■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

VOLUME 23, NUMBER 1, WINTER 2010

OF INTEREST TO MANAGERS

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This issue's Quarterly Highlights includes updates on water project operations in the Delta as well as a report on the DFG's 2009 Spring Kodiak Trawl survey. This journal also includes a large contributed papers section that is the result of a class project led by Dr. David Schoellhamer at UC Davis. The course, entitled *Hydrology of San Francisco Bay and Delta*, utilized online data sources, including IEP studies, to teach students about estuarine hydrology.

Kate Le (DWR) summarizes Central Valley Project (CVP) and State Water Project (SWP) operations in the Delta during July – September 2009. Additional transfer water made available upstream on the Sacramento River resulted in more variable flows whereas San Joaquin River flows remained stable. Pumping operations at the state and federal facilities were also variable due to water level concerns and water transfers.

Julio Adib-Samii (DFG) reports on the Spring Kodiak Trawl (SKT) survey that was conducted from January to May 14 2009. The highest ever single-tow catch of delta smelt for the SKT was recorded in the Sacramento Deep Water Shipping Channel during the first survey period and essentially elevated annual delta smelt catch-per-trawl to pre-POD levels. Adib-Samii also describes catch data response to environmental factors and makes a case for supplemental surveys that could provide valuable information regarding spawning events and more timely responses to protective actions.

David Schoellhamer (UC Davis) leads off the contributed papers section with an introduction to his student's analysis and presentation of San Francisco Bay and Delta hydrological data for water years (WY) 2008 and 2009. By using local and regional online data sources as examples, course participants were able to learn about hydrological processes in a dynamic system. Incorporating data processing, analysis, and presentation objectives into the class also improved the student's scientific skill sets. These articles are meant to provide highlights of WY 2008 and 2009 along with comparisons to historical conditions and are an excellent example of how IEP data can be used by the public and other non-IEP entities.

Katherine Maher's summary of rainfall and snow water equivalent data documents the second and third years of a statewide drought except for January 2008 and February and May of 2009 when rainfall totals were higher than historical averages. Sarah Rahimi-Ardabily describes how flows and reservoir storage in the Sacramento River catchment were all below average compared with historic conditions. Kevin Fung and Marsha Sukardi provide similar analyses for flows in the San Joaquin River and Bay area streams, respectively. Michael Rossiter's analysis of diversions from the Delta indicates that total annual exports were only 70% of the historical average. These decreases are mainly attributed to protective actions implemented at the state and federal pumping facilities in order to minimize take of delta smelt. Adrienne Aiona's analysis of tidally-averaged water flow data for the Delta documents low flows associated with drought conditions during 2008 and 2009.

Khalida Fazel documents how coastal upwelling and water temperature 18 nautical miles west of San Francisco differed between WY 2008 and 2009. Upwelling during both years was generally stronger than the historical average, which in turn lead to cooler than average sea surface temperatures. Anthony Chan's analysis of hourly water level data for five stations in the Bay documents generally higher levels during WY 2009 than 2008. Jeffrey Anderson documents how salinity in the Bay and Delta responded to the low flow conditions in WY 2008 and 2009. Amelia Holmes reports that suspended sediment concentrations in the south Bay reached near-historic peaks in May 2008. This value is likely attributed to a large wind-wave resuspension event. Ryan Jones's analysis of surface water temperature through the estuary documents several historic minimum and maximum temperatures recorded during the winter and summer of 2008 and 2009, respectively. Heather Lee describes how phytoplankton biomass (as measured by Chlorophyll *a* concentration) varied among the main subembayments of the San Francisco Bay and how conditions in WY 2008 and 2009 differed from each other and from historical values. Chlorophyll *a* concentrations were generally higher than average during both years which follows the trend of primary productivity increasing in all three subembayments.

IEP QUARTERLY HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS

Kate Le and Andy Chu (DWR), kle@water.ca.gov

During July through September 2009, San Joaquin River flow was stable, whereas Net Delta Outflow Index and Sacramento flows were more variable due to additional transfer water made available from upstream. Sacramento flows ranged between 223 cms and 557 cms, and San Joaquin flows ranged between 15 cms and 34 cms. Net Delta Outflow Index flows ranged between 34 cms and 216 cms. No precipitation activity during this period, which is normal since it was summer time.

Pumping during the July through September 2009 period was stable at the Central Valley Project (CVP), but fluctuated at the State Water Project (SWP) as shown in Figure 2. Pumping at the CVP ranged between 83 cms and 123 cms, whereas SWP pumping ranged between 27 cms and 203 cms. The brief pumping decline in early July at the CVP was in response to south Delta water level concerns due to both projects pumping at full capacity during the beginning of July. Thereafter, CVP pumping remained stable for the remainder of the period. Unlike last year, SWP pumping varied during this period to accommodate various water transfers.

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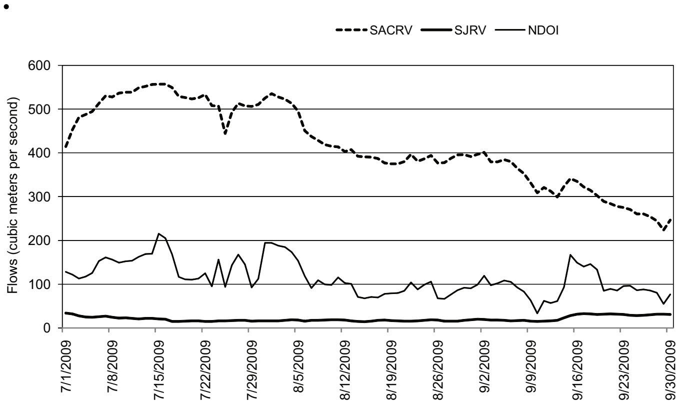

Figure 1 July through September 2009 Sacramento River, San Joaquin River, Net Delta Outflow Index.

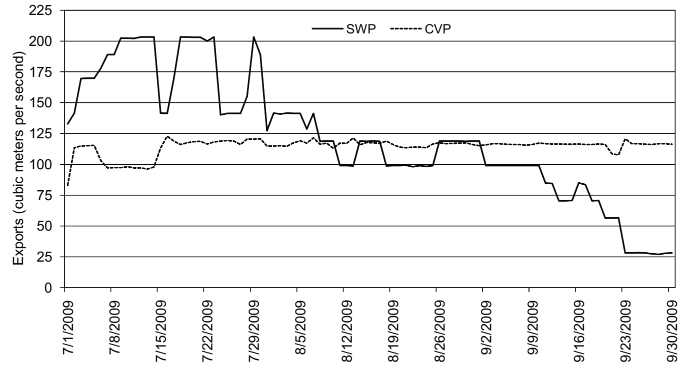

Figure 2 July through September 2009 State Water Project (SWP) and Central Valley Project (CVP) Pumping.

2009 Spring Kodiak Trawl Survey for the San Francisco Estuary

Julio Adib-Samii (DFG), jadibsamii@dfg.ca.gov

The 2009 Spring Kodiak Trawl (SKT) survey, conducted by the California Department of Fish and Game (DFG), ran from January to May 14, 2009. The objective of the SKT is to determine the distribution of delta smelt (*Hypomesus transpacificus*) and provide water managers and fisheries regulators with information on areas of probable spawning. This information is of particular interest when the distribution of delta smelt favors the eastern or southern Delta, which can lead to increased salvage of adults and subsequent juveniles. In addition to detecting distribution of adult delta smelt, the SKT survey also monitors the gonadal maturation of male and female delta smelt to determine the proportion of catch which is unripe, ripe, and spent.

From its onset in 2002, the SKT initially employed 2 alternating sampling regimes. Delta-wide surveys (numbered 1 – 5), were designed to monitor the distribution of delta smelt and sampled 40 stations from the Napa River to Ryde on the Sacramento River and to the city of Stockton on the San Joaquin River (Figure 1). Supplemental surveys (numbered 11 – 15, when conducted), were designed to monitor the reproductive maturity of delta smelt, and were conducted in areas of greatest delta smelt density indicated by the catch data from preceding Delta-wide portion of the SKT survey. Beginning in 2008 and to reduce the take of delta smelt, only monthly Delta-wide surveys were conducted.

