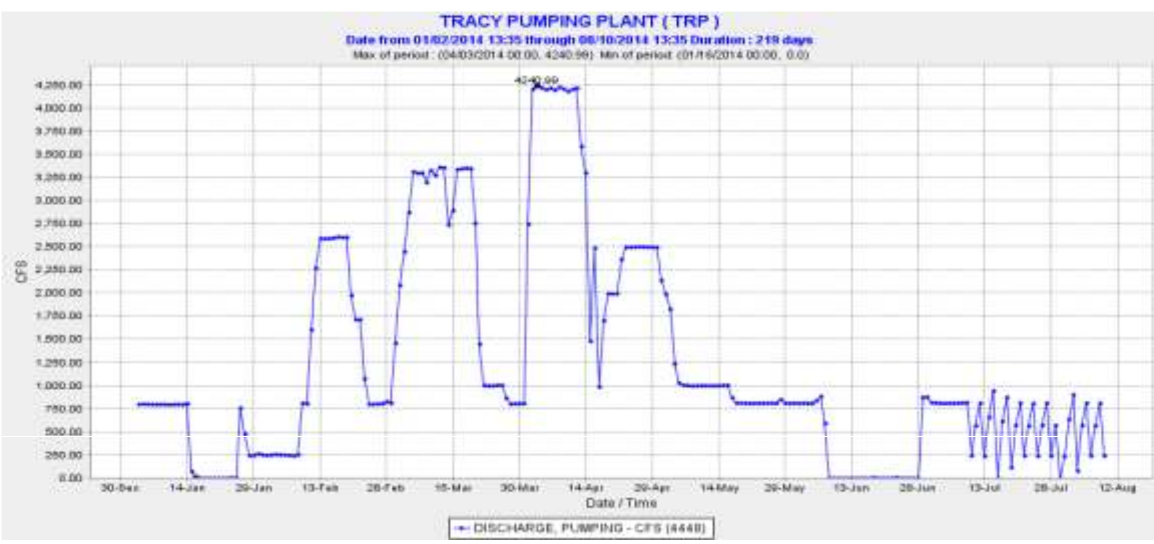


Figure 7. Exports in cfs at Federal Tracy Pumping Plant in 2014. (CDEC)

Delta Outflow
Delta outflow in 2014 (Figure 8) reflected requirements in State Board drought orders (see next section on relaxed standards) and unregulated Delta inflows from the winter-spring storm events. Standards require outflow of 7000 cfs into June. The July standard for a critical year is 4000 cfs.

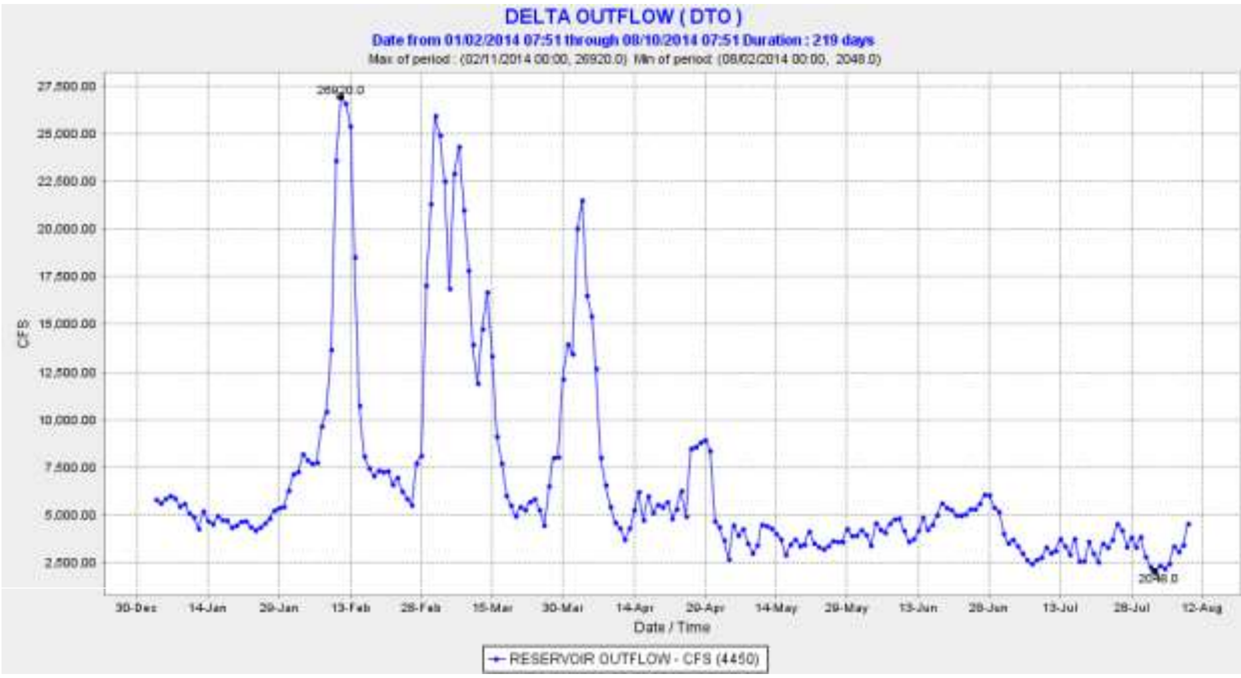


Figure 8. Delta outflow (NDOI) in 2014. (CDEC)

Independent review of the NDOI by USGS and CSPA indicates that the NDOI in low inflow-outflow conditions such as in spring-summer of 2014 is biased high by several thousand cfs. Thus, the spring-summer NDOI in 2014 of 2000 to 6000 cfs is probably only -1000 to +3000 cfs. Reviewers and water project operators note the difficulty in estimating Delta outflow as tidal flows in the Delta are up to several hundred thousand cfs; thus estimating (NDOI) or measuring (NDO) several thousand cfs of net outflow is recognized as “difficult”. Measurements of Delta Outflow (NDO) are considered accurate by USGS. How much water escapes the Delta is difficult to determine mainly because of strong tidal effect. Spring tides are up to several feet higher in elevation than neap tides during the lunar cycle, and thus have a marked effect on actual outflow. The higher spring tides act as a dam, blocking freshwater from passing through the Delta. Regardless, as discussed later, the amount of outflow greatly affects salinity, water temperature, and habitat conditions in the Delta, as well as exposure of species like the Delta smelt and their critical habitat to the effects low outflows and exports.

Water Quality Standards Relaxed

Flow and water quality objectives set forth for the Delta under State Board D-1641 were relaxed beginning in winter 2014. The changes are summarized in the April 18, 2014 State Board Order approving requests for relaxations by the California Department of Water Resources (CDWR) and US Bureau of Reclamation (Reclamation). These requests were also approved by the California Department of Fish and Wildlife (CDFW), the National Marine Fisheries Service (NMFS), and the US Fish and Wildlife Service (USFWS).

The Orders provided for the following key changes:

1. Outflows through July could be reduced from 4000 cfs to 3000 cfs, if exports were maintained less than 1500 cfs. Exports could be higher if outflow reached 7000 cfs or above.
2. The Delta salinity standard reference location for 2.78 EC limit was moved upstream several miles from Emmaton to Three Mile Slough. (This was necessary to allow the minimum 3000 cfs outflow.)

The motivation for the changes in standards was to save reservoir storage during the drought. In 2013 agencies requested changes in the year classification for 2013 from dry to critical so that reservoir storage could be retained with lower releases and relaxed Delta standards. A May 2013 letter from the State Board to DWR and Reclamation referenced a request from Maria Rea of NMFS to consider reducing Shasta Reservoir releases required to meet Delta Standards in order to conserve the cold-water pool in the reservoir for future winter-run salmon requirements. The letter also referenced Gov. Brown's Executive Order B-21-13 to expedite water transfers and water delivery actions. Further Temporary Urgency Change Orders continued into the spring of 2014 as the drought continued. Again, the motivation for changes included conserving reservoir storage to provide protections for aquatic species, water quality and water supply, and concluded that such changes were in the public interest.

Water Transfers

Water transfers from water right holders north of the Delta were allowed through the Delta State and Federal export facilities to purchasers south of the Delta during the summer of 2014. Transfers occurred beginning about July 1. Exports above 1500 cfs generally reflect the amount of water transfers. The D-1641 prescribed San Joaquin flow increase of 2000 cfs from mid-April to mid-May is also conducted as a water transfer as Delta exports were allowed to increase by that amount during the enhanced flow period.

Delta Water Quality

Changes in Delta outflow, inflow, and exports during the 2014 drought are reflected in Delta water quality – principally salinity, water temperature, and turbidity – which are critical habitat parameters of Delta smelt.

Salinity

Delta smelt gravitate to the LSZ near X2 in summer. Delta outflow, inflow, and exports affect the location and character of the LSZ in summer. Lower Delta outflow generally results in an upstream shift in the LSZ and higher salinity at a specific location (Figure 9).

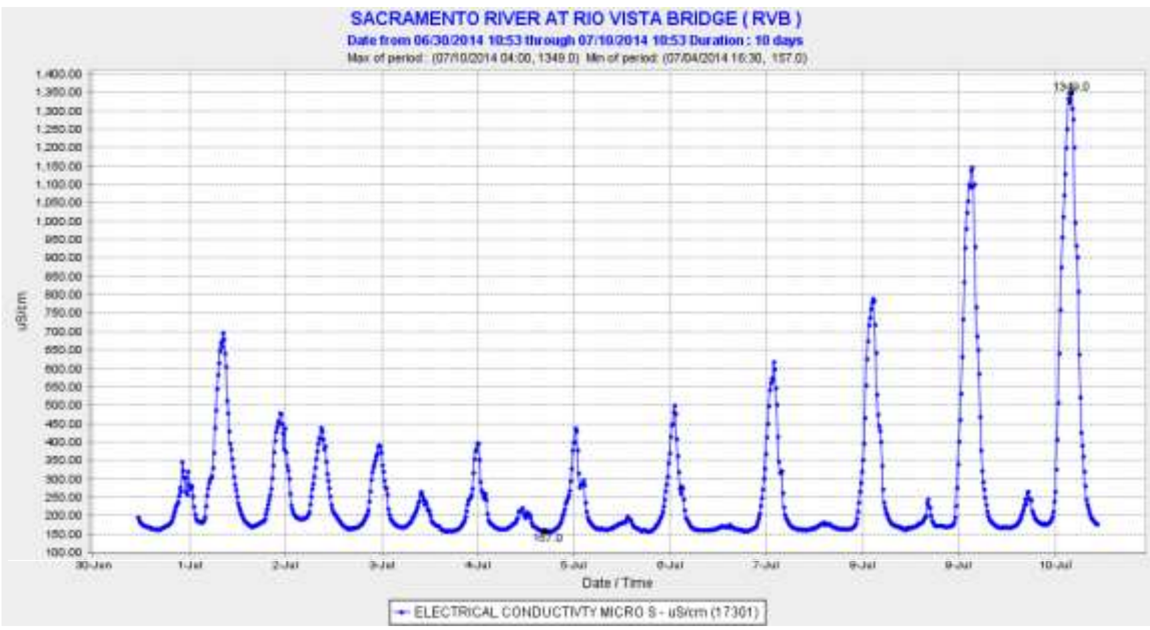


Figure 9. Salinity at Rio Vista during the first ten days of July when Delta outflow dropped nearly 3000 cfs (see Figure 8).

Water Temperature
Water temperature above 75F are generally considered lethal to Delta smelt. Water temperatures from 70 to 75F are considered sublethal or providing stressful conditions. Drought years like 2012, 2013, and 2014 generally lead to higher water temperatures in the Delta than non-drought years like 2010 and 2011 for a variety of reasons. The temperature of the water entering the Delta as measured at Freeport is higher during the drought years (Figures 10-14). Lower flows (longer transport times), warmer reservoir releases, warmer air temperatures, and higher solar radiation are some of the causes. The fact remains that Delta inflow is warmer in drought years.

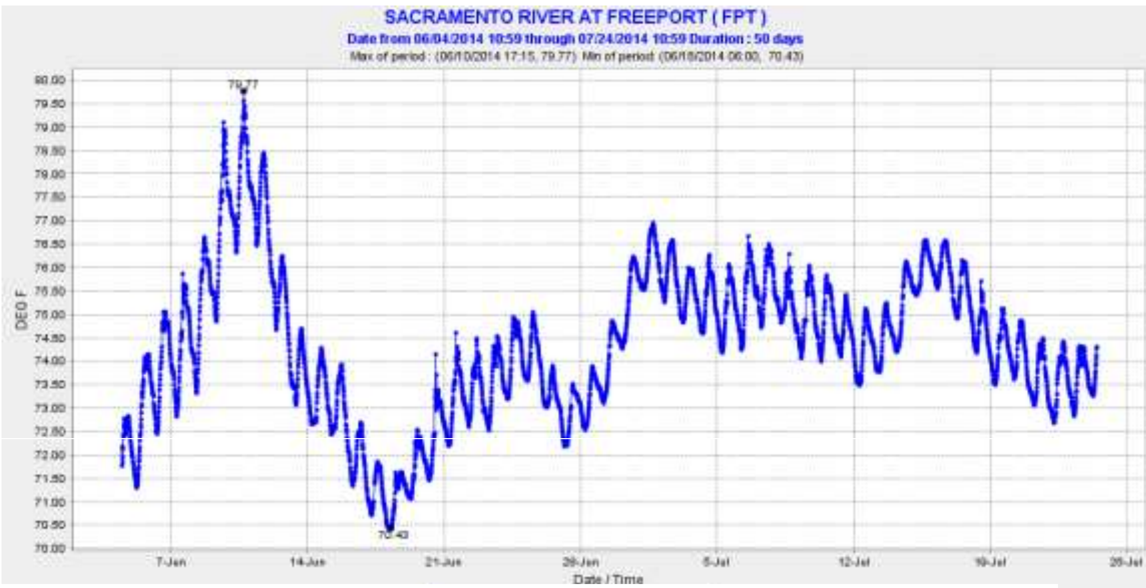


Figure 10. Water temperature at Freeport in June and July 2014.

Figure 11. Water temperature at Freeport in spring and summer of 2010.

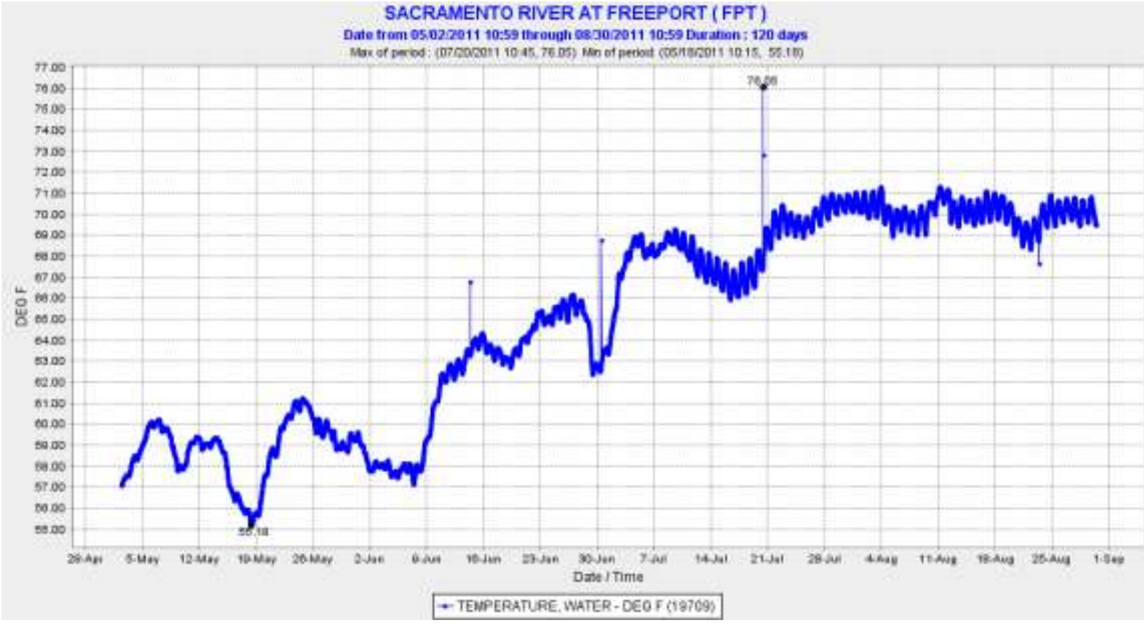


Figure 12. Water temperature at Freeport in spring and summer 2011.

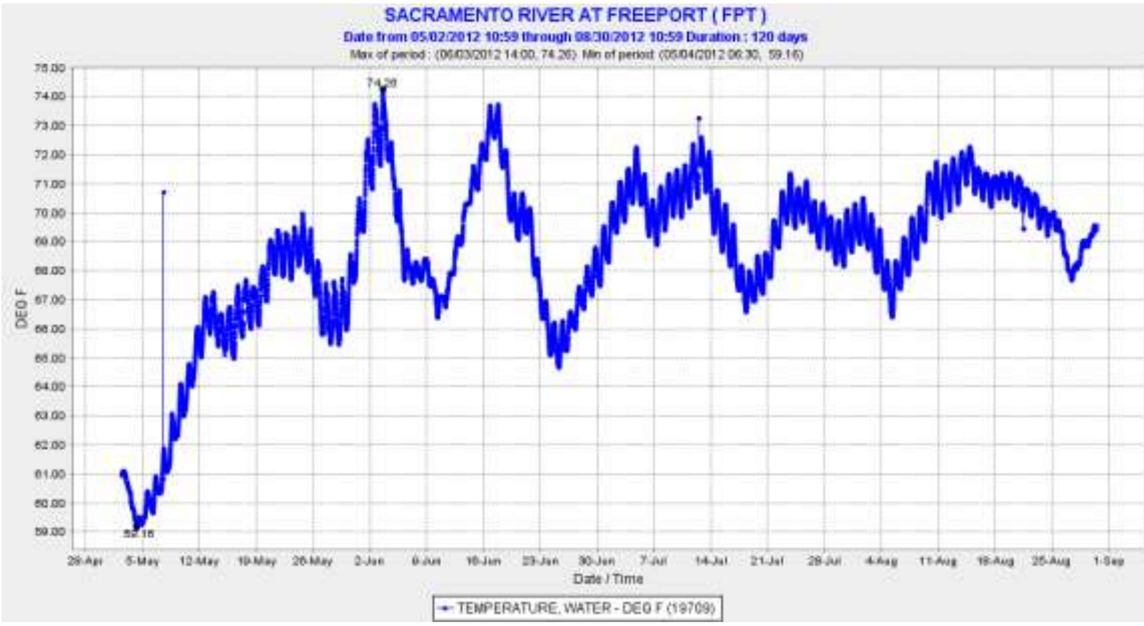


Figure 13. Water temperature at Freeport in spring and summer 2012.

Figure 14. Water temperature at Freeport in spring and summer 2013.

Another fact is that water temperatures are warmer the further east or upstream in the Delta channels of the Sacramento and San Joaquin Rivers. Therefore the LSZ habitat of the Delta smelt is warmer in drought years because the LSZ is located further upstream in the Delta. In summer 2014 the LSZ was located even further upstream than normally would occur in a drought year because of the relaxed outflow and salinity standards. During the first 10 days of July 2014 when Delta outflow declined several thousand cfs and the LSZ moved upstream into the Rio Vista area, water temperatures in the LSZ reached 73-75F (Figure 15).

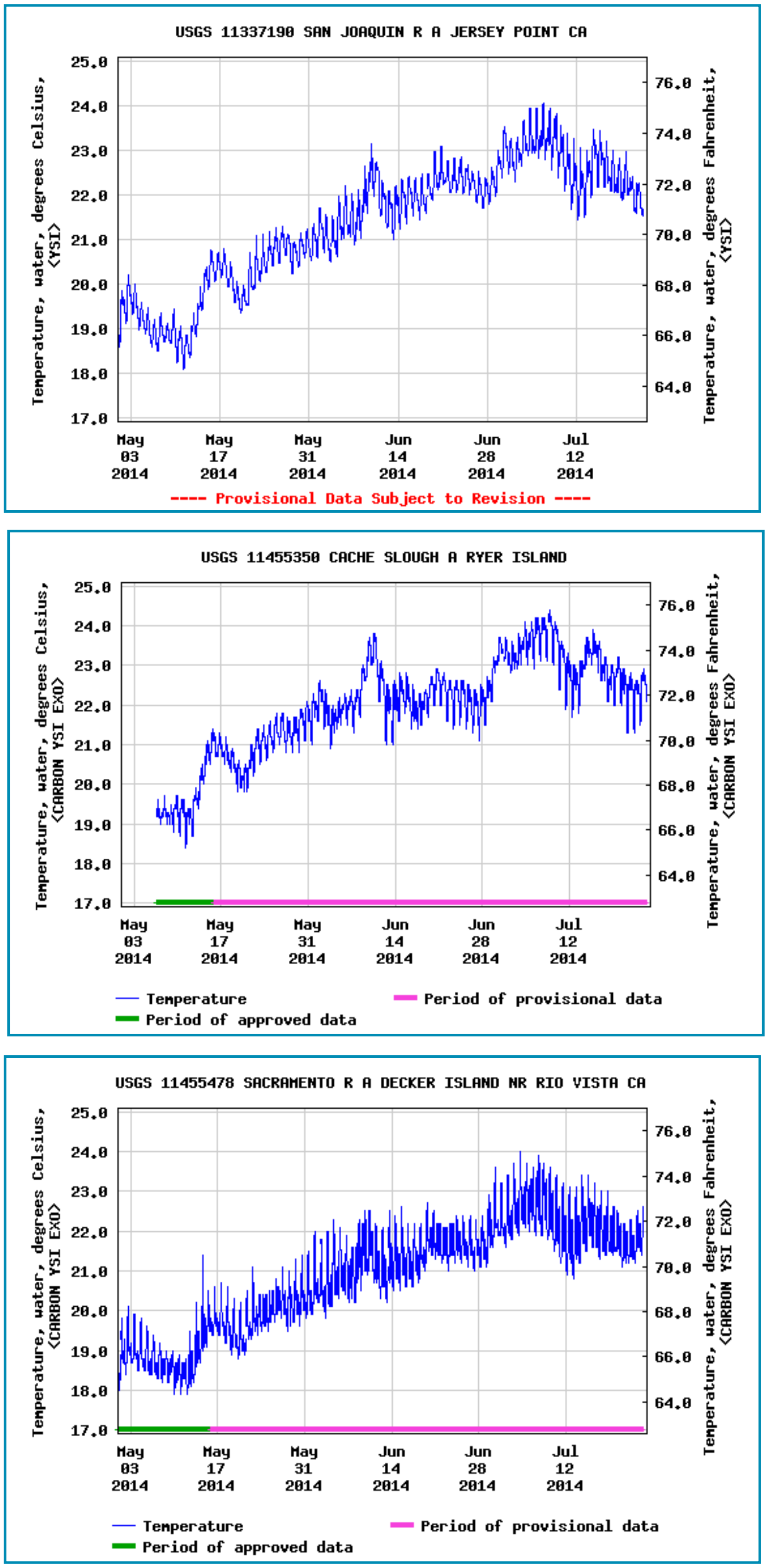


Figure 15 a,b, and c. Water temperatures at selected locations in the LSZ in late spring and early summer 2014.

Turbidity

Delta smelt are generally known to prefer high turbidity habitats where they can capture prey and minimize their own predation. Waters with turbidities less than 10-18 NTUs or FNUs are thought to be avoided (Hasenbein et al. 2013). Survey data for the LSZ in spring and summer indicate declining turbidity levels (Figures 16 and 17).

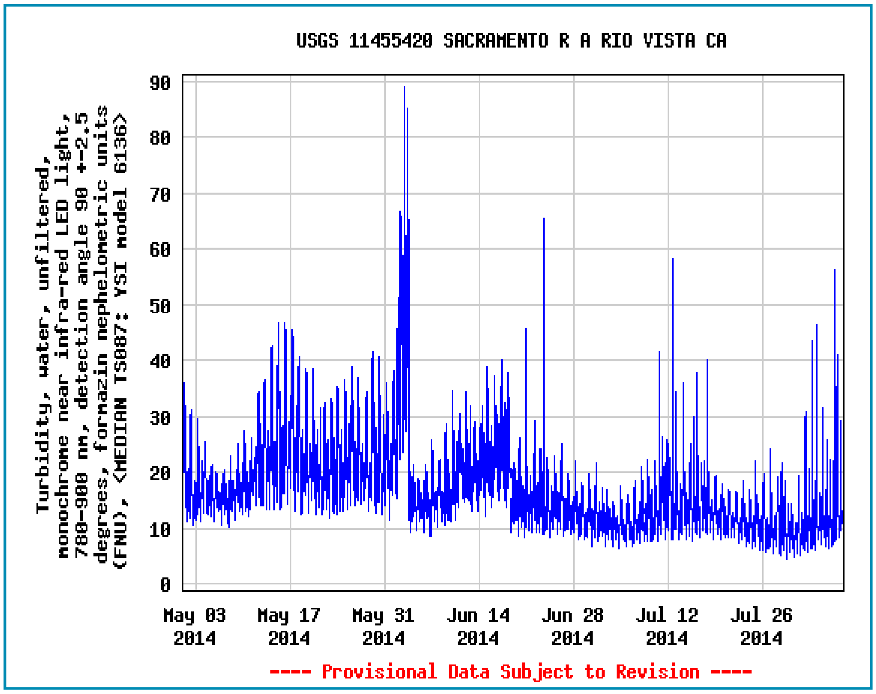


Figure 16. Turbidity at Antioch in LSZ in 2014. (USGS)

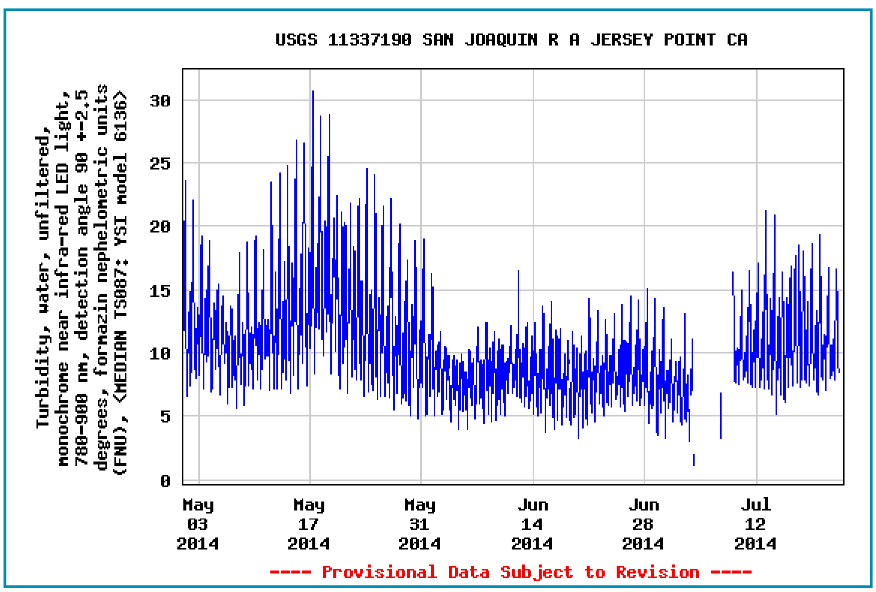


Figure 17. Turbidity at Jersey Point on lower San Joaquin River in spring and summer of 2014. (USGS)

Comparison of LSZ Conditions between 2013 and 2014

LSZ conditions in drought year 2014 were worse than drought year 2013 because of the relaxed standards. Salinity at Antioch was generally higher through the spring and summer of 2014 (Figure 18) than 2013 (Figure 19) reflecting the further upstream position of the LSZ because of lower Delta outflow resulting from relaxed standards.

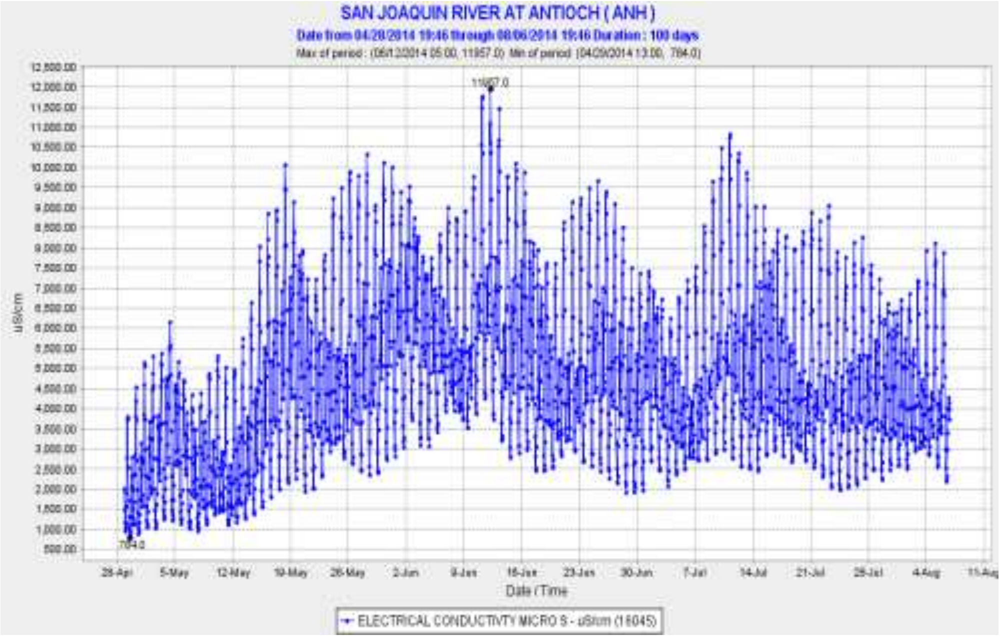


Figure 18. Salinity at Antioch spring and summer of 2014.