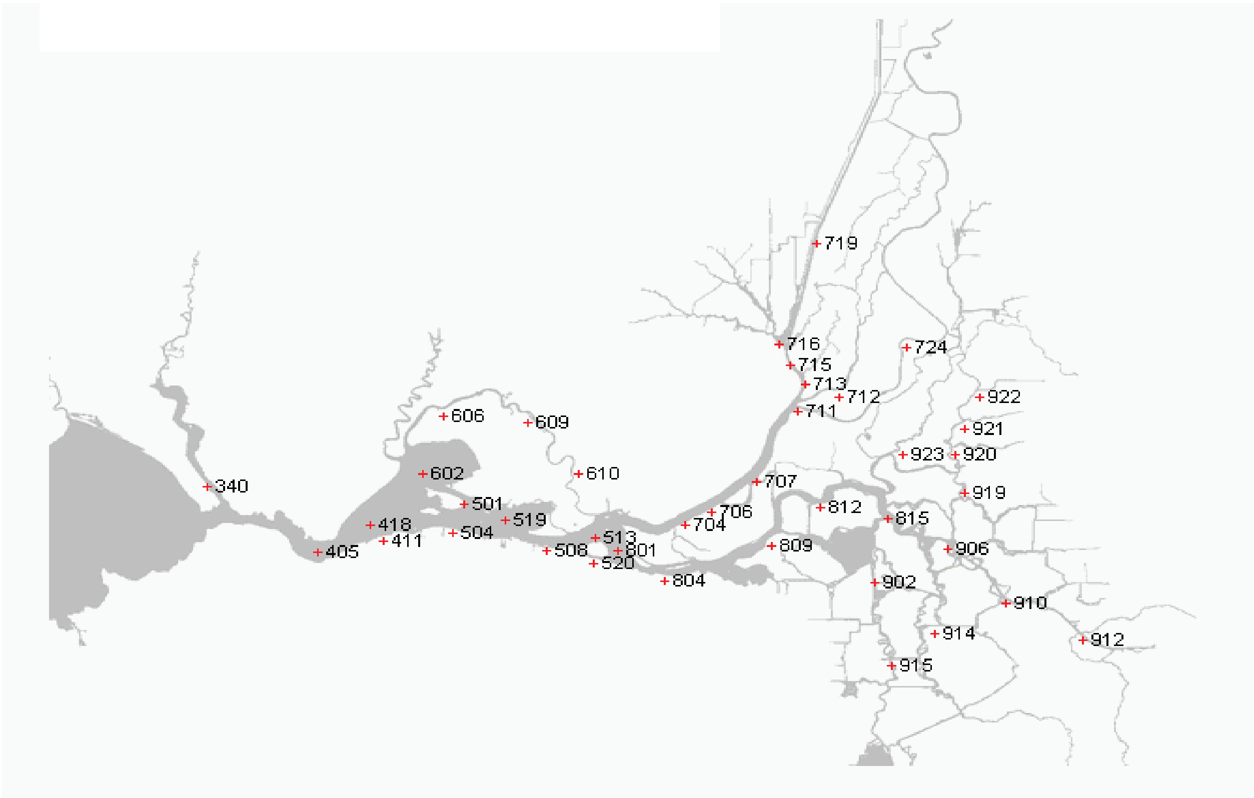

Figure 1 Current station locations sampled for the DFG Spring Kodiak Trawl Delta-wide Survey.

Gear and gear deployment methods are previously described by Souza (2002). All fish caught were speciated, enumerated, and measured to the nearest millimeter for fork length (FL). Sex and reproductive stage were recorded for all adult delta smelt. Sub-samples of delta smelt were preserved in ethanol (heads) and 10% buffered formalin (bodies), for later age, fecundity, and histopathology evaluations.

The 2009 survey recorded the greatest single-tow catch (375) of delta smelt for the period of record (2002 through 2009). The catch occurred during Survey 1 in the Sacramento Deep Water Shipping Channel (SDWC) and is 1.5 times greater than the second largest single-trawl catch for any Delta-wide survey, which occurred in 2004 (Table 1). This single catch effectively boosted annual delta smelt catch per trawl to pre-POD levels (Figure 2). Total catch per survey was (as is typical) higher early in the year then declined (Figure 3).

Originally described as semelparous, delta smelt were believed die after 1 spawning event. Field observations from 2008 and 2009 reveal that female delta smelt collected in the SKT show evidence of multiple spawning events within the reproductive season. Individual females exhibited multiple stages of ova development at the same time. Specifically, these females were staged in the field as being in pre-spawn condition, but contained at least one egg that was often enlarged, hydrated, and translucent indicating over-ripeness and believed to represent eggs retained from a previous clutch.

Table 1 Ten highest single-trawl catches of delta smelt from the DFG's Spring Kodiak Trawl for the period of record: 2002 - 2009.

Catch Rank	*Year*	*Survey*	*Date*	*Station*	*Catch*
1	2009	1	14-Jan-09	719	375
2	2004	1	15-Jan-04	609	248
3	2002	2	05-Feb-02	606	184
4	2004	2	17-Feb-04	609	105
5	2002	3	05-Mar-02	609	103
6	2004	3	09-Mar-04	606	93
7	2002	1	08-Jan-02	609	89
8	2009	1	13-Jan-09	706	87
9	2005	2	24-Feb-05	606	85
10	2005	1	27-Jan-05	609	81

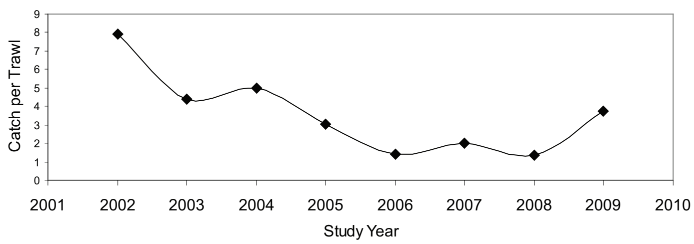

Figure 2 Summed annual delta smelt catch divided by the summed annual number of trawls from the DFG Spring Kodiak Trawl for the period of record: 2002 - 2009.

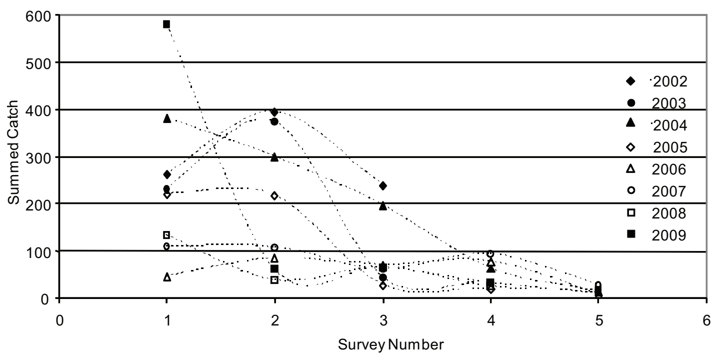

Figure 3 Summed catch of delta smelt by survey number of the DFG Spring Kodiak Trawl for the period of record: 2002 - 2009.

Delta smelt distribution throughout the upper estuary during Survey 1 was broad; ranging from western Montezuma Slough to the lower San Joaquin and Sacramento rivers, and north to the SDWC (Figure 4A). The SDWC had the highest concentrations of delta smelt for 4 out of the 5 surveys conducted in 2009. Only Survey 2 recorded higher densities of delta smelt outside of the SDWC. Survey 2's largest catch occurred in eastern Montezuma Slough, and higher densities of delta smelt were also detected at 2 lower Sacramento River stations than in the SDWC (Figure 4B). Survey 3 proved to be broad in delta smelt distribution as well, with a slight shift east from Survey 1. Fish were detected from Montezuma Slough and eastern Suisun Bay to the San Joaquin and Mokelumne rivers, and again north to the SDWC (Figure 4C). With the season progressing and catch dropping off, Survey 4's delta smelt distribution was limited to 2 areas; the lowest reaches of the San Joaquin and Sacramento rivers, and the Cache Slough and SDWC complex (Figure 4D). During Survey 5, detection of only 1 delta smelt occurred outside of the SDWC. This was located in western Montezuma Slough, while the rest of the delta smelt detected in Survey 5 (9 fish) were located in the SDWC (Figure 4E). Since the addition of the SDWC station (Stn. 719) to the SKT in 2005, the project consistently observes relatively higher delta smelt densities in the SDWC suggesting that this is a preferred spawning location. However, there is little information on what specific factors contributed to this preference or occurrence.

Delta smelt catch data from all 2009 Delta-wide surveys were combined to account for the frequency of occurrence in particular temperature and specific conductance ranges. Driven mainly by the single record-high haul from Survey 1, we see that approximately 67% of all delta smelt collected in 2009 occur in the <9°C and <1000 µS/cm ranges for water temperature and specific conductance respectively (Figures 5 & 6).

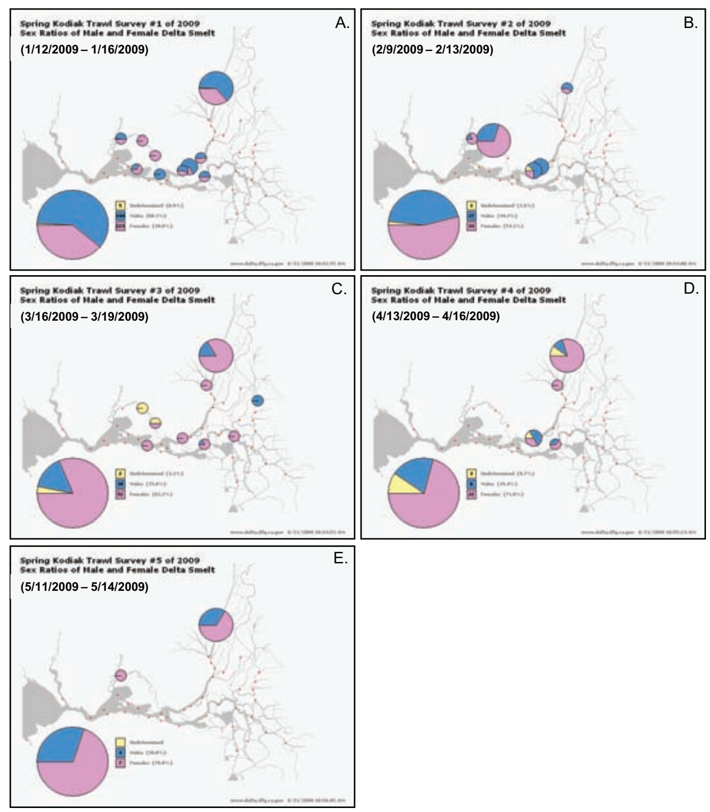

Figure 4 Geographical distribution of delta smelt by catch and by male-female ratio for each 2009 Delta-wide survey, from the DFG Spring Kodiak Trawl web-page (http://www.delta.dfg.ca.gov/data/projects/?ProjectID=SKT).

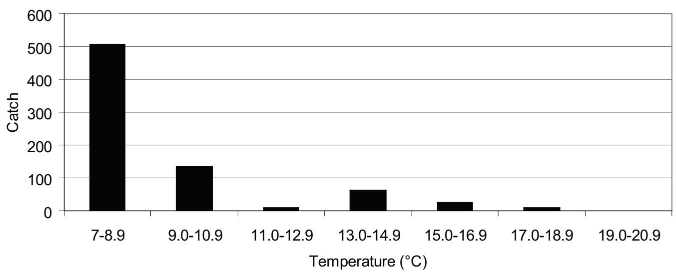

Figure 5 Temperature ranges in which delta smelt were collected during the DFG Spring Kodiak Trawl 2009 field season.