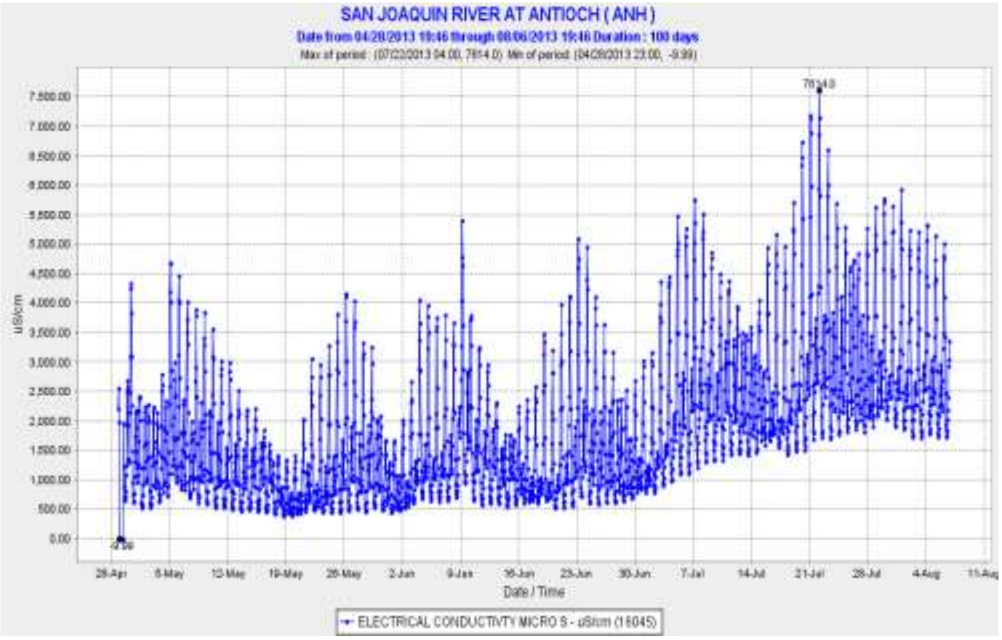


Figure 19. Salinity at Antioch spring and summer of 2013.

Mechanism for LSZ Degradation

The mechanism for LSZ degradation in the summer of 2014 is depicted in Figure 20. Warm, freshwater from reservoir releases enters the northern Delta (blue arrows) and upper LSZ at green boundaries. South Delta export water is drawn directly from the LSZ via channels depicted with red arrows. Simply put, LSZ water is exported and replaced by warm, fresh, low turbidity reservoir water in Delta inflow from the Sacramento River.

Figure 20. Location of LSZ in summer 2014. The upper boundary of the LSZ is depicted by green boundaries on the lower Sacramento and San Joaquin rivers and Central Delta on Old River. South Delta export water is drawn from the LSZ from areas characterized by net negative flow (red arrows). Export water is replaced by incoming warm, fresh, low turbidity water from the Sacramento River (blue arrows).

Delta Smelt in 2014

March-May Delta Smelt Distribution

Delta smelt first appeared in surveys in March 2014 as newly hatched larvae (Figure 21). They were dispersing downstream from spawning areas to the LSZ (blue boundary). The spawning area for Delta smelt is the freshwater zone of the Sacramento River and Delta above the LSZ.

By late April, X2 had moved upstream under lower outflows and juvenile Delta smelt were concentrated in the North and Central Delta, and subject to the cross-Delta flow of water to the South Delta export facilities (Figure 22).

In mid-May juvenile Delta smelt continued to be concentrated in the North and Central Delta upstream of X2 (Figure 23).

At the end of May juvenile Delta smelt remained concentrated in the North and Central Delta with salinity and outflow patterns similar to mid-May (Figure 24). Water temperatures had by then reached the stressful threshold of 70F (see Figure 15).

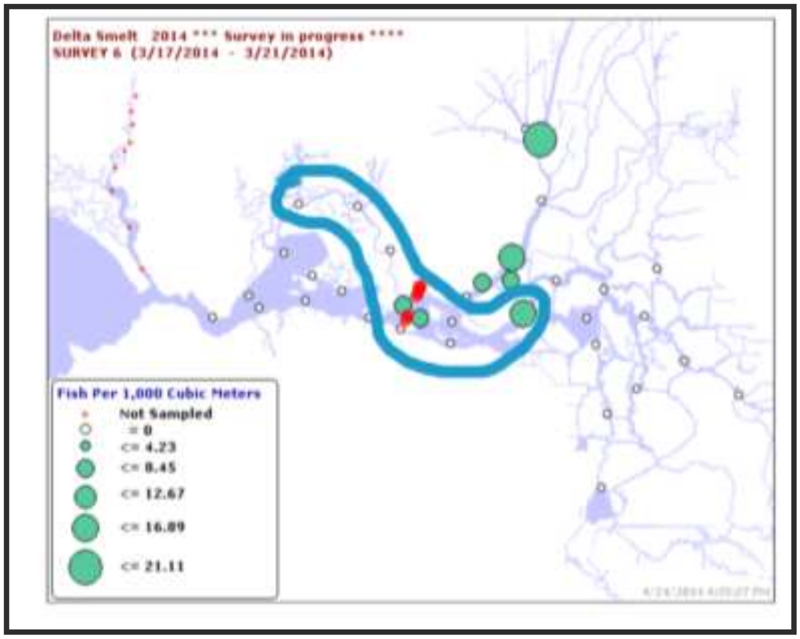


Figure 21. Distribution of Delta smelt in CDFG Larval Fish Survey in mid-March 2014. Blue boundary is LSZ. Red dashed line is X2 location.

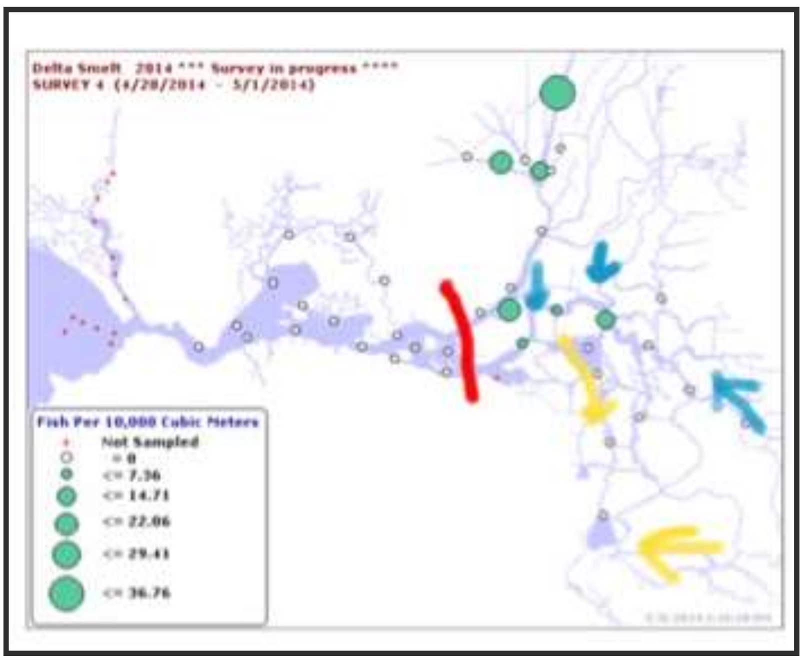


Figure 22. Delta smelt distribution in Survey 4 (end of April) of the 20mm survey. Red line is location of X2. Yellow arrows represent flow to export pumps. Blue arrows represent freshwater inflow to the Delta.

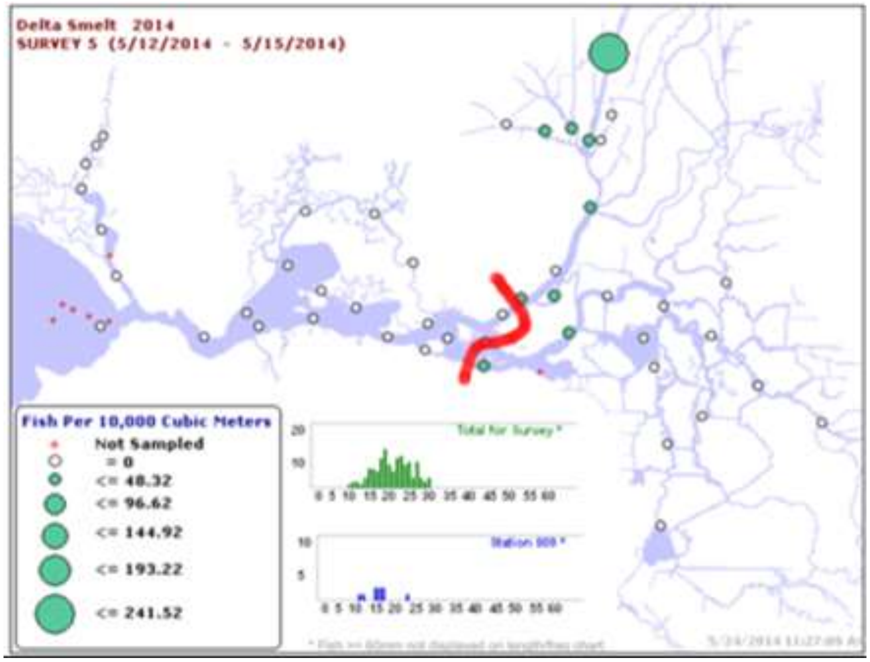


Figure 23. Delta smelt distribution in Survey 5 (mid-May) of the 20mm survey. Red line is location of X2.

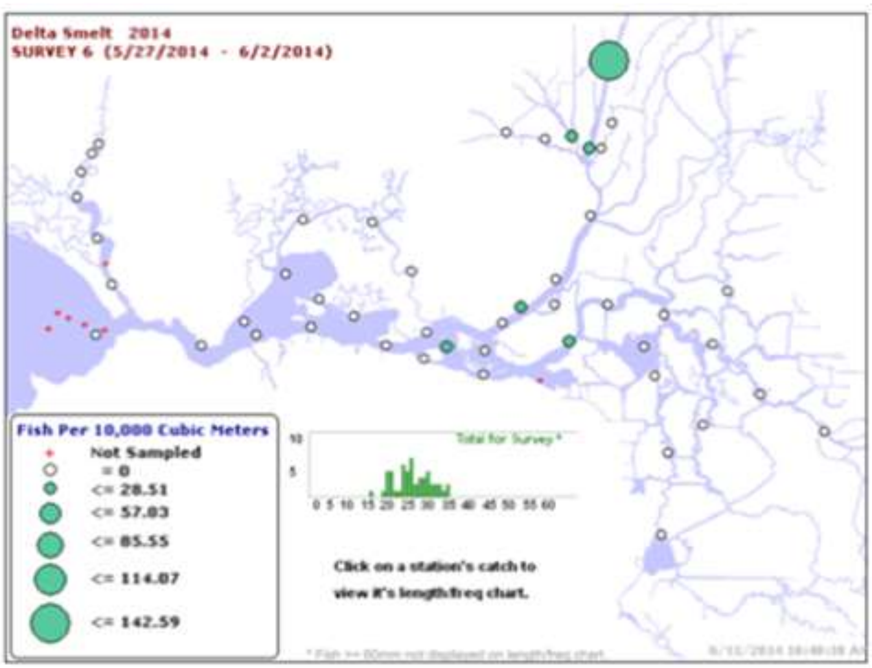


Figure 24. Delta smelt distribution in Survey 6 (end of May) of the 20mm survey.

June-July Delta Smelt Distribution

In June (Figures 25 and 26) Delta smelt catch dropped sharply as water temperatures in the upper LSZ and upstream in the freshwater Delta reached lethal conditions (74-75F). Most were found in the Sacramento Deepwater Shipping Channel in the North Delta, and the X2 area near the west side of Sherman Island where waters were slightly cooler.

By early July (Figure 27) only two Delta smelt were captured in the 20mm Survey on the west side of Sherman Island, the only area of the LSZ where water temperature was below lethal levels.

For comparison, the previous lowest catch in the 20mm Survey in recent years in early July occurred in 2007 (Figure 28). Water temperatures were up to several degrees cooler in the LSZ in 2007. Outflow was higher and the LSZ extended west into Eastern Suisun Bay and Montezuma Slough.

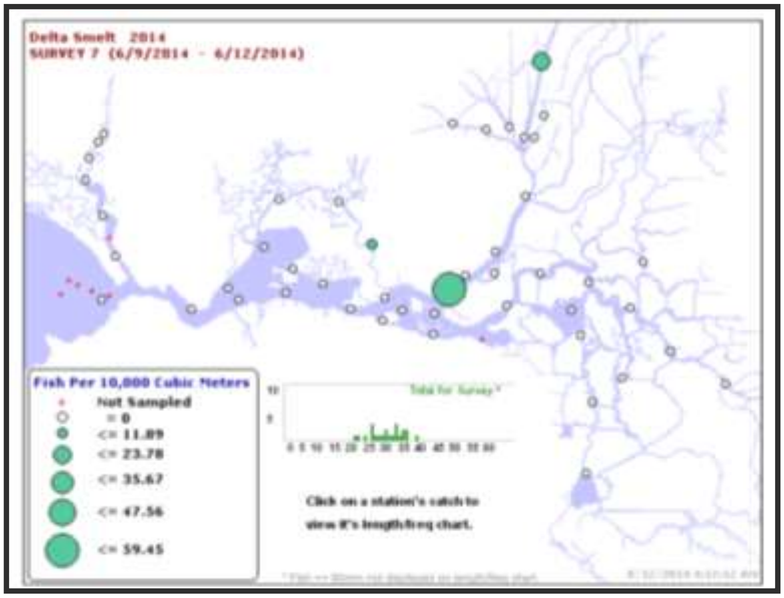


Figure 25. Delta smelt distribution in Survey 7 (early June 2014) of the 20mm survey.

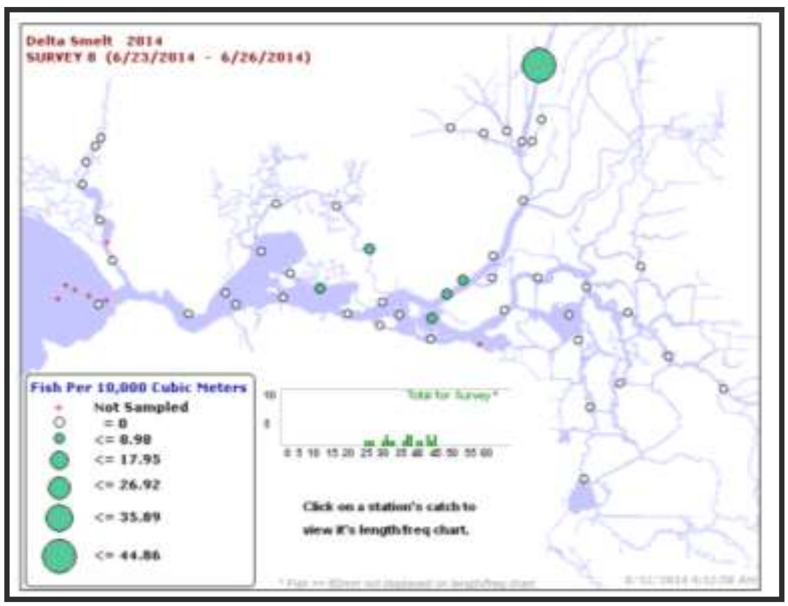


Figure 26. Delta smelt distribution in Survey 8 (late June 2014) of the 20mm survey.

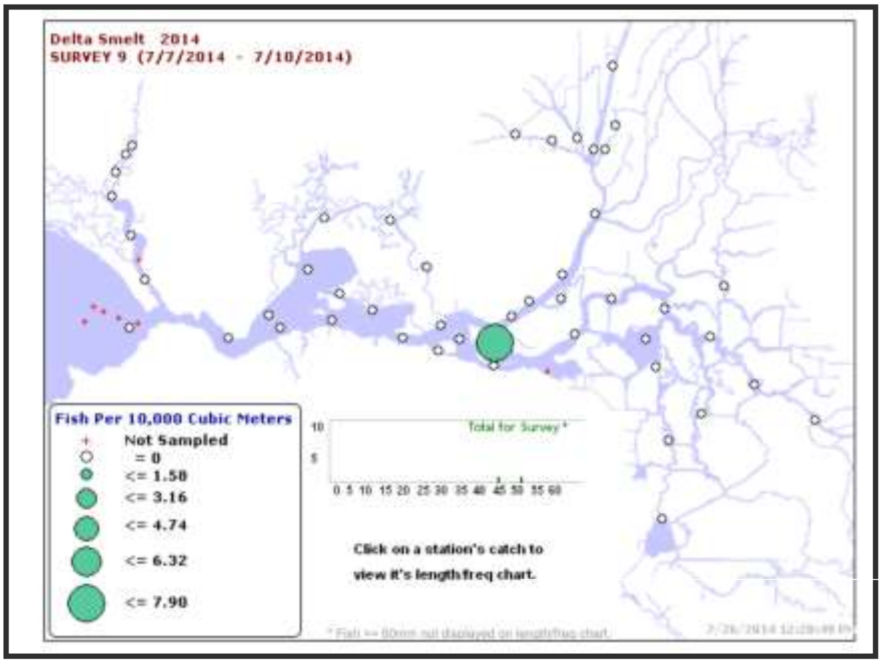


Figure 27. Delta smelt distribution in Survey 9 (early July 2014) of the 20mm survey.