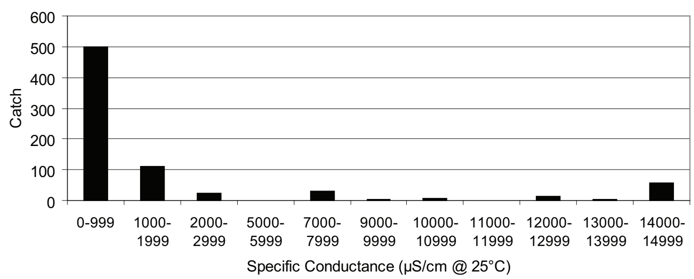

Figure 6 Specific conductance ranges in which delta smelt were collected during the DFG Spring Kodiak Trawl 2009 field season.

To examine the relationship of water temperature and the reproductive status of female delta smelt, female catch data from all 2009 Delta-wide surveys were combined and then adjusted to account for the frequency of temperature readings, so that more frequent readings are not overrepresented. Delta smelt catch in each temperature group was divided by the number of times the respective group was observed in the field. Greater than 68% of all pre-spawn females were collected at water temperatures <9°C, while 100% of spent females were collected at temperatures >12°C (Figure 7).

Figure 8 shows the female gonadal stage distribution for the 2009 sampling year and(as is typical) the fraction of both ripe and spent fish increases with the seasonal increase in water temperature. Spawning (i.e. ripe or spent females) was detected during Survey 3, coincident to a 3.1°C rise in average survey temperature from Survey 2 to Survey 3 which pushed the average survey water temperature (Figure 9) above a purported 12°C trigger/threshold to initiate spawning (Lindberg et al., 1997). Water temperatures reported by the California Data Exchange Center (CDEC, http://cdec.water.ca.gov/) for three delta locations revealed that a warming trend to >12°C in the Cache Slough region occurred up to three weeks before the start of Survey 3 (Figure 10), which indicates spawning may have initiated just days after Survey 2 was completed.

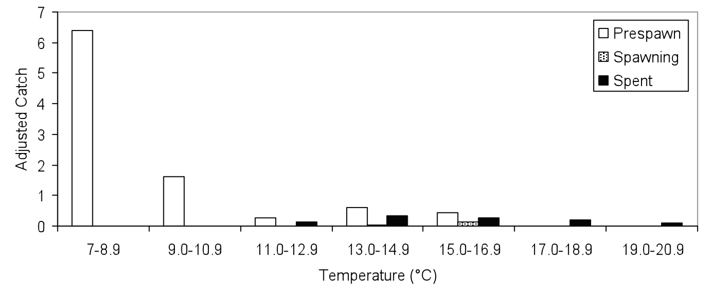

Figure 7 Temperature ranges in which female delta smelt were collected during the DFG Spring Kodiak Trawl 2009 field season. Female gonadal stages are broken down into pre-spawn, ripe, and spent groups.

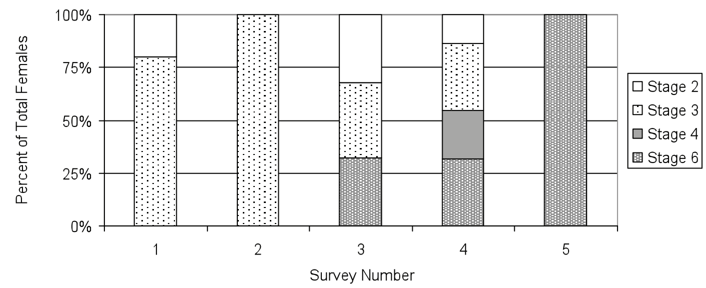

Figure 8 Gonadal-stage percent distribution of female delta smelt during each 2009 Delta-wide survey of the DFG Spring Kodiak Trawl. Stages 2 & 3 are pre-spawn, Stage 4 is ripe, and Stage 6 is spent.

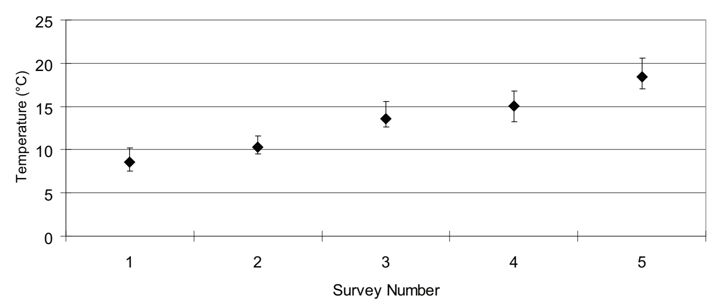

Figure 9 Temperature readings taken from every sample in each 2009 Delta-wide survey of the DFG's Spring Kodiak Trawl; survey average temperatures are noted.

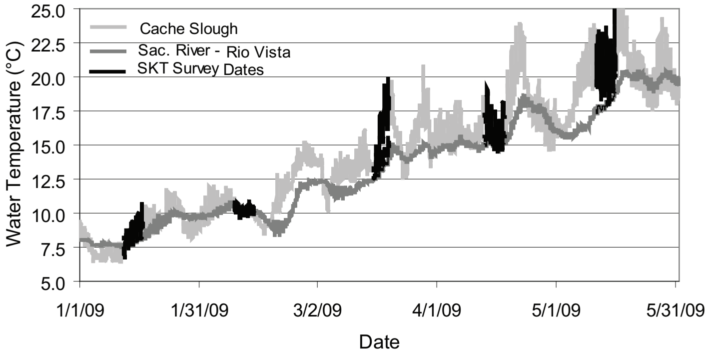

Figure 10 Hourly water temperatures recorded in the Sacramento River at Rio Vista, Cache Slough, and Montezuma Slough as reported by CDEC (http://cdec.water.ca.gov/). Black lines highlight and represent corresponding DFG's Spring Kodiak Trawl survey dates.

The 2010 Spring Kodiak Trawl field season is scheduled to begin in January 2010 and run through May 2010 using monthly surveys. Currently, there are no plans to alter 2010 field sampling in any way from the previous year. However, the addition of a precisely-timed supplemental survey might provide valuable data regarding the timing and environmental factors of certain spawning events. A supplemental survey may also provide additional presence/absence information in areas of high interest (e.g., the south Delta). Minor laboratory processing changes will be implemented in 2010 to facilitate later genetic analysis. These data, along with the geographic distributions of delta smelt, are available for viewing on our web page at http://www.delta.dfg.ca.gov/data/projects/?ProjectID=SKT .

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CONTRIBUTED PAPERS

Hydrology of San Francisco Bay and Watershed, Water Years 2008 and 2009

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Hydrology is the study of the properties and distribution of water. California has two distinct hydrologic seasons: a wet season from late autumn to early spring with the remainder of the year being dry. Thus, the water year, which begins on October 1 and ends on September 30, is a convenient period to study hydrology because it begins in the dry season, includes a single wet season, and ends in the dry season.

The purpose of this series of short articles is to describe the hydrology of San Francisco Bay and its watershed during water years (WY) 2008 and 2009. The articles describe precipitation and surface water flows in the watershed (Figure 1), flows and diversions in the Sacramento – San Joaquin River Delta (Figure 2), water levels and currents, salinity, suspended sediment, temperature, and chlorophyll-*a* in San Francisco Bay (Figure 3), and temperature and upwelling offshore in the Pacific Ocean (Figure 3). Temporal variation and spatial distribution are described and WY 2008 and WY 2009 conditions are compared to historical conditions and to each other. These water years were the second and third years of a drought (Maher, this issue). For all three-year periods from WY 1970-2009, precipitation during WY 2007-2009 was at the 16th percentile, Delta water diversions during WY 2007-2009 were at the 29th percentile, and Delta outflow during WY 2007-2009 was at the 13th percentile (Villagomez and Schoellhamer 2009). All data are available to the public from online sources. Due to the breadth of the subject matter and quantity of data available, the articles provide highlights of the hydrology of the Bay, Delta, Ocean, and watershed rather than in-depth analysis. Water managers and scientists may find that the articles are a convenient resource to access hydrologic conditions in WY 2008 and WY 2009. A previous set of articles described WY 2005 and WY 2006-2007 (Schoellhamer 2007a and 2007b).

These articles were written and reviewed by the students enrolled in the class *Hydrology of San Francisco Bay and Delta* that I taught at UC Davis in Fall 2009 (Schoellhamer 2009). The students also downloaded and processed the data presented in these articles. I would like to thank the many individuals, organizations, and agencies who serve the public by collecting and disseminating hydrologic data and Roger Fujii, John Largier, Michelle Lent, Jay Lund, Greg Shellenbarger, Pete Smith, Ted Sommer, and Laura Valoppi for their assistance.

Figure 1 Central Valley watershed that drains to San Francisco Bay. Selected rivers, reservoirs, and streamflow gages are shown.

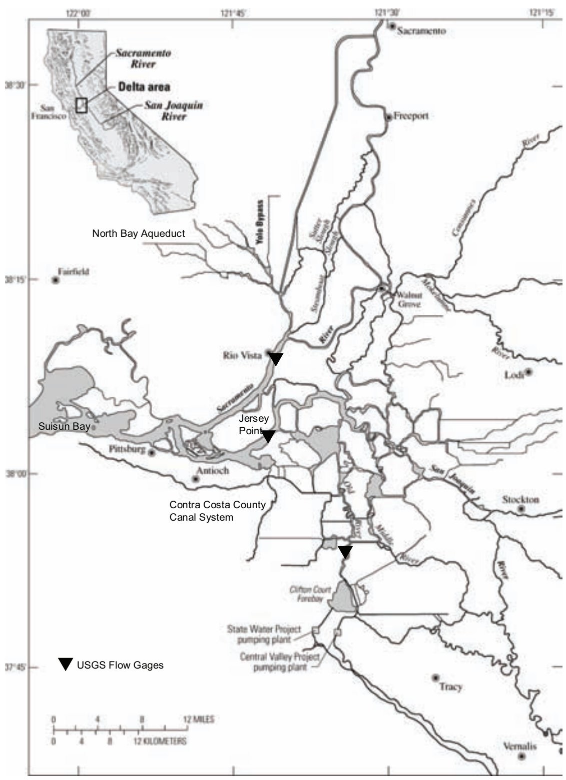

Figure 2 Sacramento-San Joaquin River Delta. Data from indicated Delta flow gages operated by the U.S. Geological Survey were examined by Aiona (this issue).

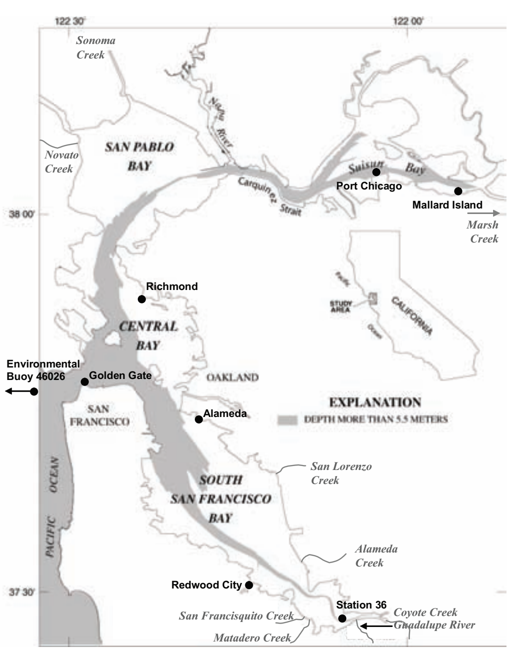

Figure 3 San Francisco Bay and the offshore Pacific Ocean. Measurement stations and local tributaries examined in this series of articles are shown.

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Precipitation in the San Francisco Bay Watershed, Water Years 2008 and 2009

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Precipitation data indicate that Water Year (WY) 2008 and Water Year 2009 were both drier than normal. Water Year 2008 and WY 2009 are the second and third year of a statewide drought, following below average conditions in WY 2007 in which precipitation levels were 63 percent of average (DWR 2009). Average monthly rainfall data (CDEC 2009a) was analyzed for five major river basins in the Sacramento region, six in the San Joaquin region, and two in the San Francisco Bay area. Monthly snow pack data (CDEC 2009b) was also evaluated for ten river basins in the Sierra Nevada using snow water equivalent (SWE) in inches of water.

In WY 2008, rainfall values were near or below average for all months except January, which was 23% above average. WY 2009 rainfall values were near or below average for all months except February and May, which were 31percent and 90 percent above average, respectively. In both water years, the month of April was very dry (22 percent of average in WY 2008 and 36% of average in WY 2009).

Regional water supply is heavily dependant on snowpack, which provides 40 percent of the annual water supply in the San Francisco Bay watershed (Knowles and Cayan 2004). Compared to historical values, WY 2008 snow-water equivalent (SWE) values peaked earlier in the year, with above average values in February and March and below average values for April and May (Figure 1). In contrast, WY 2009 SWE values are consistently below average throughout the year. Below average snowpack values or early peaking can have significant impact on reservoir levels and the ability to regulate precipitation for water supply purposes. The low precipitation levels in WY 2008 and 2009 confirm the continuing drought in California, and raise concerns about potential water management problems if similar dry conditions continue in WY 2010.

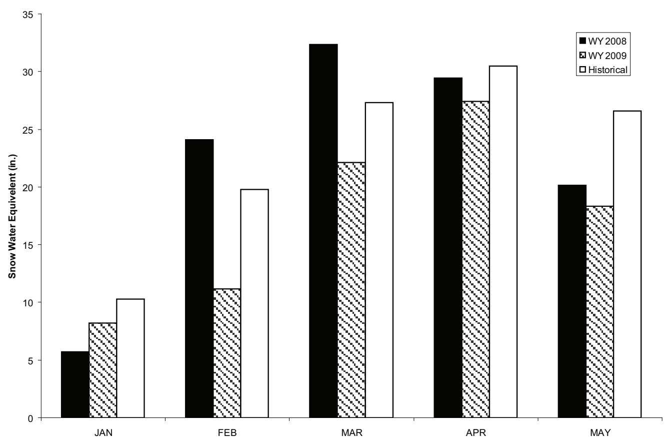

Figure 1 Unweighted mean SWE for WY 2008, WY 2009, and historical monthly averages for the period of record (varies by basin) for the San Francisco Bay watershed (CDEC 2009b).

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Sacramento River Flows, Water Years 2008 and 2009

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Data were retrieved for the daily mean average flows within the Sacramento River and its tributaries (Schoellhamer, this issue, Figure 1) for the water years (WY) 2008 and 2009 and a historical period of record starting from various dates until WY 2009 from the California Data Exchange Center (CDEC 2009) and the U.S. Geological Survey (USGS 2009). The flow through the Sacramento River and tributaries is primarily supplied by rainfall runoff as the Sacramento Valley often experiences wet winters. The spring snowmelt typically is stored in the reservoirs which is released throughout the summer and supplies the water flow during the summer dry months. Daily mean average flows for WY 2008 and 2009 for the Sacramento River and its tributaries were below the historical average due to precipitation being lower than the historical average (Maher, this issue); (CDEC 2009; USGS 2009).

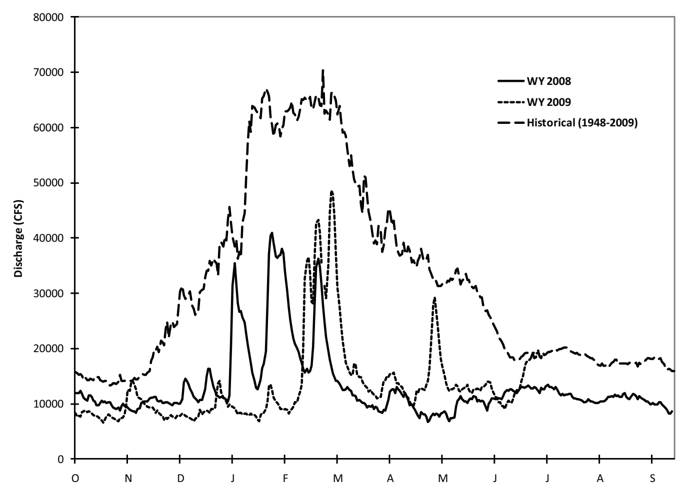

Figure 1 Streamflow discharge (CFS) at Freeport in the Sacramento River.

Sacramento River flow measured at Freeport gives an accurate representation of daily mean flows in the Sacramento River as it is the most downstream site in the Sacramento River and it integrates all the tributary flows above it. The historical data shows the majority of discharge from Freeport occurs between the months of January and May (Figure 1). The average daily mean flows at Freeport for WY 2008 and 2009 follow the same trend as the historical data but were consistently lower than the historical average. Discharge from Freeport for WY 2008 was 41.26 percent of that of the historical discharge and for WY 2009 was 42.47 percent of that of the historical discharge (USGS 2009).

Furthermore, flow thru the Yolo Bypass, which protects Sacramento and other cities from flooding, was minimal for WY 2008 and WY 2009 (Figure 2), (USGS 2009). Following a similar pattern, flow passed over the Sutter Bypass weirs on several occasions in WY 2008 and 2009 (not shown), (CDEC 2009). Due to the drought and snowpack levels being lower than the historical average (Maher, this issue), the storage within the three reservoirs, Folsom, Shasta, and Oroville all had lower than normal averages in WY 2008 and WY 2009 when compared to the historical period, (Figure 3), (CDEC 2009). The mean daily inflow and outflow of the dams for WY 2008 and 2009 followed a similar trend of being below the historical averages (not shown).

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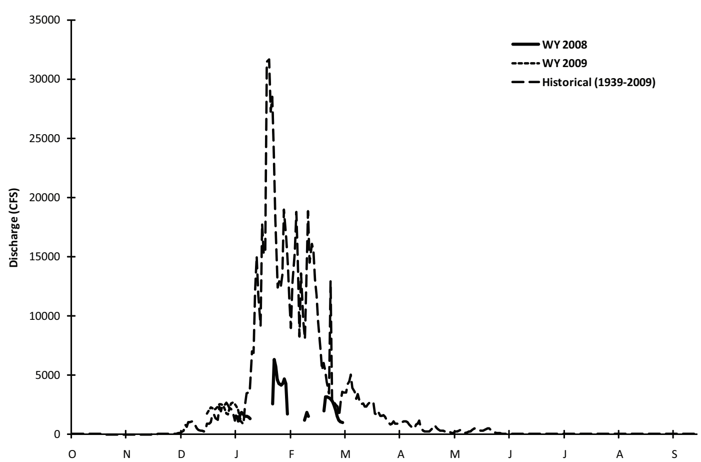

Figure 2 Streamflow discharge (CFS) in the Yolo Bypass at the Sacramento River.