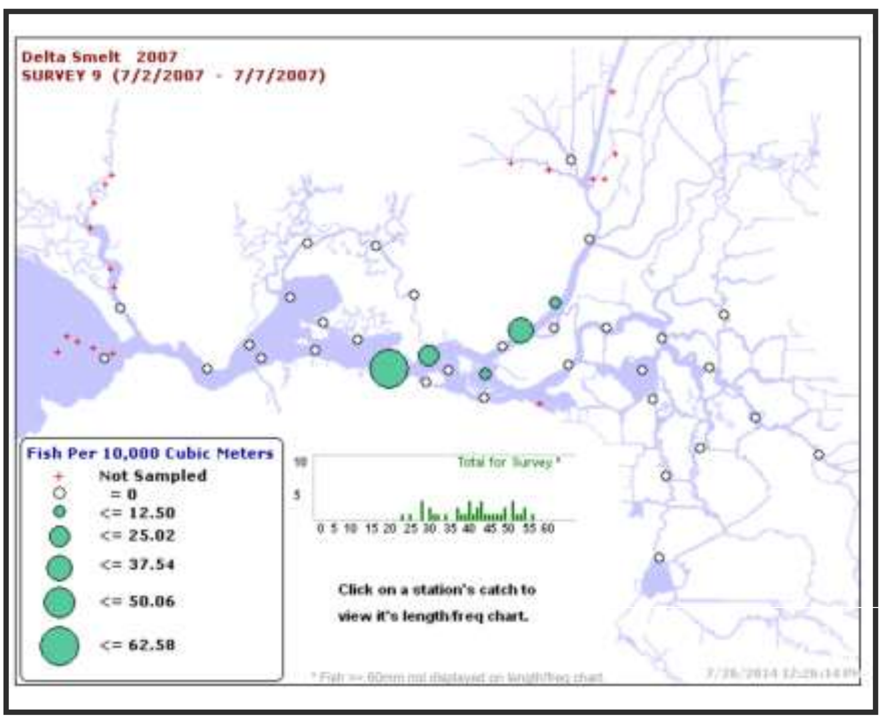


Figure 28. Delta smelt distribution in Survey 9 (early July) of the 20mm survey in 2007.

Delta Smelt Abundance Indices for Summer 2014

CDFW conducts three primary net surveys of Delta smelt in the Bay-Delta: 20-mm, Summer Townet, and Fall Midwater Trawl (Table 1). Each survey provides an annual index of abundance for specific life stages of Delta smelt. Results from the 2014 20-mm Survey and the Summer Townet are available as of August 2014.

Table 1. CDFW Smelt Surveys (Source: CDFW)

Delta Smelt 20 mm Survey (20 mm Survey)	Monitors postlarval-juvenile delta smelt distribution and relative abundance, March–June, 1995–present.	• Delta smelt: postlarval and juvenile abundance index, distribution, length frequency
Summer Townet Survey (Townet Survey)	Monitors striped bass and delta smelt abundance indices, July–August, 1959–present.	• Delta smelt: juvenile delta smelt abundance index, distribution, and length frequency • Longfin smelt: postlarval juvenile longfin smelt abundance index, distribution, and length frequency • Sacramento splittail: young-of-year splittail, distribution, and length frequency
Fall Midwater Trawl Survey	Monitors striped bass and delta smelt abundance indices, September–December, 1967–present.	• Delta smelt: preadult delta smelt abundance index • Longfin smelt: preadult longfin smelt abundance index • Sacramento splittail: abundance of all size classes

CDFW calculated a June 2014 index from the 20-mm survey (Figure 29) based on an average density of the two June surveys. The index was nearly as low as the record low index of 2007.

Year	Index
1995	4.4
1996	33.9
1997	19.2
1998	7.7
1999	39.4
2000	23.7
2001	10.9
2002	7.7
2003	13.0
2004	8.2
2005	15.4
2006	9.8
2007	1.0
2008	2.9
2009	2.3
2010	3.8
2011	8.0
2012	11.1
2013	7.8
2014	1.1

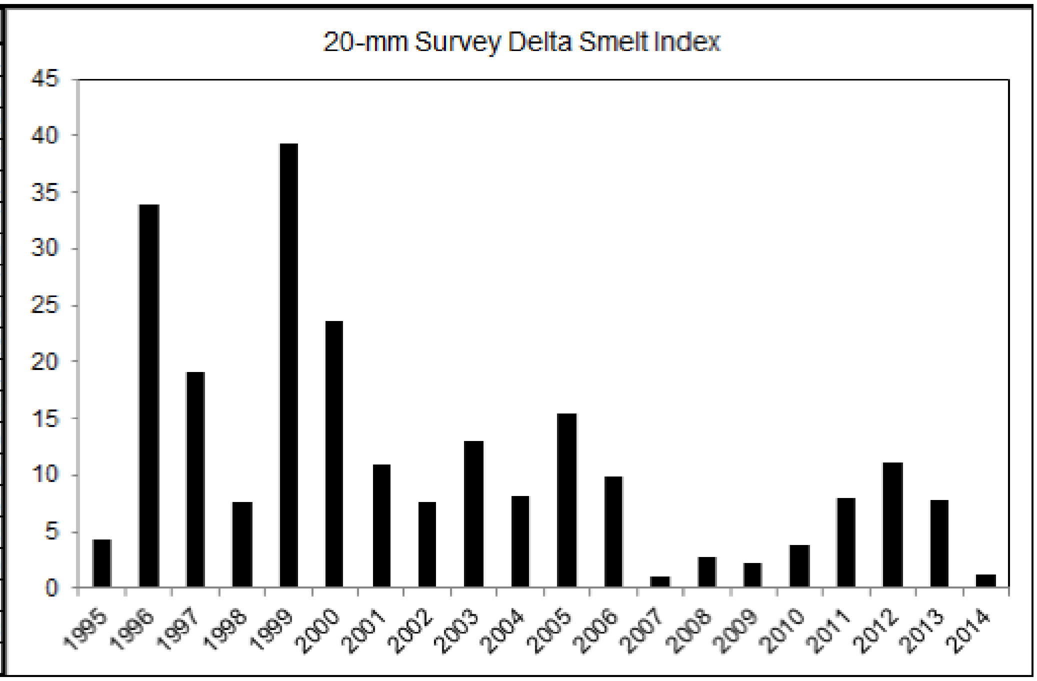


Figure 29. CDFW June 20-mm Delta Smelt Index (CDFW unpublished data)

CSPA also calculated a summer 2014 indices for Delta smelt from the 20-mm survey. Our method was simply to stack average densities from survey areas for each survey on a bar graph to derive an index. We developed indices for early June, late June, and early July surveys from 1996-2014 are shown in Figures 30-32. Our indices show changes over the three survey periods and the relative contribution of different Delta regions: 400s are western Suisun Bay; 500s are eastern Suisun Bay; 600s are Montezuma Slough/Suisun Marsh; 700s are lower Sacramento River in western Delta; 710s are lower Sacramento River/Cache Slough in north Delta; 800s are lower San Joaquin River in western Delta. Our indices are not weighted by the area or volume of the regions. Our indices include stations in Cache Slough and the Sacramento Deep Water Ship Channel that were added to the 710s group in the past decade.

The CDFW and CSPA index methods provide similar results and patterns of indices over the years.

What is ominous from all the indices is the poor 2014 indices, especially the early July CSPA index in 2014, not covered in the CDFW index. The previous low index was 2007. For comparison, the early July 2007 20-mm survey captured 38 smelt over a wider area (see Figure 28). The early July 2014 20-mm survey captured only 2 smelt (see Figure 27), which is reflected in the respective index (Figure 32).

The early July 20-mm index pattern over the years has proven similar to the Fall Midwater Trawl Indices, which is a premonition for this fall's upcoming index.

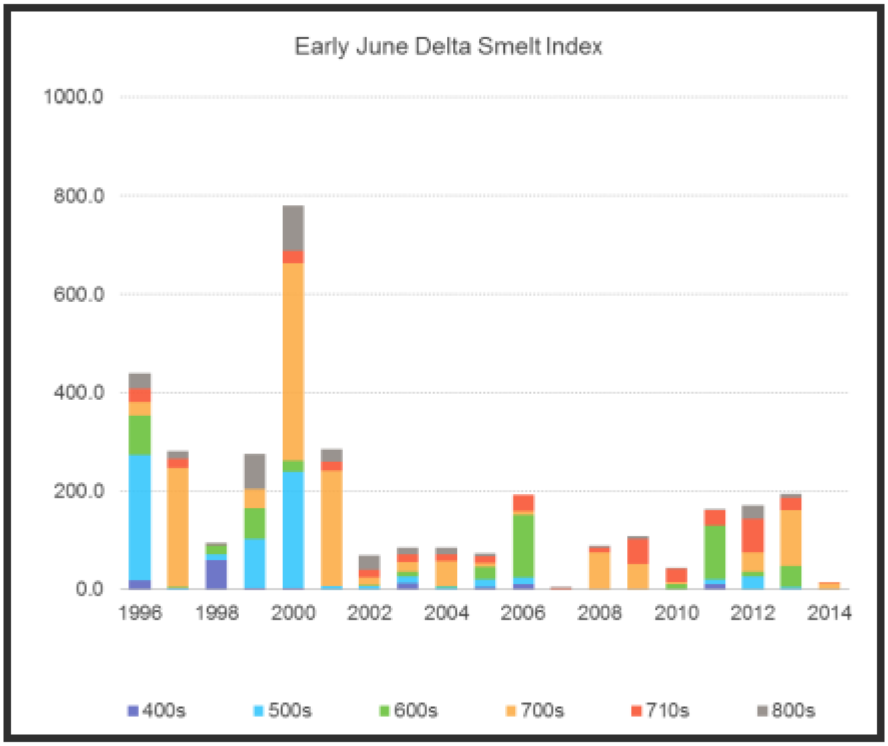


Figure 30. CSPA Delta Smelt 20-mm Survey index for early June 2014.

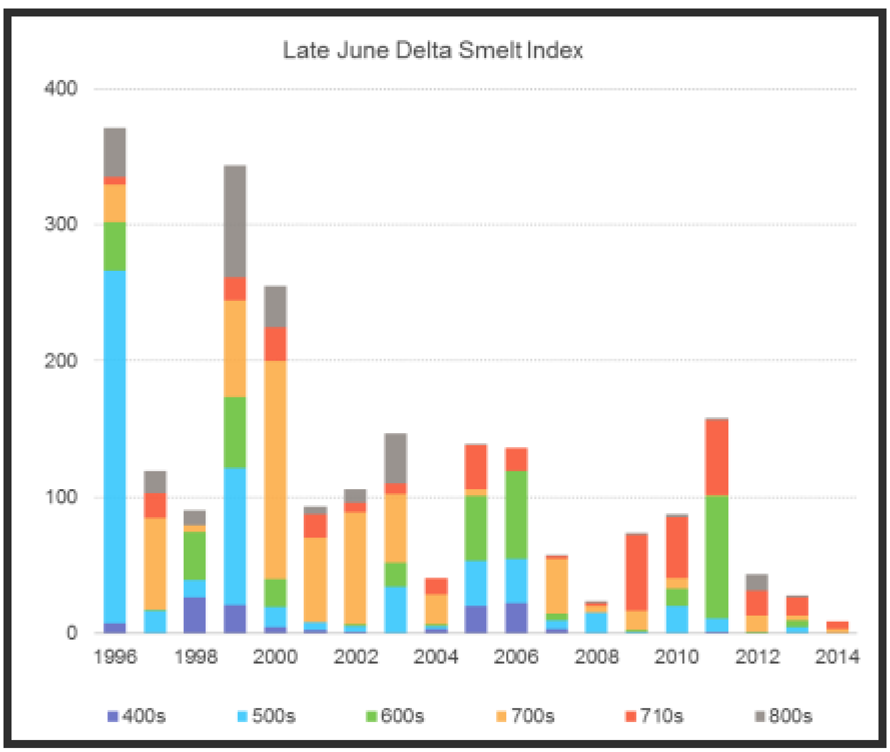


Figure 31. CSPA Delta Smelt 20-mm Survey index for late June 2014.

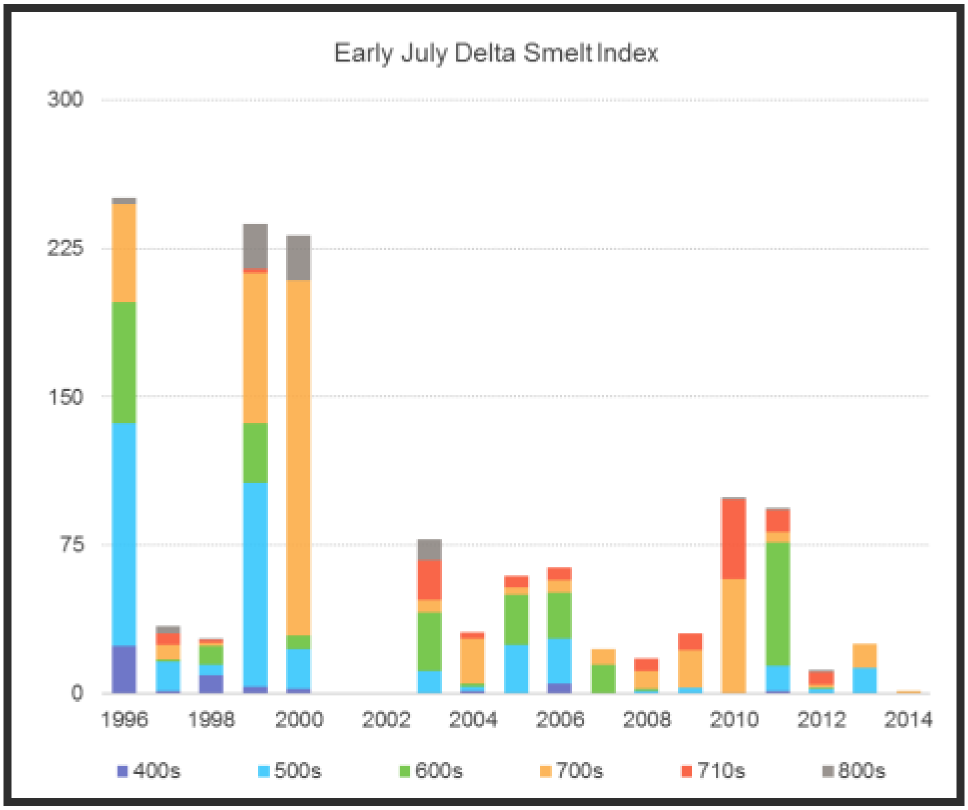


Figure 32. CSPA Delta Smelt 20-mm Survey index for early July 2014. (Note: no surveys were conducted in early July in 2001 and 2002.)

CDFW also provides an index of Delta smelt abundance for June from the first two surveys of the Summer Townet Survey (Figure 33). This recently released survey index is also near a record low in 2014. Again, this only reflects relative abundance during June.

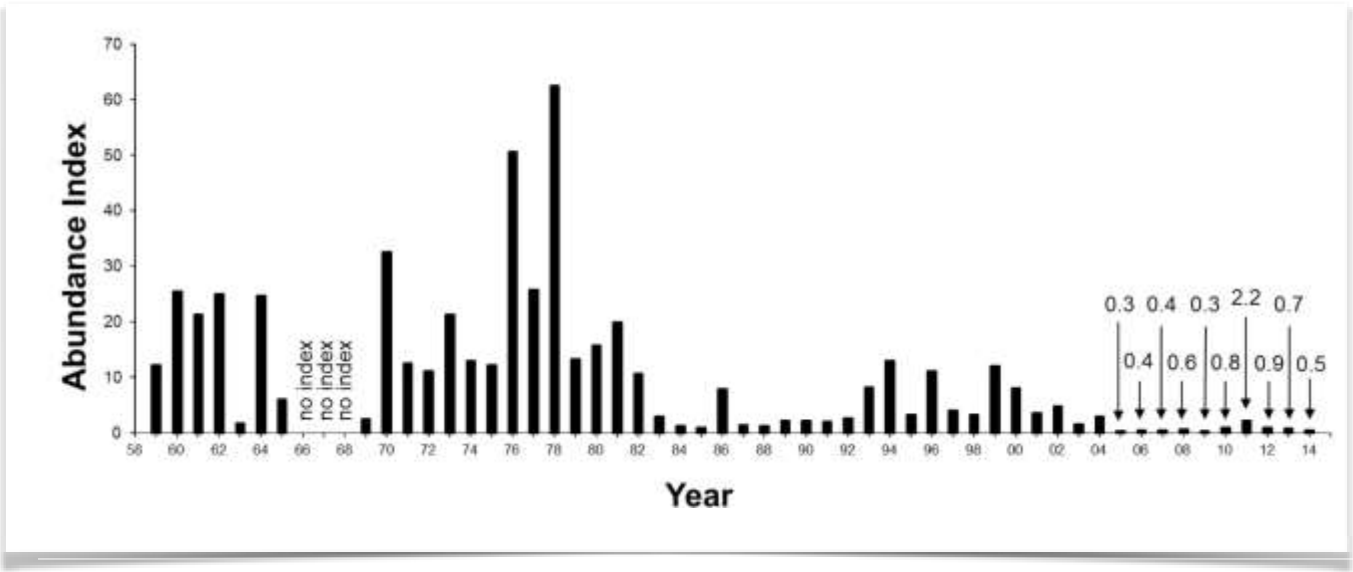


Figure 33. CDFW June Summer Townet Index for Delta smelt as derived from the first two (June) surveys.

Delta Smelt Population Dynamics

The Delta smelt population abundance indices reflect the fact that low numbers of smelt are produced in periods of drought. However, they also reflect the fact that low numbers in the population also reduce subsequent recruitment in the population. Or in other words, a main factor controlling the population reproduction each year is the population itself. The population is driven down in droughts by poor conditions, but also the poor number of subsequent adult spawners that keep the population down in each subsequent year of drought, which limit recovery after droughts. Such relationships between life stages are commonly referred to as stock-recruitment curves. That is, the number of spawners is related to the number of juveniles that preceded them, or the juvenile numbers are related to the number of spawners that produced them. In the case of Delta smelt, stock-recruitment relationships derived from the various indices (see Table 1), in my opinion, appear to be amongst the strongest ever determined for any fish species. This is very important because not only is the population driven down in droughts, its ability to recover is also compromised. The effect of the drought is compounded.

Summer Juvenile Abundance Determines Fall Adult Abundance

The relationship between the Summer Townet and Fall Midwater Trawl indices is shown in Figure 34. This is a strong relationship especially given some of the outlier years can be explained by factors such as drought conditions. The main theme is that for very low summer juvenile abundance such as occurred over the past decade, it is likely that only low fall abundance (adult spawners) can be produced, thus indicating that adult population levels are limited by summer habitat conditions. The fourth lowest summer index in 2014 (red dash in Figure 34) is likely to produce a very low fall index.

Fall Adult Abundance Determines Subsequent Summer Juvenile Abundance

The relationship between the Fall Midwater Trawl and subsequent year's Summer Townet indices is shown in Figure 35. This also is a strong relationship especially given some of the outlier years can be explained by factors such as drought conditions. The main theme is that very low summer abundance such as occurred over the past decade, produced low fall adult abundance, thus indicating that adult population levels (possibly in terms of potential egg production) is a major factor in subsequent summer juvenile abundance. Note years 04 and 11 with relatively high fall indices produced relatively low summer indices, which possibly reflects poor winter through early summer survival in the subsequent year.

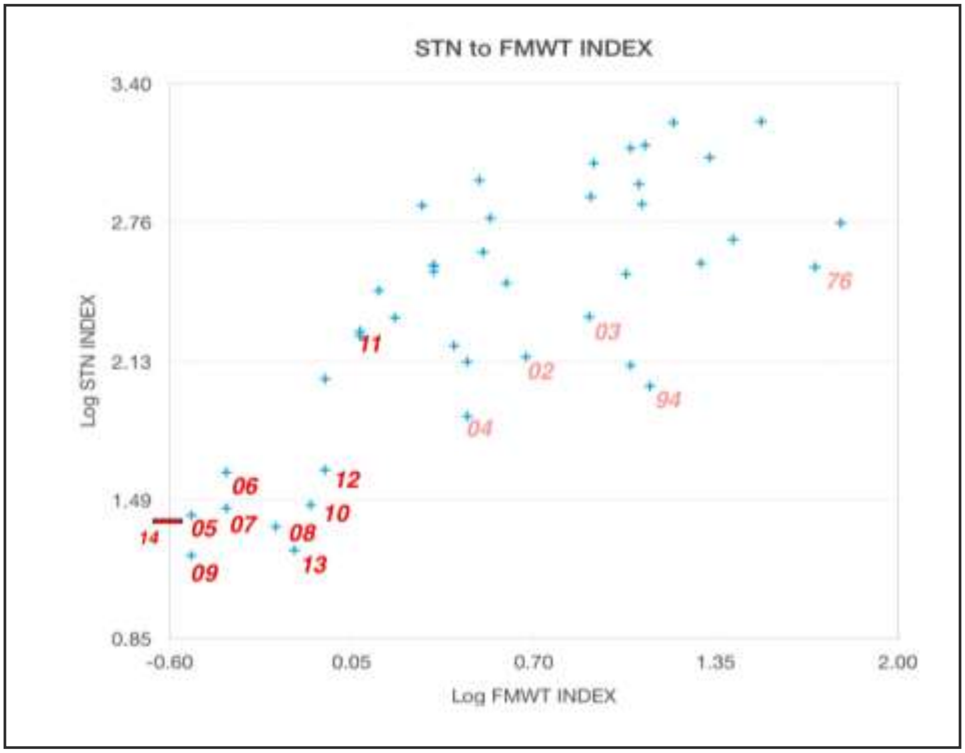


Figure 34. Relationship between summer index and fall index in the same year from Summer Townet Survey and Fall Midwater Trawl Survey. Indices are log-transformed.

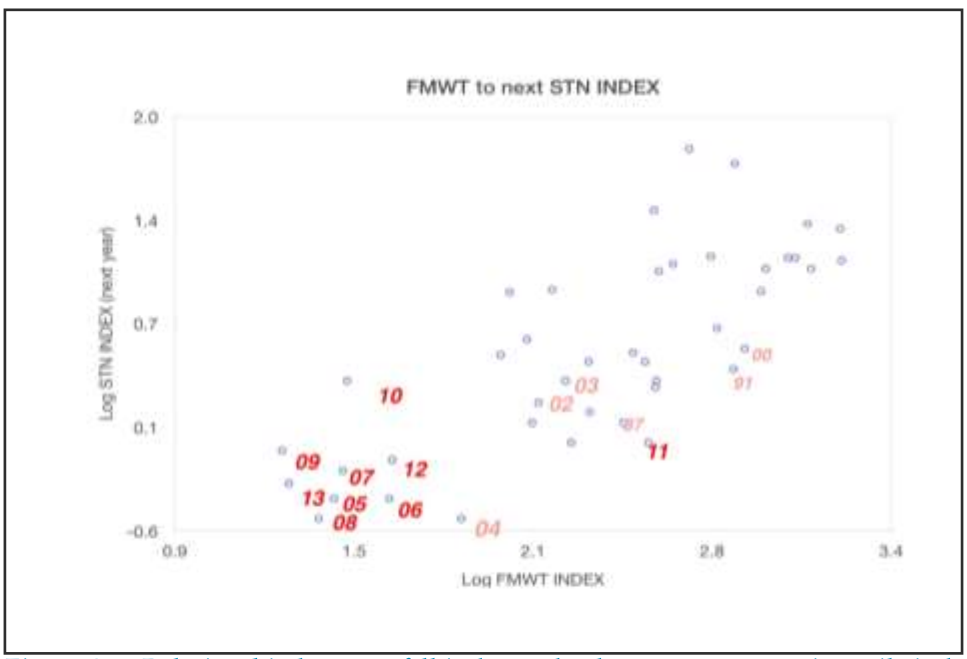


Figure 35. Relationship between fall index and subsequent summer juvenile index from Summer Townet Survey and Fall Midwater Trawl Survey. Indices are log-transformed.

How Much Water are We Talking About

The main theme of this report is that low Delta outflow to the Bay in summer results in poor LSZ habitat conditions (in terms of warm, low turbidity water and upstream location), which leads to poor juvenile Delta smelt survival. Low 2014 summer Delta outflows were further reduced by Delta standard relaxations (i.e., 4000 cfs to 3000 cfs outflow requirements, and the change in salinity standard location to Three Mile Slough) to save water in storage reservoirs and deliver more water to thirsty customers. We believe that habitat conditions in the LSZ would have been better if outflows had been maintained at 5000 cfs (NDOI), a level that would have provided approximately 2000 cfs real outflow instead of the near zero outflow (NDO) provided during most of the late spring and summer. The amount of water needed is shown in Figure 36. The amount is approximately 200-250 thousand acre-ft. That amount of water could have been provided by reservoir releases or cutbacks in the use of reservoir-released water (i.e., exports or upstream of Delta uses). Less than 100 thousand acre-ft of water would have been necessary to maintain the D-1641 standard of 4000 cfs minimum outflow without relaxations.

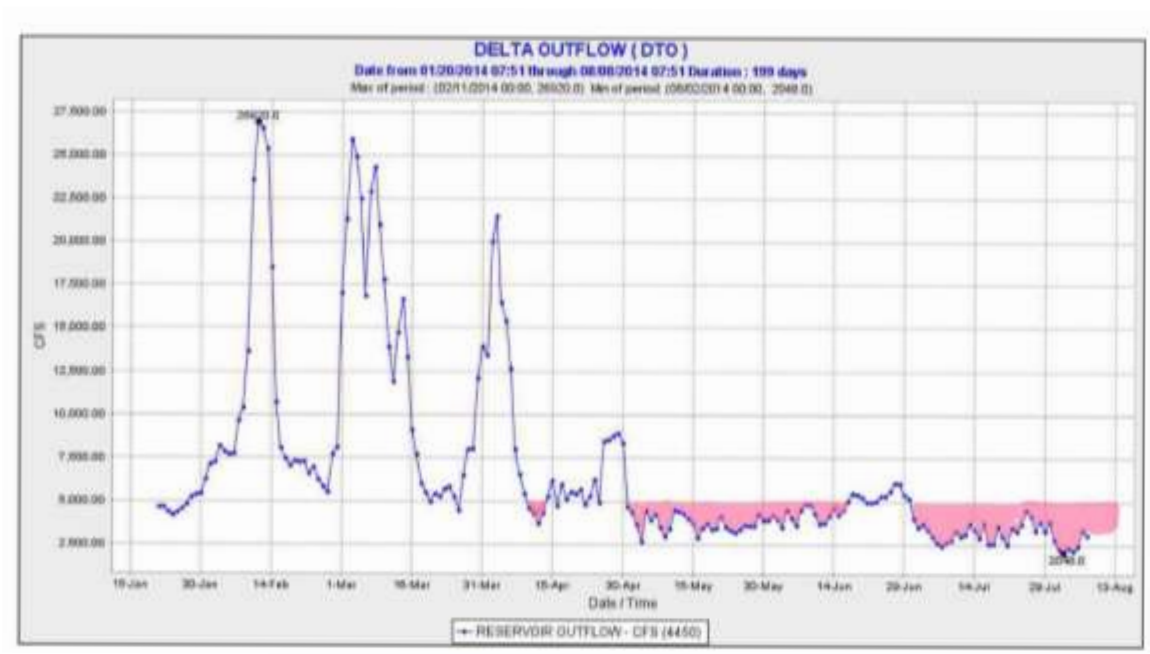


Figure 36. The amount of water needed to provide 5000 cfs of Delta outflow in spring and summer 2014 is shown in pink.

To put that amount of water in perspective we looked at the totals released this summer from reservoirs above the minimum downstream requirements, as well as the totals exported from the Delta. Given approximately 1 million acre-ft were exported south of the Delta, the amount needed for outflow would have been 25% of exports. In other words, a 25% reduction in exports would have provided the needed water. However, because nearly half the exports occurred during storms when outflows were already above 5000 cfs, it is more realistic to state that providing 5000 cfs outflow would have required near 50% reduction in exports.

But what about reservoir releases this year? Shasta releases from Keswick Reservoir (upper Sacramento River) above minimum requirements were nearly 1 MAF (Figure 37). Folsom releases (American River) above minimum requirements were approximately 200 TAF (Figure 38). Oroville (Feather River) releases above minimum requirements were approximately 800 TAF (Figure 39). These very restricted releases were provided to meet the minimum downstream water supply demands. Foregoing approximately 10% of the 2 million acre-ft released for minimum drought water supplies from the three reservoirs would have provided a 5000 cfs minimum Delta outflow. Only 5% of the reservoir releases would have been necessary to maintain an un-relaxed standard of 4000 cfs Delta outflow.

Figure 37. Storage releases from Shasta Reservoir in spring and summer 2014 above minimum downstream requirements are shown in pink.