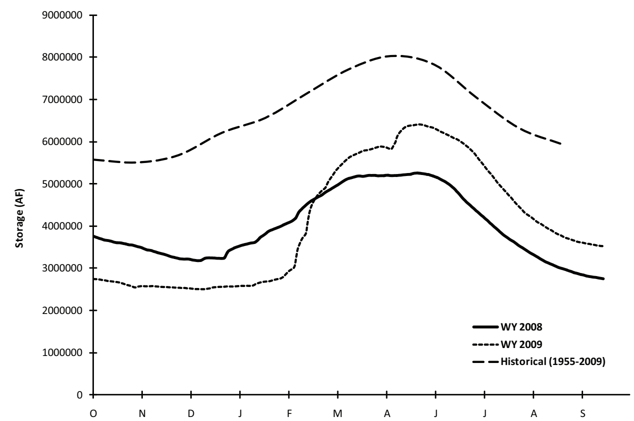

Figure 3 Sum of water storage (AF) at Shasta, Folsom, and Oroville Dams.

San Joaquin River Flows, Water Years 2008 and 2009

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The San Joaquin River (SJR) Basin is a large area that covers 15,214 square miles, which is about 9.6 percent of the state (Schoellhamer, Figure 1, this issue). Mean daily flow data were collected for 5 reservoirs and 15 stations throughout the basin for water years(WY) 2008 and 2009. Additionally, historical averages were gathered for comparison. Overall, these were two dry years with below average precipitation (Maher, this issue). In most cases, the total monthly flows were less than historical averages and flows were greater in WY 2009 than WY 2008 (CDEC 2009). Some stream gages reported decreased flows from WY 2008 to WY 2009 such as at Stevinson, Newman, and Vernalis stations on the SJR (CDEC 2009).

Vernalis is the most downstream gage along the SJR and flows in WY 2008 and WY 2009 were below normal (Figure 1). Snowpack was lower than average as was the precipitation in the San Joaquin watershed (Maher, this issue). There is a significant difference at the end of May of almost 6500 cfs between the peak historical outflow and both WY 2008 and WY 2009 outflows (Figure 1). The peak flow for WY 2008 occurred in February at about 4500 cfs, which is 1500 cfs greater than in WY 2009 (Figure 1). The peak flow for WY 2009 occured in May with a peak of 2500 cfs, which is almost 1000 cfs less than the year before. For January through July, the outflows were significantly less than the historical mean at Vernalis (USGS 2009).

Storage data for the major reservoirs in the SJR watershed were retrieved and combined (Figure 2). Storage was below the historical average until May 2009 (Figure 2). It is interesting to note that the beginning of WY 2008 was the only time that storage was close to the historical mean. Total storage dropped in the reservoirs to a low at the end of WY 2008 and beginning of WY 2009. However, due to increased rains in May of WY 2009 (Maher, this issue), the overall storage increased nearing the historical mean in May of WY 2009 and remained close to the mean from that point on.

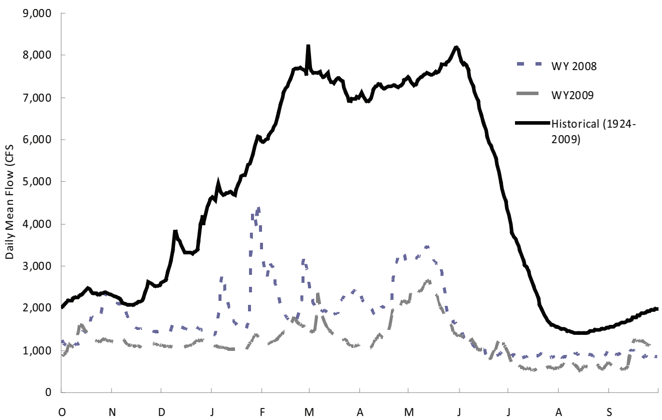

Figure 1 San Joaquin River discharge at Vernalis (USGS station 11303500).

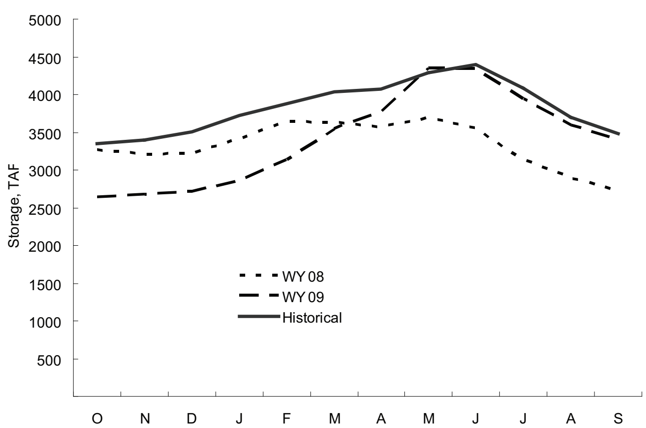

Figure 2 Total daily storage in San Joaquin River Basin reservoirs Lake McClure, Don Pedro Reservoir, New Melones Reservoir, New Hogan Reservoir, and Millerton Lake (Friant Dam) (CDEC).

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Streamflows of San Francisco Bay Tributaries, Water Years 2008 and 2009

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Streamflows of 12 tributaries emptying into the San Francisco Bay (Bay tributaries) were evaluated using daily streamflow data collected by the U.S. Geological Survey (USGS). Historical daily streamflow was averaged from 1929 to 2009 and compared to the daily Bay tributary flows of water years (WY) 2008 and 2009.

Seven tributaries were located in the South Bay and five in the North Bay (refer to Table 1 and Schoellhamer, this issue, Figure 3). Drainage surface areas above the recording station range from 7.26 square miles for Matadero Creek (USGS 11166000) to 639 square miles for Alameda Creek Flood Control Channel (USGS 11180700) (USGS 2009). The total drainage area of these tributaries is 2,251 square miles and is approximately 88 percent of the San Francisco Bay watershed (Leatherbarrow 2007). However, the bay tributaries provide only 10 percent of the freshwater inflow to the San Francisco Bay, the majority of which occurs primarily during the winter months (Conomos and others 1985). During the summer months some stations had missing data such as Matadero Creek (USGS Gauge 11166000) from June to August.

Figure 1 illustrates that WY 2008 and 2009 had below average streamflow. However, peak events did occur that exceeded average historical streamflow during early and late January 2008 and in the months of February and March 2009. Despite peak events, Table 1outlines each tributaries' annual mean discharge rates, which are lower than their historical mean discharge rates with the exception of Napa River at Napa (USGS 11458000) and Matadero Creek (USGS Gauge 11166000). The total flow volume for WY 2008 and 2009 were 0.33 million acre feet (maf) and 0.26 maf, respectively, which were below the historical annual flow volume of 0.4 maf.

These reduced flows in WY 2008 and 2009 indicate three years of drought starting from WY 2007 as confirmed by Maher (this issue). Comparatively, the total flow volume of WY 2008 and 2009 are 82 percent and 65 percent of their historical annual flow volume, greater than the historical annual percentage of 40% for WY 2007 (Pan 2007).

Table 1 Annual mean discharge in Bay tributaries for WY 2008 and 2009. Annual mean discharge is in cubic feet per second (cfs).

Station name	Station ID	Period of record	Drainage area *(sq miles)*	Annual mean discharge *(cfs)*		
				Historical	*2008*	*2009*
San Francisquito C.	11164500	1970-2009	633	21	13	12
Matadero C.	11166000	1952-2009	7.3	2	3	3
Guadalupe R.	11169025	2003-2009	78.8	67	53	47
Coyote C.	11172175		218	46	37	33
Alameda C.	11179000	1999-2009	38.3	135	77	99
Napa R.	11456000	1929-2009	160	95	60	38
Napa R.	11458000	1998-2009	319	86	113	86
Sonoma C.	11458500	1959-2009	639	71	55	31
Novato C.	11459500	1959-2008	58.4	13	8	
San Lorenzo C.	11181040	1967-2008	44.6	22	13	
Marsh C.	11337600	1930-2009	37.4	11	6	3
Alameda C.	11180700	1947-2009	17.6	98	51	36
Total		1929-2009	2251.4	667	490	399

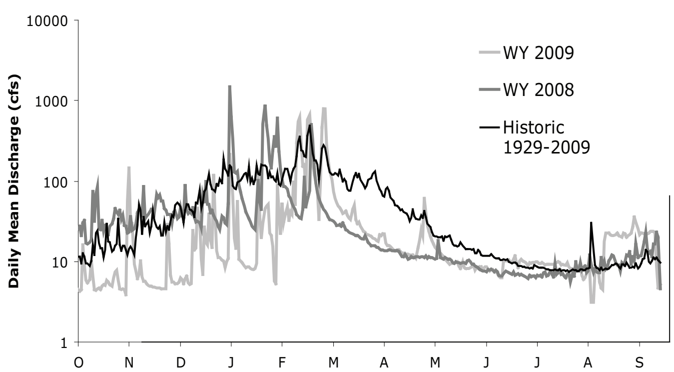

Figure 1 Daily mean discharge in local Bay tributaries in WY 2008 and 2009 compared to historical averages. Daily mean discharge is in cubic feet per second (cfs) on a logarithmic scale and represents the combined flows from twelve gauged Bay tributaries listed in Table 1.

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Diversions from the Delta, Water Years 2008 and 2009

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Annual and daily mean exports for WY 2008 and 2009 were compared with the averaged historical exports during WY's 1998-2009. Key Delta diversions analyzed for this comparison included the Contra Costa Canal (CCC), the State Water Project (SWP) and Central Valley Project (CVP) pumping plants, and the North Bay Aqueduct (NBAQ) (Schoellhamer, this issue, Figure 2). The sum of these data makes up the 'Total Exports' which provides a standard for comparison of the overall Delta diversions from year to year. Net flows related to channel depletions (CD) were also compared.

Data were obtained primarily from the DAYFLOW database, an Interagency Ecological Program (IEP) tool that calculates various flows within the Delta (IEP, 2009). DAYFLOW data are preliminary for WY 2009 and were not available between September 23- 30, 2009; California Data Exchange Center (CDEC) data were instead used to determine SWP, CVP, and 'Total Exports' during this last week of September (CDEC, 2009). Values for CCC, NBAQ, and CD during September 23-30, 2009 were assumed to equal the mean values from September 1-22, 2009.

Total daily exports during WY 2008 and 2009 were generally lower than the historical mean (Figure 1). Total annual exports were only 70 percent of the historical mean in WY 2008 and 69 percent of the historical mean in WY 2009 (Table 1). Historically, SWP and CVP pumping made up 97 percent of Delta Diversions. Exports for SWP and CVP were only 55 percent and 83 percent, respectively, of their historical averages during WY 2008 and 60 percent and 77 percent, respectively, of their historical averages during WY 2009 (Figure 2 and Table 1). The observed reductions in pumping can largely be attributed to flow and water quality restrictions placed upon the SWP and CVP facilities as a result of recent biological opinions.

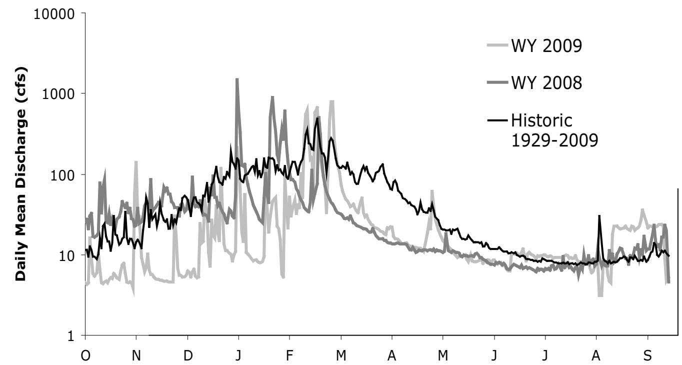

Figure 1 Mean daily Delta exports (cfs) for water years 2008 and 2009 as compared to historical mean data (1998-2009).

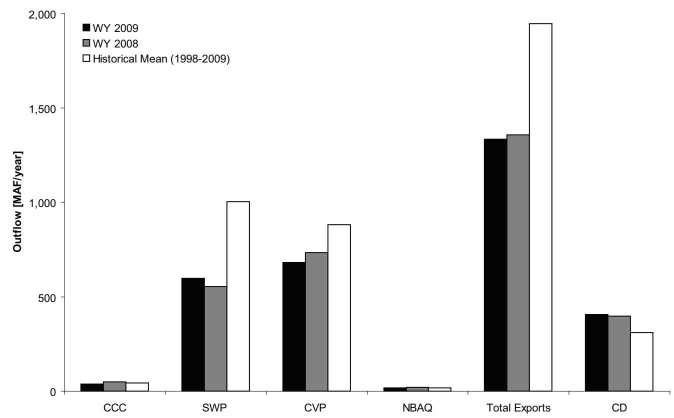

Figure 2 Annual Delta exports (MAF/year) for water years 2008 and 2009 as compared to historical mean data (1998-2009).

Table 1 Comparison of annual Delta exports (cfs) for water years 2008 and 2009 as compared to historical mean data (1998-2009).

	CCC	*SWP*	*CVP*	*NBAQ*	*Total exports*	*CD*
WY 2009 [cfs]	53,624	824,874	938,590	23,172	1,840,259	559,530
% of Historical	87%	60%	77%	98%	69%	131%
WY 2008 [cfs]	67,735	765,604	1,013,211	27,655	1,874,205	548,780
% of Historical	109%	55%	83%	116%	70%	128%
Historical Mean (1998-2009) [cfs]	61,881	1,383,595	1,215,933	23,749	2,685,150	428,203

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Flows in the Delta, Water Years 2008 and 2009

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This article describes flow patterns within the Delta for water years 2008 and 2009 by comparing these years with historic records. Both of these years were drought years (Maher, this issue). Meeting the co-equal goals of a reliable water supply and a healthy ecosystem, as recommended by the 2008 Delta Vision Report (Delta Vision, 2008) becomes more difficult when there is less water.

The Interagency Ecological Program's Dayflow website (IEP 2009) provided estimates for total outflow from the Delta to San Francisco Bay, independent of tidal flows. Daily outflows for 2008 and 2009 were 35% and 34% of the historic mean, respectively; a symptom of the drought conditions in these years (Figure 1 and Table 1).

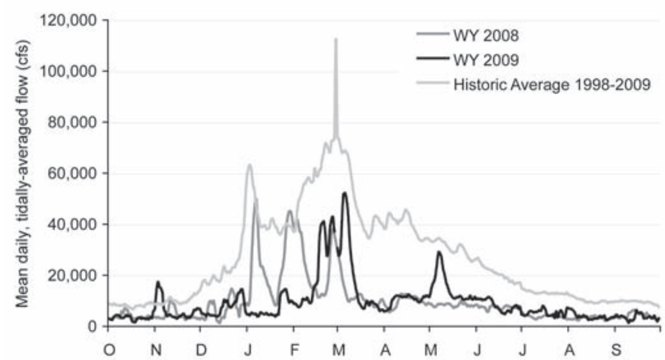

Figure 1 Outflow to San Francisco Bay from the Delta. (CDEC 2009).

Geographic variation in quantity of flow in different regions of the Delta was observed using the mean daily, tidally-averaged flow data at twelve USGS monitoring locations throughout the delta (USGS 2009). This article examines Water Year (WY) 2008, WY 2009 and historic flow data for three representative sites: the Sacramento River at Rio Vista, the San Joaquin River at Jersey Point, and Old River at Byron Tract (Figure 2). See Figure 2 in Schoellhamer (this issue) for locations. The Sacramento and San Joaquin Rivers are the two largest tributaries contributing around 75% and 15% of freshwater inputs, respectively (DWR 1995). Old River flows are largely driven by exports to the State Water Project resulting in landward flows (Figure 2). In drought years, such as 2008 and 2009, exports also create landward flows in the San Joaquin River.

Table 1 Percentage of average annual flow at representative sites for WY 2008 and WY 2009.

	Historic mean-daily flow (cfs)	*Percent of historic average*	
		WY 2008	WY 2009
Sacramento River at Rio Vista	21,873	45%	46%
San Joaquin River at Jersey Point	7,539	24%	24%
Old River at Byron Tract (landward flow is negative)	-3,736	70%	75%
Total Delta Outflow	26,266	35%	34%

Fish species abundance is linked to the quantity of fresh water flow (Sommer et al. 2007), making flow a focus of policy discussions. The Delta Vision report includes measures recommending the quantity and timing of flow in specific channels to improve habitat for, and increase abundance of, organisms within the delta (Delta Vision, 2008). For example, one recommendation calls for a "net downstream flow on [the] San Joaquin River at Jersey Point [for] Feb. 1 to Jun. 30"; a standard that was not met in either WY 2008 or WY 2009. In drought years, the competing needs of a growing urban population, agricultural production and maintaining ecological function will ensure that the management of flows will continue to be a crucial issue of California water policy.

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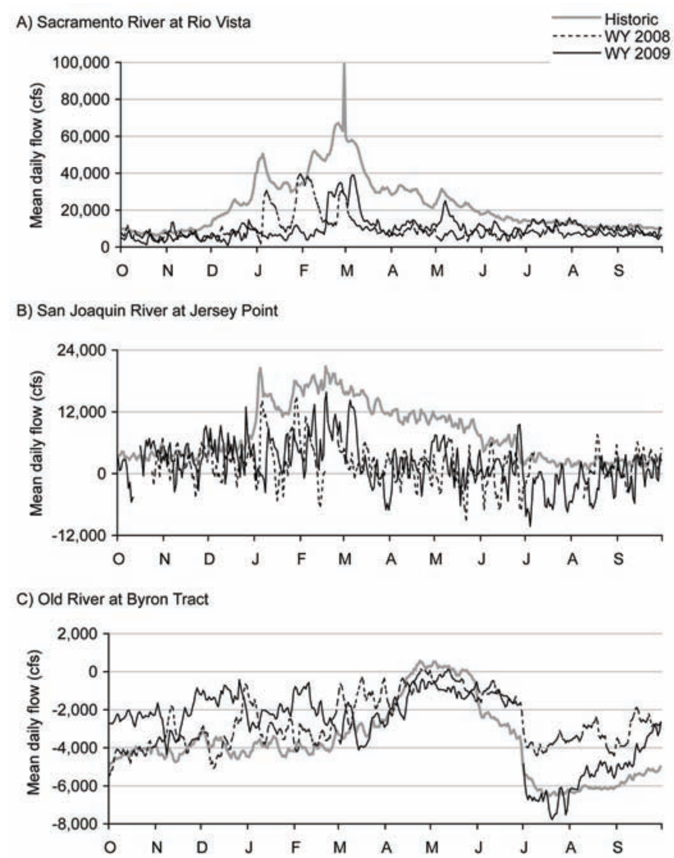

Figure 2 Mean daily, tidally-averaged flows for representative stations for WY 2008, WY 2009 and historic averages. Historic records are as follows, A) Sacramento River: 1996 - 2009; B) San Joaquin River: 1994 - 2009; and C) Old River at Byron Tract: 2000 - 2009 (USGS 2009).

Coastal Upwelling and Sea Surface Temperature, Water Years 2008 and 2009

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Coastal upwelling on the eastern edge of the Pacific Ocean is responsible for high productivity of the marine ecosystem. Upwelling occurs when there are shifts in seasonal wind patterns that cause coastal surface waters to move seaward, giving way for cooler, nutrient-rich waters from depths of 50 to 100 meters to advance towards the surface (NOAA ERD 2009a). The upwelling index measures the intensity of coastal upwelling and is calculated based on wind-induced stresses and other parameters. Upwelling indices were retrieved for 39°N 125°W from NOAA's Pacific Fisheries Environmental Laboratory (NOAA ERD 2009b), providing historic data from 1946 to 2009. Figures 1 and 2 present upwelling indices and sea water temperatures, respectively, for water years (WY) 2008 and 2009 and for the historic monthly mean. Sea water temperature data was retrieved from the National Oceanic and Atmospheric Administration's (NOAA NDBC 2009) buoy 46026, located 18 nautical miles west of San Francisco Bay, providing historic data from 1982 to 2001 (Schoellhamer, this issue, Figure 3).