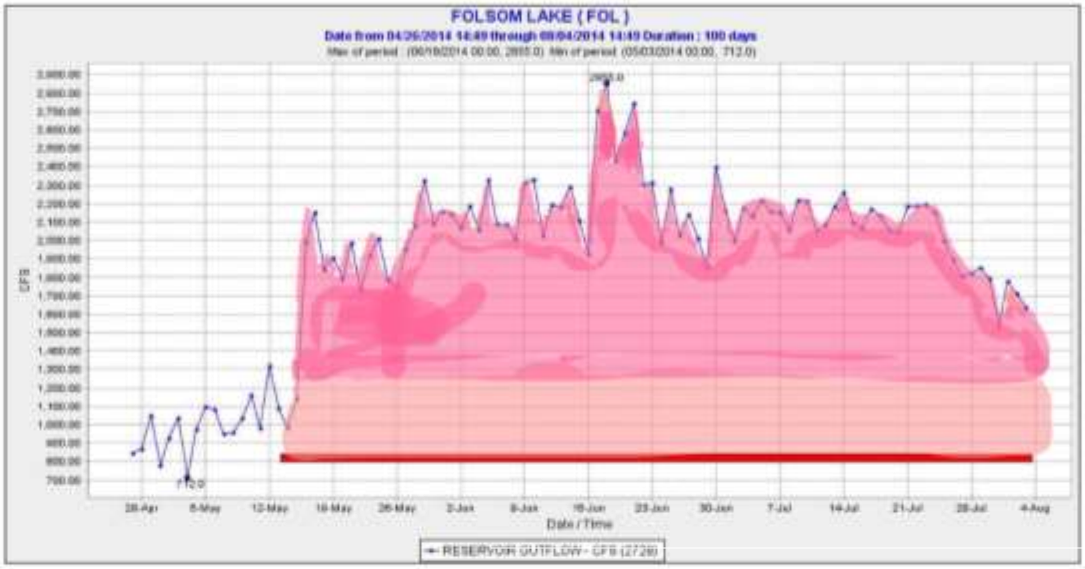


Figure 38. Storage releases from Folsom Reservoir in spring and summer 2014 above minimum downstream requirements are shown in pink.

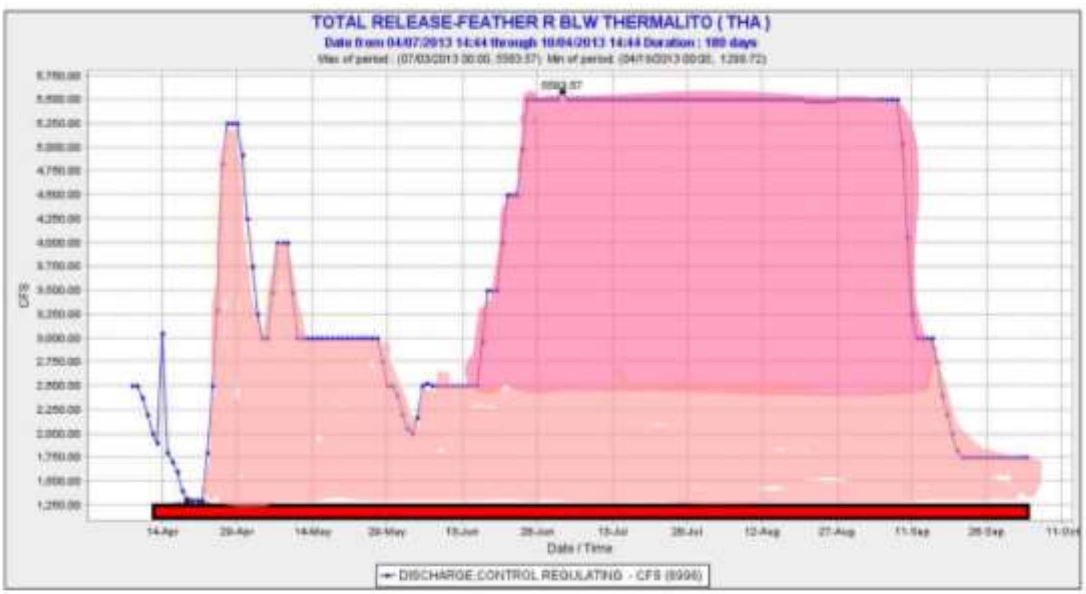


Figure 39. Storage releases from Oroville Reservoir in spring and summer 2014 above minimum downstream requirements are shown in pink.

Summary and Conclusions

The Delta smelt population had the lowest summer production of juveniles on record. We determined the cause of this record low abundance was low Delta outflow exacerbated by relaxed Delta standards for outflow and salinity. Low Delta outflow resulted in an upstream position of the LSZ that extended into the Central Delta. As a consequence, the LSZ was warmer, less turbid, and located further upstream than normal where it was subject to continual degradation by loss of its constituent productivity to south Delta exports and replacement by warm, low turbidity reservoir water.

We predict a very low Fall Midwater Trawl Index for Delta smelt based on the record low summer indices. These low indices point out the precarious nature of this endangered species first listed in the early 1990s after the 1987-1992 drought.

We contend that the amount of water saved by relaxing the outflow standard to 3000 cfs this summer is minimal, especially given that outflow was near zero. Maintaining real outflow of 1000-2000 cfs to save this endangered fish and what remains of the San Francisco Bay Estuary seems reasonable given it represents only 5-10 percent of the amount of water released from Valley reservoirs this spring and summer. Allocation of 10 percent of storage releases prescribed for spring and summer seems more than reasonable to protect the Bay-Delta estuary and Delta smelt.

Literature Cited

Hasenbein, M, Komoroske, LM, Connon, RE, Geist, J, and Fangue, NA. 2013. Turbidity and salinity affect feeding performance and physiological stress in endangered delta smelt. Integr. Comp. Biol. 53(4) : 620-34.

Appendix A -The Smelt Foodweb Sub-Story for 2014

It is highly likely that conditions in the spring and summer of 2014 included very poor food production for Delta smelt. In previous sections we outlined how upstream movement of the LSZ in the Delta increased the detrimental effects of exports, and degradation of the LSZ from high water temperatures and low turbidity. In this section we summarize one of the potential features of the LSZ that are degraded, plankton food supply. Though information from the zooplankton surveys in 2014 is not available, data from previous years provides a clue as to the fate of this primary Delta smelt food supply in drought years.

Importance of Pseudodiaptomus

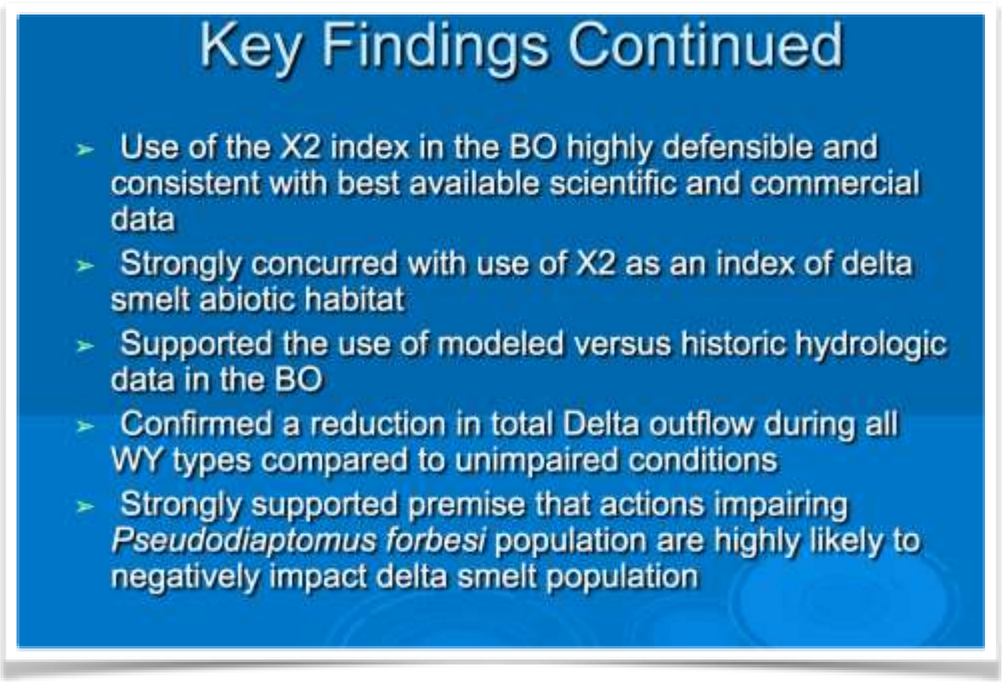
The key food supply of Delta smelt is zooplankton, principally the copepod *Pseudodiaptomus forbesi.*

Native copepod Eurytemora affinis (magnified, left), and introduced Pseudodiaptomus forbesi (right), prey of the delta smelt. Both images courtesy of Jeffery R. Cordell, Copepod Gallery, University of Washington.

"*The prey of the delta smelt are small crustaceans and insect larvae, and consist primarily of a native copepod, Eurytemora affinis. Recently an exotic copepod species from the Yangtze area of China and Japan, Pseudodiaptomus forbesi, has been replacing E. affinis. While delta smelt appear to consume this exotic species, the full impact of its presence is unknown.*" (EPA[1])

[1]http://www.epa.gov/espp/factsheets/delta-smelt.pdf

Independent scientific reviewers of the Smelt BO[2] had these conclusions:



2 http://www.westcoast.fisheries.noaa.gov/publications/Central_Valley/Water%20Operations/NAS%20Review/nas_fws_3_rpa_actions_and_peer_review.pps

Dr. BJ Miller, representing the San Luis and Delta-Mendota Water Authority, stated in a presentation[3]: "*The delta smelt fall midwater trawl index of sub-adult abundance reached an all time low last year of 74. The cause of this low index was an extremely low level of prey (the zooplankton, Pseudodiaptomus forbesi), in the lower Sacramento River and nearby areas.*"

The following charts depict the survey data for key copepods in the food supply of Delta smelt for the three years of drought, 2007-2009, for which zooplankton survey data are available. In each case the relative vulnerability of the zooplankton to South Delta exports is relatively obvious. A following figure from the BDCP on export probability for a dry year helps in understanding this vulnerability:

[3] http://www.water.ca.gov/swp/operationscontrol/calfed/notes/2005/apr/export2005.pdf

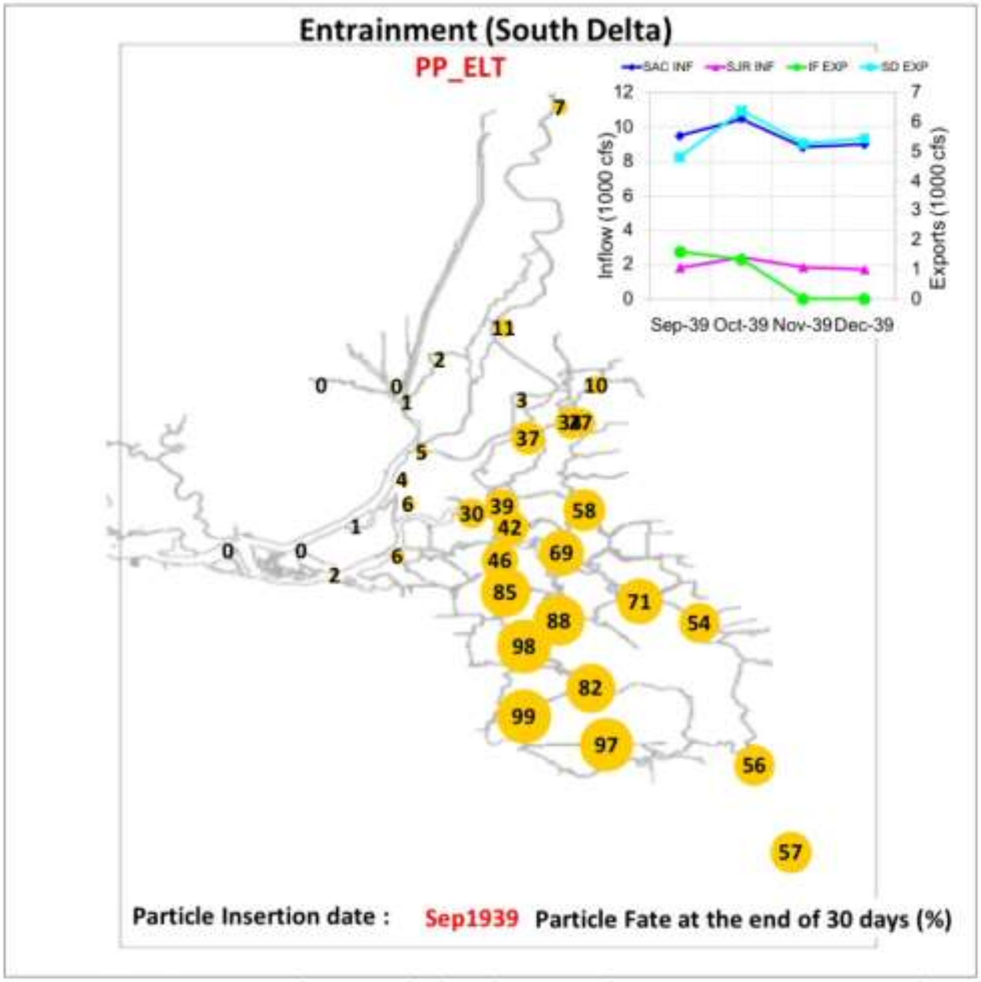
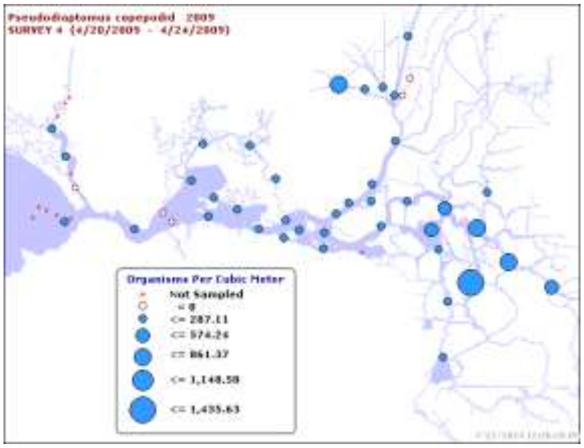
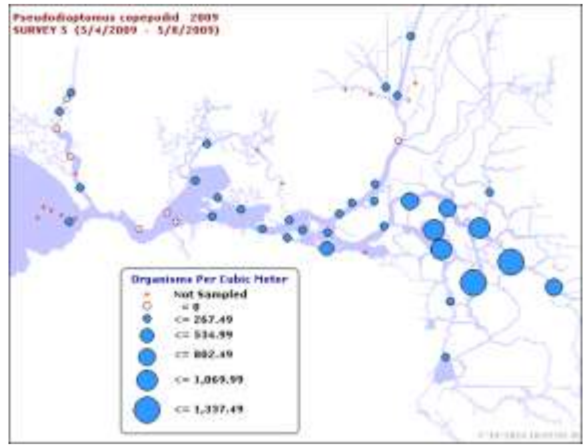
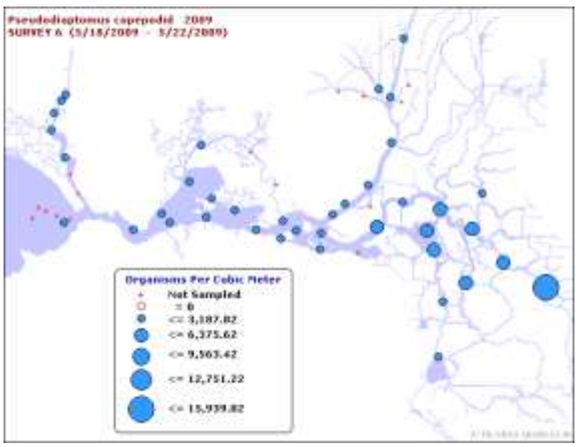


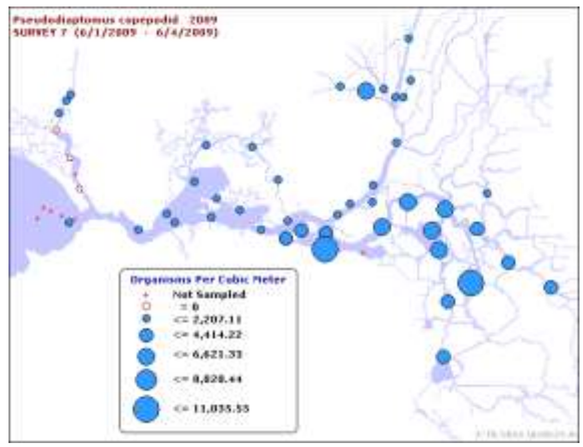
Figure A-21: An example spatial plot showing the percent entrainment for particles released at various locations in the Delta at the end of 30 days after insertion