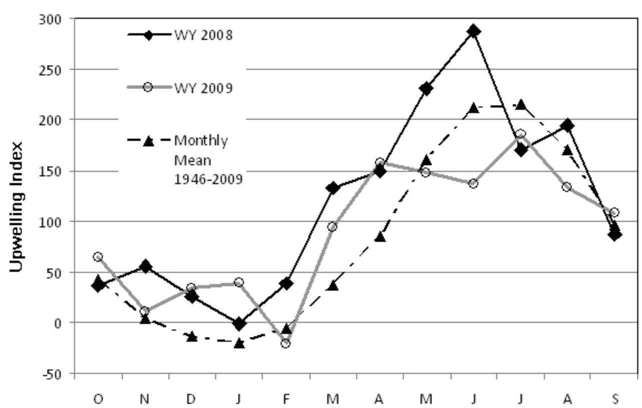

Figure 1 Mean monthly upwelling index for WY 2008, WY 2009, and the historical period of record (1946-2009).

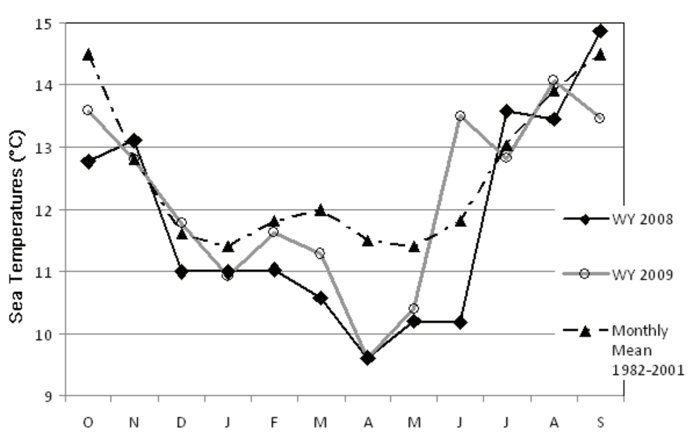

Figure 2 Monthly mean temperatures at NOAA Buoy 46026 for WY 2008, WY 2009, and the historical period of record (1982-2001).

Upwelling varies seasonally and is greatest in spring and early summer and lowest in winter (Figure 1). From April to June 2008, upwelling was strong, peaking in June (Figure 1); these months corresponded with generally cooler ocean temperatures for WY 2008 (Figure 2). Upwelling indices decreased from July to September 2008, during which temperatures climbed to peak values. Temperatures were also generally high from October to December 2008, while upwelling was weaker during these months. Figure 2 shows a minimum temperature of 9.6 °C in April 2009, corresponding with a high upwelling index of 158.

The upwelling and temperature anomalies of Figure 3 were determined by taking the difference between the parameter of interest (WY 2008/2009 upwelling or temperature) and the historic mean of the respective parameter. A positive anomaly represents a larger value for the given year with respect to the historic mean, while a negative anomaly represents the opposite. Upwelling in WY 2008 was generally stronger than the historic mean, with the exception of July, when upwelling was weaker than the historic mean. Upwelling in WY 2009 compared to the historic mean showed more variation, with negative anomalies in several months, particularly during the warmer months of May through August. The greatest positive anomaly was in March 2008 and the most negative anomaly was in June 2009.

With a few exceptions, WY 2008 and 2009 sea temperatures were generally cooler than those of the historic mean (Figure 3). In WY 2008, temperatures were warmer than the historic mean in October, November, July, and September, and WY 2009 produced similar exceptions during December, June, and August. The greatest positive anomalies occurred in October 2008 and June 2009 and the most negative anomalies occurred in April 2008 and April 2009.

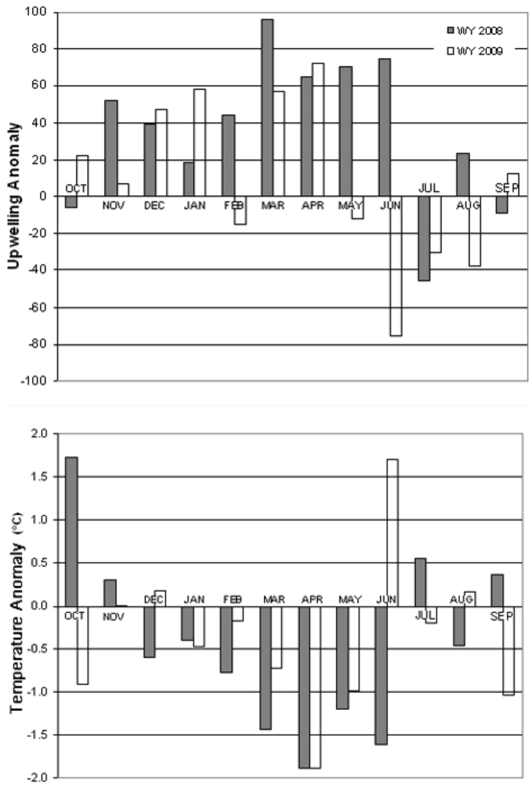

Figure 3 Upwelling and temperature anomalies of WY 2008 and WY 2009.

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Water Levels in San Francisco Bay, Water Years 2008 and 2009

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In this article, I compare water levels in San Francisco Bay for water years (WY) 2008 and 2009. The data were retrieved from the National Oceanographic and Atmospheric Administration Physical Oceanographic Real-Time System (NOAA PORTS 2009). Hourly water level data were obtained from the Port of Chicago, Richmond, San Francisco at Golden Gate, Alameda, and Redwood City stations using a datum of mean-lower-low-water (MLLW).

In order to calculate the tidally averaged water level, a sixth-order low-pass Butterworth filter with a cutoff frequency of 0.025/h, or a period of 40 hours was used (Warner et al. 2002). Water level difference at all locations was between 0.7 and 2.9 cm higher in WY 2009 than WY 2008 (Table 1). These differences were then calculated as a percentage change from WY 2008 that yielded an increase of between 0.899 to 2.247 percent. The purpose of the percentage change calculation was to show that a relatively large increase in water level at Redwood City was only a 2.247 percent increase, and did not deviate far from the 2.009 percent increase at Golden Gate and the 1.854 percent increase at Alameda. Even though the percentage change in water level had a small range and deviated with the variance of the data, these tidally averaged calculations signify the similar increases in water level at different locations in the bay and highlight the water level difference between two years. The stations are listed in order of closeness to the fresh water source as seen in Figure 3 (Schoellhamer, this issue). An increasing mean water level difference from Port Chicago to Redwood City was measured fromWY 2008 to WY 2009.

Table 1 Mean water level for WY 2008 and 2009. Absolute and percentage difference are also calculated. The datum is measured from the mean-lower-low-water (MLLW) level.

Station name	Mean water level (m)		Water level change	
	WY 2008	WY 2009	2009-2008	% Change
Port of Chicago	0.763	0.770	0.007	0.899
Richmond	0.939	0.950	0.011	1.153
Golden Gate	0.916	0.935	0.018	2.009
Alameda	1.005	1.024	0.019	1.854
Redwood City	1.325	1.354	0.030	2.247

Increase in water level can be associated with an increase in precipitation and resulting snowmelt. Monthly precipitation for WY 2009 was generally greater than WY 2008 (Maher, this issue, figure 1). Rainfall events in January 2008 and February 2009 that were above historical average are reflected with corresponding increases in water level (Figure 1) and decreases in salinity (Anderson, this issue, Figure 1). Port Chicago experiences more drastic water level changes than Redwood City because it is closest to the water source from the Delta. Figure 1 also shows water level lows around April for both water years.

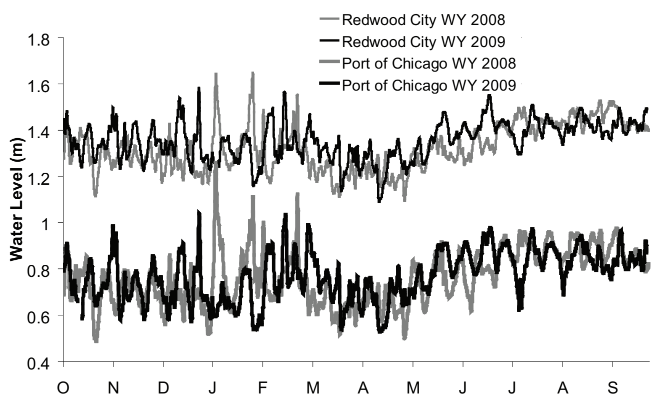

Figure 1 Tidally averaged water level at Port of Chicago and Redwood City station for WY 2008 and 2009 (NOAA PORTS 2009). Redwood City WY are shown as the top two lines, while Port of Chicago WY are shown as the bottom two lines.

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Salinity in San Francisco Bay and Delta, Water Years 2008 and 2009

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Salinity data for San Francisco (SF) Bay and Delta for water years (WY) 2008 and 2009 were obtained through the U.S. Geological Survey website of monthly water-quality cruise data (USGS 2009). Vertical profiles of SF Bay are measured at fixed stations from the *RV Polaris*. These data were then analyzed and plotted to identify trends and relationships using station 36, a sampling location in South SF Bay, as a reference point (Schoellhamer, this issue, Figure 3). The range of salinity in SF Bay varies from a standard ocean salinity of 33 to 35 near the Golden Gate Bridge to a freshwater salinity of zero in the Delta (Figure 1). The primary driving force of the salinity gradient in SF Bay is the freshwater flows into the Bay through the Delta that originate as snowmelt runoff and precipitation. For further information on salinity driving forces in the SF Bay, see Knowles (2002).