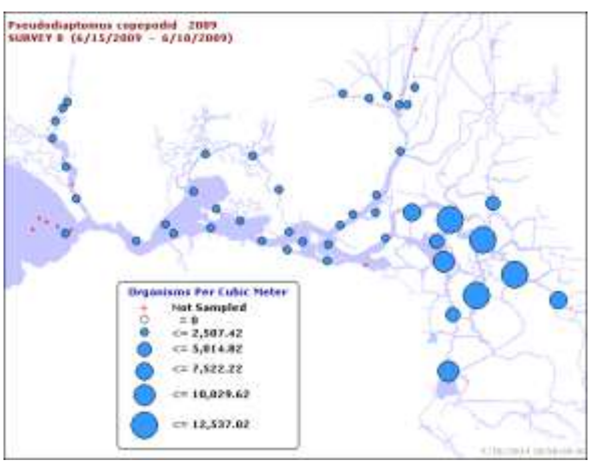
Pseudodiaptomus Distribution in Dry Years

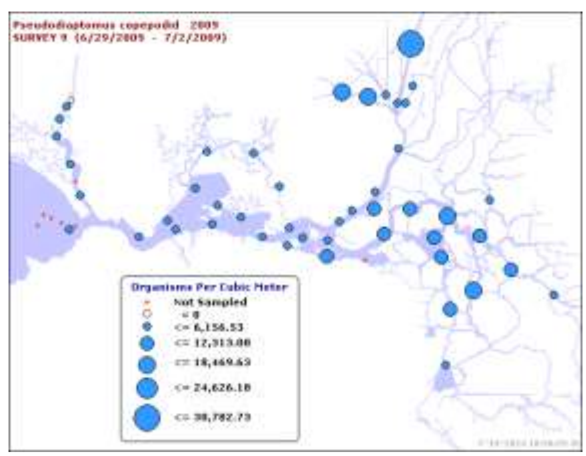


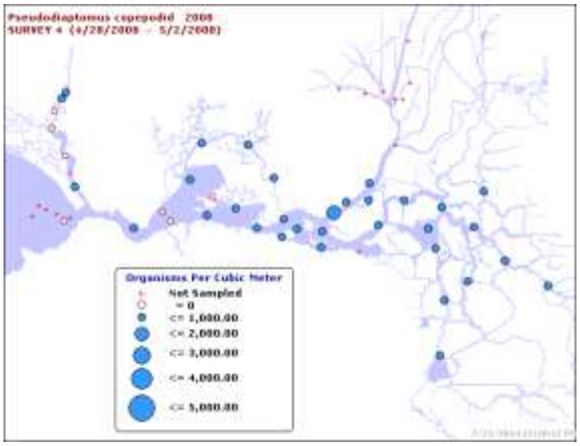











Pseudodiaptomus copepodid 2008
SURVEY 4 (4/28/2008 - 5/2/2008)
Organisms Per Cubic Meter
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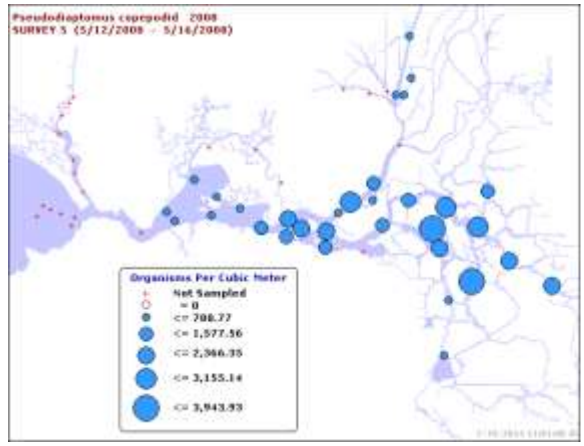
<= 2,000.00
<= 3,000.00
<= 4,000.00
<= 5,000.00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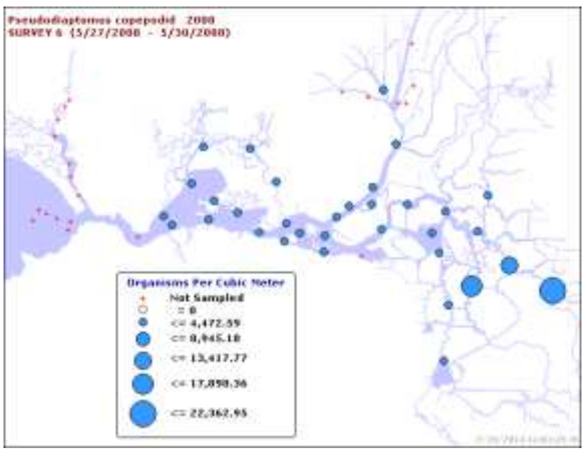
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<= 17,890.36
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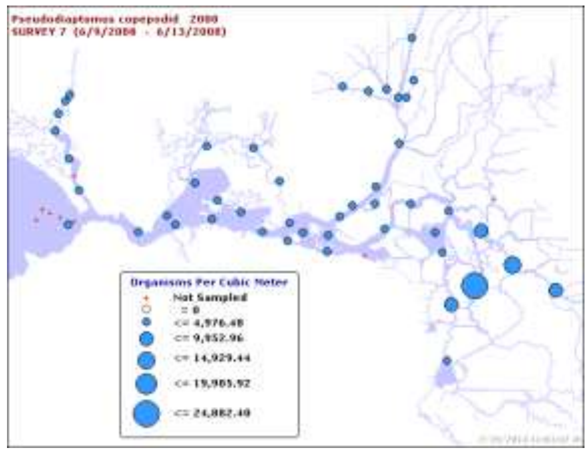
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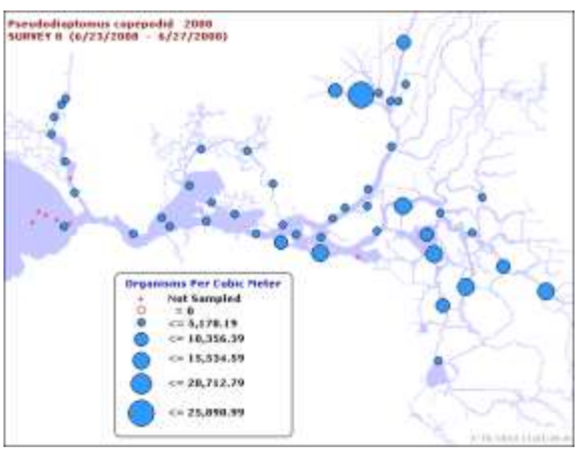
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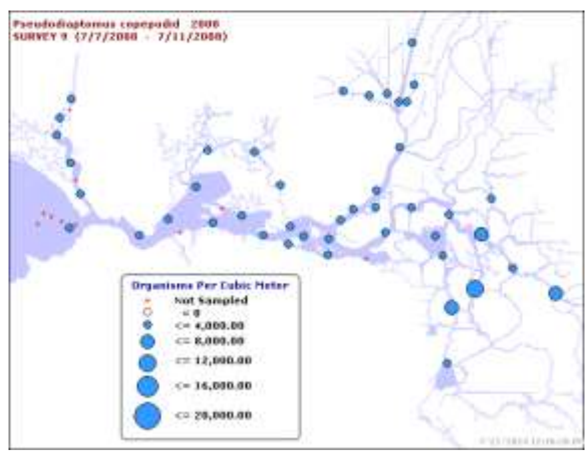
<= 25,890.99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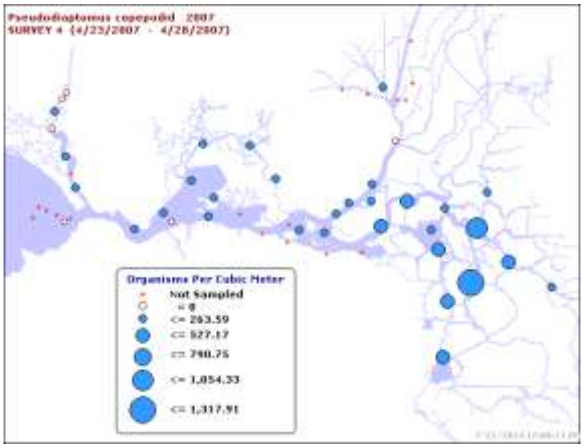
<= 20,000.00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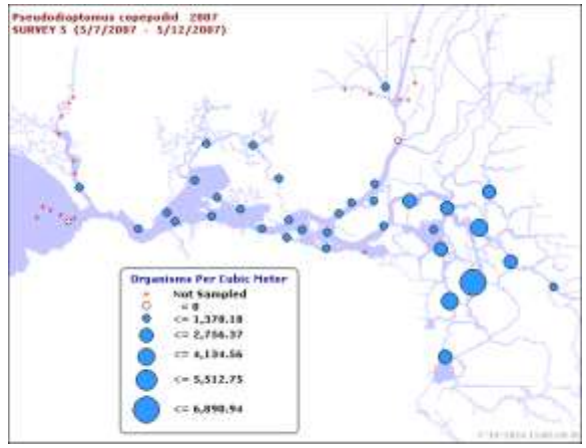
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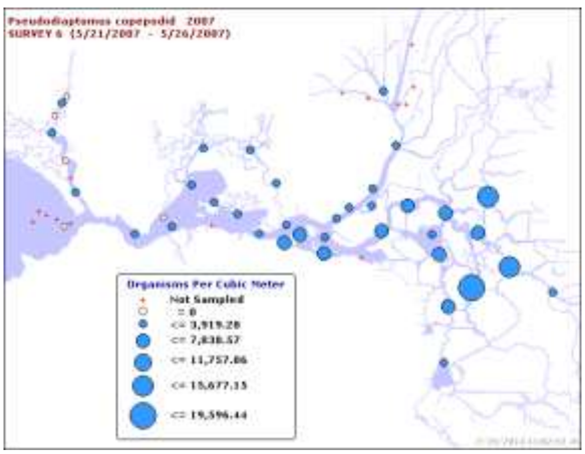
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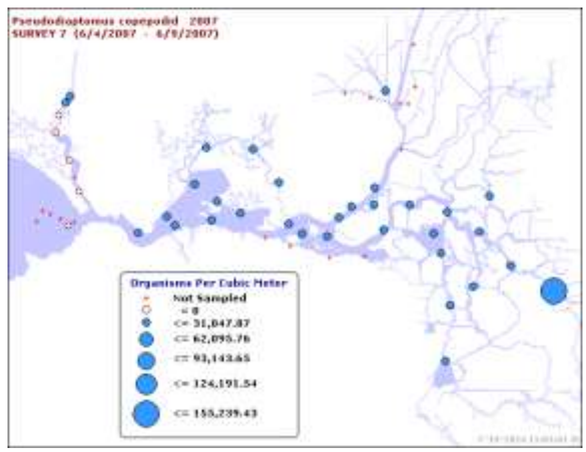
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Organisms Per Cubic Meter
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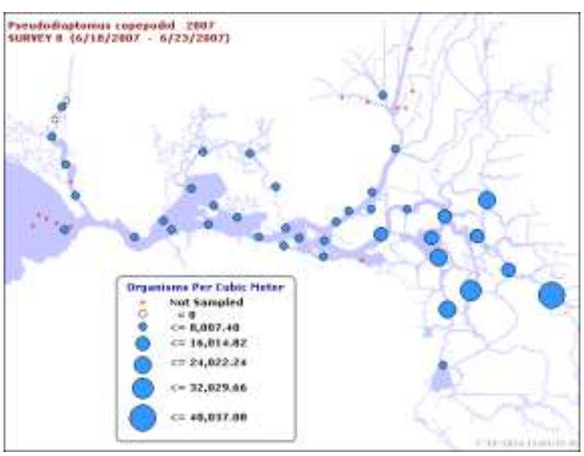
<= 155,239.43


Pseudodiaptomus copepodid 2007
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Organisms Per Cubic Meter
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<= 16,014.82
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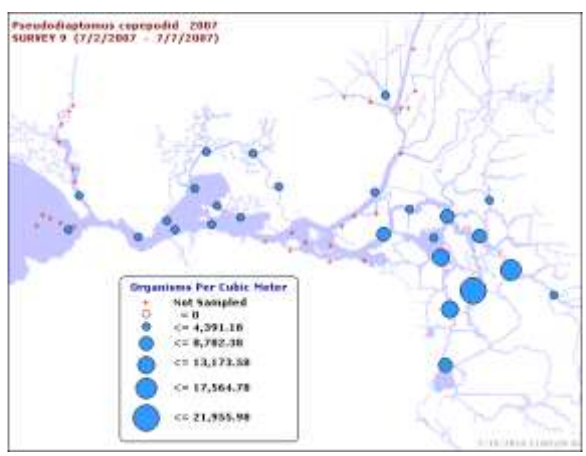
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Organisms Per Cubic Meter
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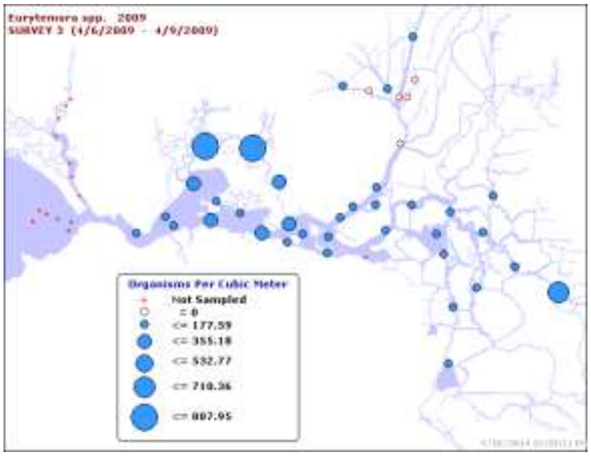
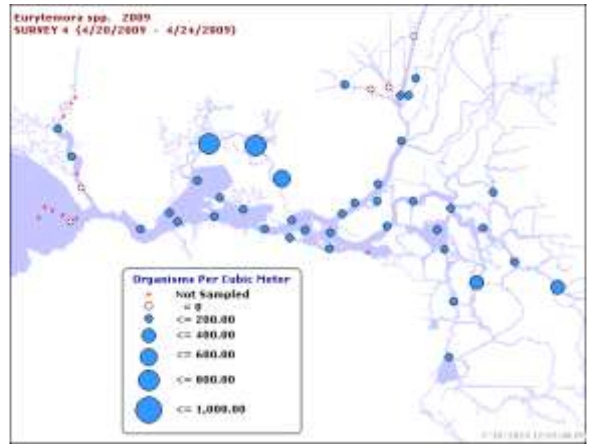
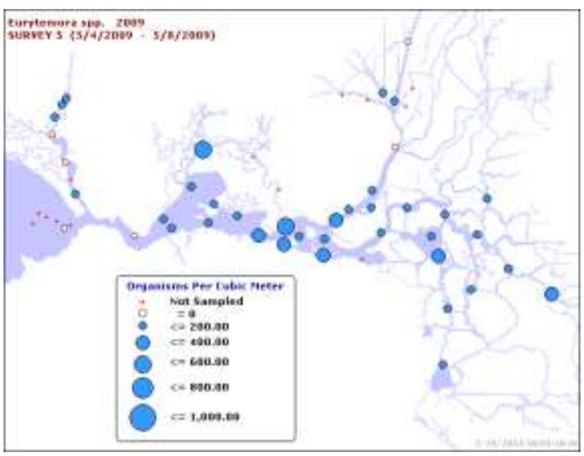
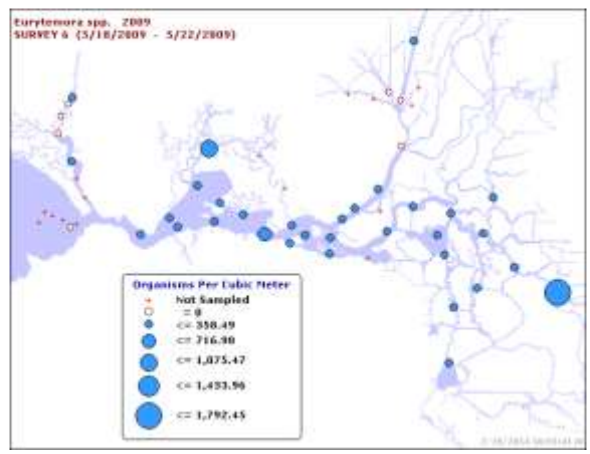
<= 17,564.78
<= 21,955.98

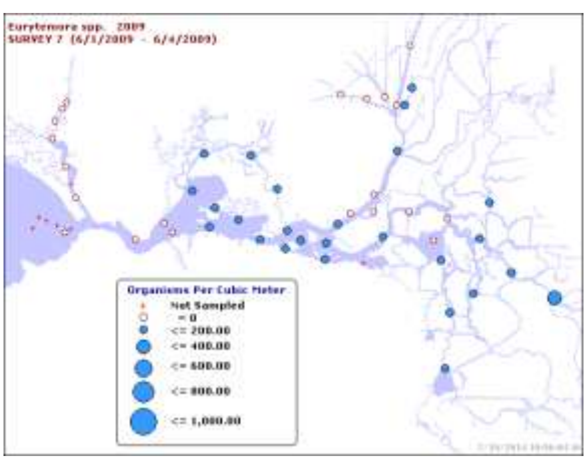
Review of Eurytemora Distribution in Dry Year

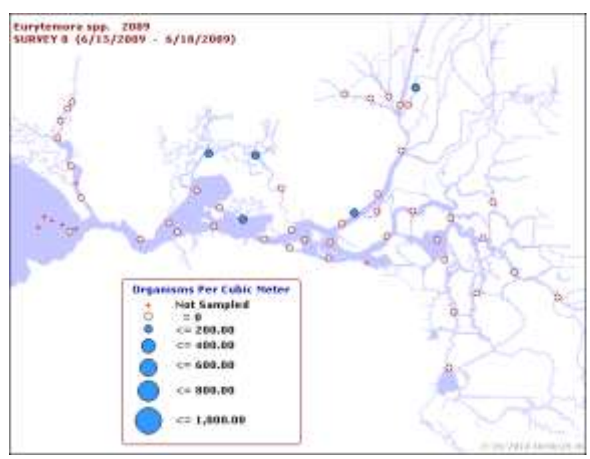


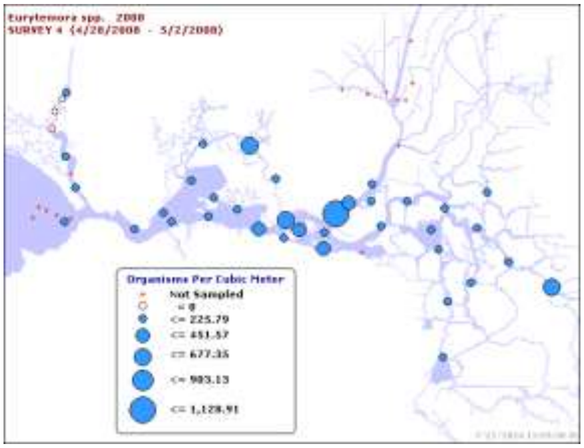











Eurytemora spp. 2008
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Organisms Per Cubic Meter
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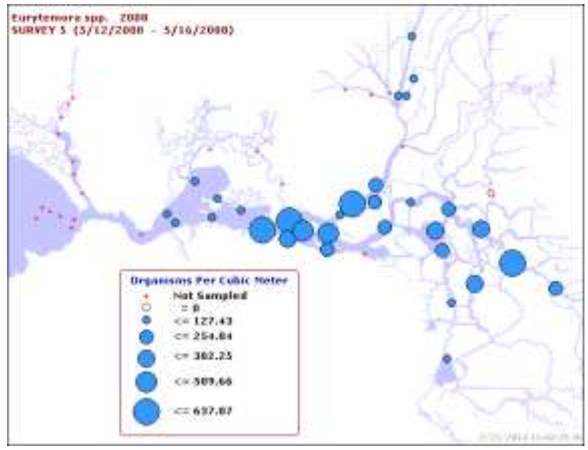
Eurytemora spp. 2008
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Organisms Per Cubic Meter
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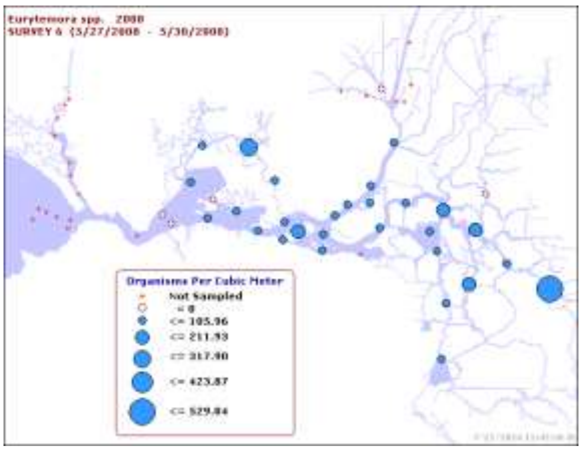
Eurytemora spp. 2008
SURVEY 6 (5/27/2008 - 5/30/2008)
Organisms Per Cubic Meter
Not Sampled
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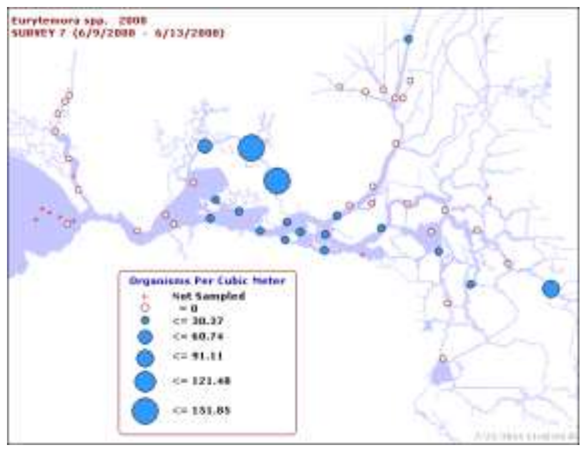
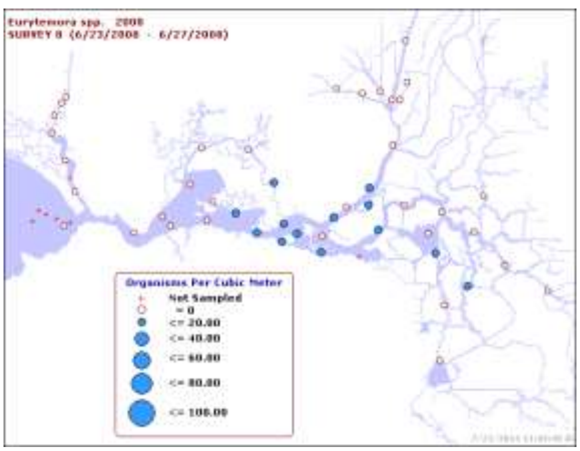
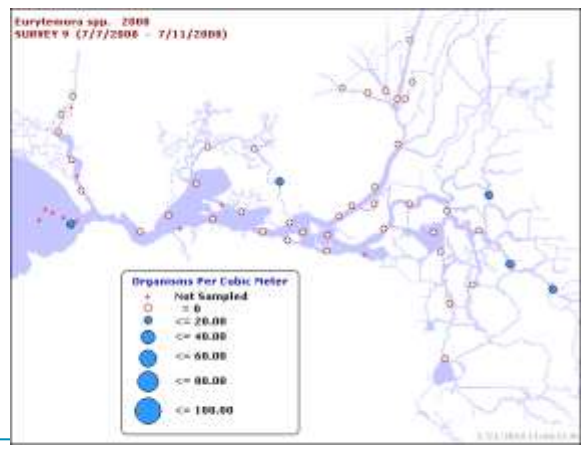
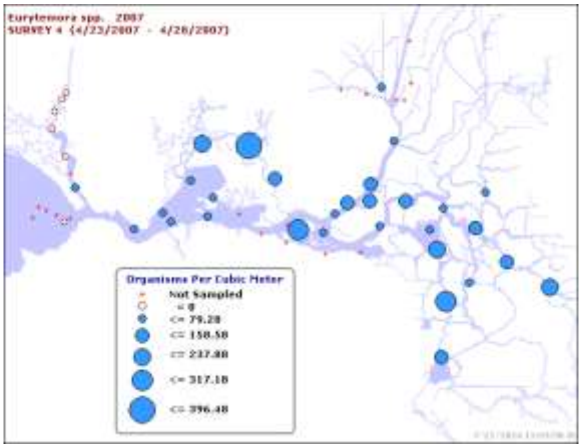
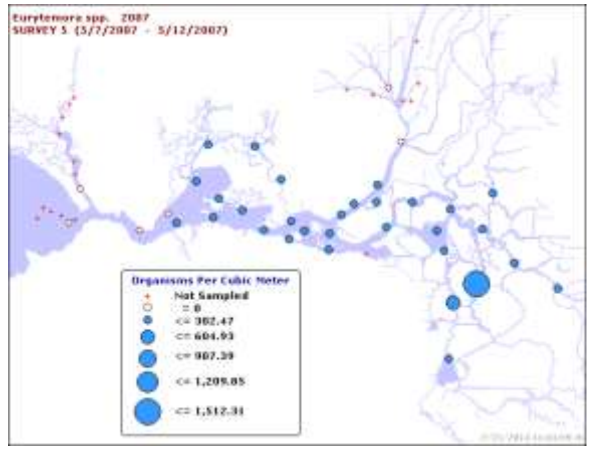
<= 105.96
<= 211.93
<= 317.90
<= 423.87
<= 529.84

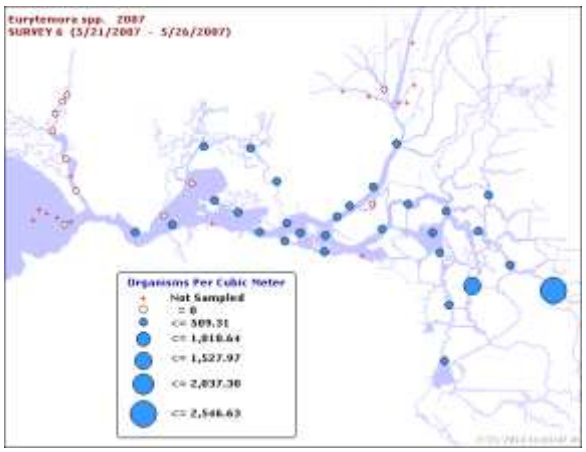

Eurytemora spp. 2008
SURVEY 7 (6/9/2008 - 6/13/2008)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 30.37
<= 60.74
<= 91.11
<= 121.48
<= 151.85

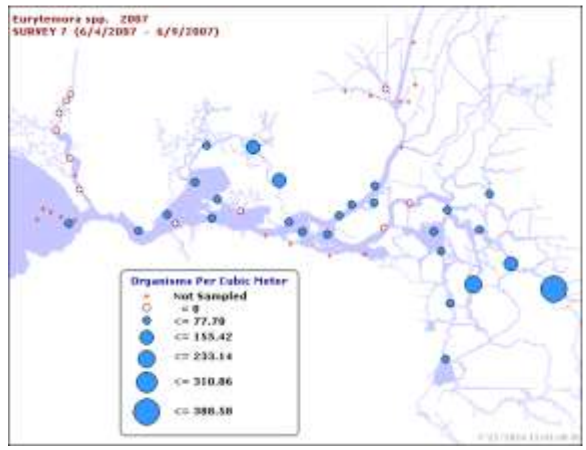

Eurytemora spp. 2008
SURVEY 8 (6/23/2008 - 6/27/2008)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 20.00
<= 40.00
<= 60.00
<= 80.00
<= 100.00

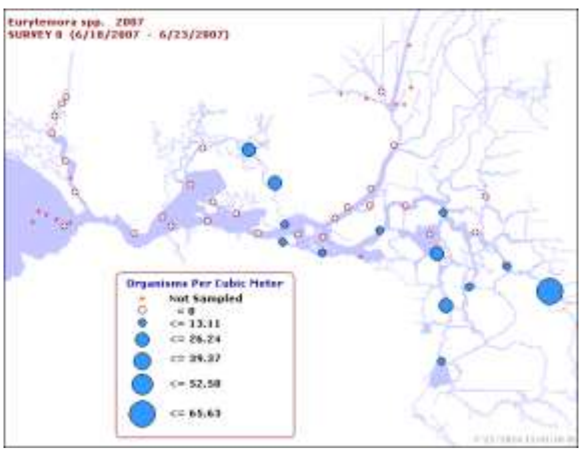

Eurytemora spp. 2008
SURVEY 9 (7/7/2008 - 7/11/2008)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 20.00
<= 40.00
<= 60.00
<= 80.00
<= 100.00

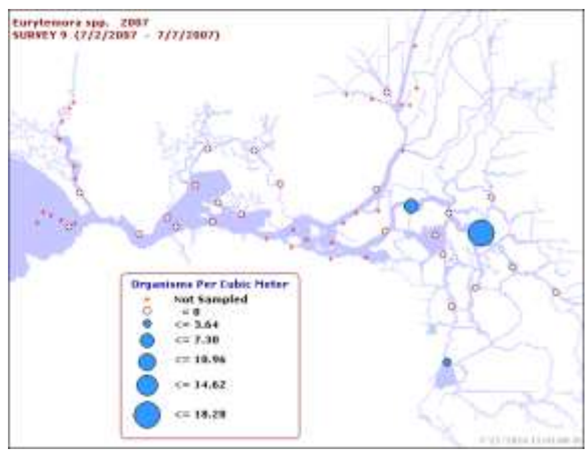

Eurytemora spp. 2007
SURVEY 4 (4/23/2007 - 4/28/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 79.28
<= 158.58
<= 237.88
<= 317.18
<= 396.48


Eurytemora spp. 2007
SURVEY 5 (5/7/2007 - 5/12/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 302.47
<= 604.93
<= 907.39
<= 1,209.85
<= 1,512.31


Eurytemora spp. 2007
SURVEY 6 (5/21/2007 - 5/26/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 509.31
<= 1,018.64
<= 1,527.97
<= 2,037.30
<= 2,546.63


Eurytemora spp. 2007
SURVEY 7 (6/4/2007 - 6/9/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 77.70
<= 155.42
<= 233.14
<= 310.86
<= 388.58


Eurytemora spp. 2007
SURVEY 8 (6/18/2007 - 6/23/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 13.11
<= 26.24
<= 39.37
<= 52.50
<= 65.63


Eurytemora spp. 2007
SURVEY 9 (7/2/2007 - 7/7/2007)
Organisms Per Cubic Meter
Not Sampled
= 0
<= 3.64
<= 7.30
<= 10.96
<= 14.62
<= 18.28