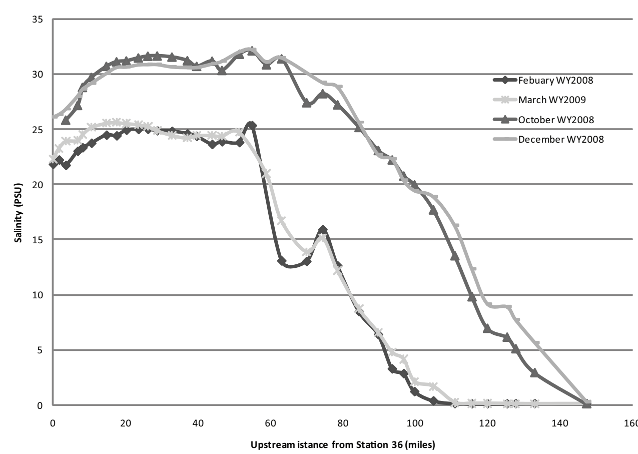

Figure 1 The monthly variability of salinity with space and time over water years 2008 and 2009. The 2-isohalene, X2, is shown as a salinity value of 2 on this figure.

For WY 2008 and 2009, the lowest salinity levels were recorded in June 2008 for most stations in the Central SF Bay through the Delta. The highest salinity levels were recorded in October 2008, which had maximum salinity in Central SF Bay (Figure 1). Water Years 2008 and 2009 were the second and third years of a drought (Maher, this issue), with time series data showing a cumulative increase in salinity. Location data shows that during the wet seasons, salinities were 22 PSU in WY 2008 and 19 PSU in WY 2009, not showing the cumulative increase.

During drought years less freshwater flows into the Bay, moving the marker of salinity intrusion, the 2-isohalene, as far as 20 km landward into the Delta , while in wet years, the 2-isohaline is pushed seaward into the bay. In WYs 2008 and 2009, the 2-isohaline moved from Northern Carquinez Strait in February 2008 and mid Suisun Bay in March 2009 (Figure 1). When the salinity moves into the Delta, there is a greater risk of entraining saltier water in the State and federal pumping facilities in the southern Delta, reducing the quality of exported water.

The drought in WY 2008 and 2009 caused an increase in salinity throughout SF Bay compared to the historical average salinity. According to salinity time series data collected hourly throughout the year, the salinity at Mallard Island (CDEC 2009), for example, was 25% higher than the historical average in WY 2008, and 50% higher than the historical average in WY 2009.

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Suspended Sediment in San Francisco Bay, Water Years 2008 and 2009

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Suspended sediment in San Francisco Bay and Delta generally followed historic trends during both water year (WY) 2008 and WY 2009. However, higher than historic suspended sediment concentration (SSC) peaks were observed during summer months in South, Central and San Pablo bays, while historic winter peaks were not observed in the Delta, Suisun Bay, Carquinez Strait and San Pablo Bay. Potential forcings include wind waves, precipitation, tidal currents, and gravitational circulation. Only wind-waves and precipitation are discussed herein.

Suspended sediment concentration values are based on optical backscatter (OBS) data collected by the U.S. Geological Survey's *RV Polaris* (USGS 2009). The OBS data were collected at least monthly and calibrated using discrete SSC values obtained through measurement of filtered and dried water samples. Optical backscatter is an inherently imprecise surrogate for SSC. (See Ganju et al. 2005 and Schoellhamer et al. 2007 for further discussion of SSC calibration for OBS data.)

Figures 1a–f thus represent surface SSC data from multiple sampling locations that have been compiled for each of six subembayments. (See Schoellhamer, this issue, Figure 3 for locations of subembayments.) Median values are plotted in lieu of mean values, which tended to be dominated by extreme events. Shading of historical data (1970 – 2009) in Figure 1 shows average behavior of SSC in each subembayment using the tenth percentile as the lower limit and the 90th percentile as the upper limit, while median values are shown with a solid white line. Water year 2008 and WY 2009 SSC are represented as monthly median values from a single cruise with linear interpolation between months as well as between months of missing data (January and April of WY 2008). Data for bottom (maximum depth) SSC were not available.

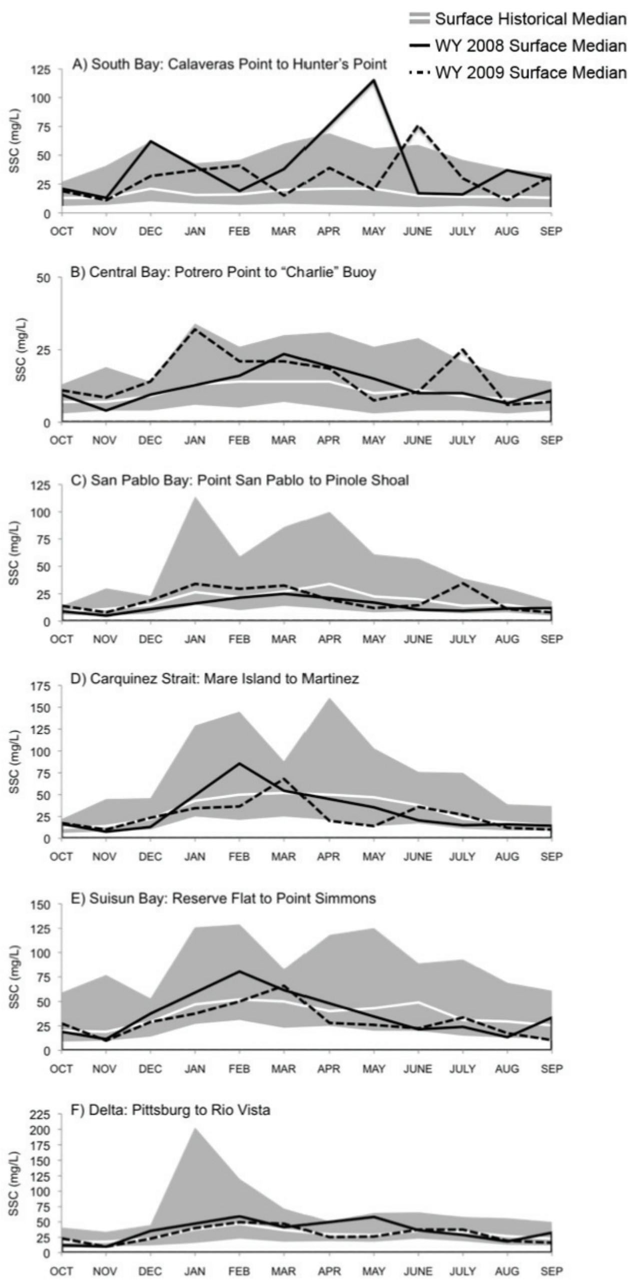

Figure 1 Median surface suspended sediment concentrations (SSC) in mg/L compiled for South Bay (A), Central Bay (B), San Pablo Bay (C), Carquinez Strait (D), Suisun Bay (E), and the Delta (F) plotted for WY 2008 (solid line), WY 2009 (dashed line), and historical (1970-2009). Historical data are shown as shaded area using the tenth percentile as the lower limit and the 90th percentile as the upper limit, while median values are shown with a solid white line.

It is likely that early summer winds drove a large resuspension event in South Bay during May of WY 2008. Given its shallow bathymetry, the South Bay, especially in its southern end, is subject to wind-wave resuspension of sediments (Schoellhamer 1996). The May 2008 event represents a significant (above 90th percentile) peak in SSC(Figure 1a), but does not represent an historic maximum. San Pablo Bay is also a shallow subembayment and, therefore, is also subject to wind-wave resuspension (Schoellhamer 2008). Summer winds likely drove a SSC peak in July of WY 2009 (Figure 1c) here as well. However, wind data analysis was not within scope of this article.

Lower than average precipitation (Maher, this issue), and inflow to the Bay from the Delta (Aiona, this issue), is reflected in winter SSC for northern subembayments, including San Pablo Bay, Carquinez Strait, Suisun Bay and the Delta itself, none of which experienced the same magnitude of SSC peaks typically seen during this time (Figures 1c, d, e, f). Although the Napa River, which feeds San Pablo Bay from the north, did experience nearly average flows (Sukardi, this issue, Table 1), the river's relatively small contributing basin area results in a proportionally small sediment supply.

The bulk decrease of suspended sediment supplied to the bay from Delta inflows has potentially adverse ramifications for maintenance of tidal wetlands, especially in Suisun and South Bays. Maintenance of near-shore elevations is further complicated by continued rise in tidally-averaged sea level (Cayan et al. 2008). Ongoing data collection is crucial to understanding how sediment can be supplied to these areas such that this critical habitat remains intact.

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Water Temperature in San Francisco Bay, Water Years 2008 and 2009

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Water temperature in San Francisco Bay is directly influenced by the regional climate through air temperature (Lehman, 2006). Water temperature data for San Francisco Bay is collected during monthly USGS cruises with the *RV Polaris* from South San Francisco Bay station 36, at Calaveras Point, to Rio Vista (USGS, 2009). For water years 2008 and 2009, February and June data are presented as representative data for the winter and summer seasons (Figures 1 and 2). The winter and summer seasons are considered November to April and May to October, respectively. The wet winter season encompasses the six wettest months of the year (Maher, Figure 1, this issue). Data is presented as a function of distance from South San Francisco Bay station 36 in order to display spatial variability of the data.

In February, the San Francisco Bay average temperature was 10.3º C in water year 2008 and 10.9º C in water year 2009 (Figures 1 and 2); while in June, the average temperature of San Francisco Bay was 18.8º C in water year 2008 and 19.7º in water year 2009. The June average water temperature is influenced by the cooler ocean water. During water year 2008 one recorded water temperature, in May in the Central Bay, was a minimum for historical water temperature measurements taken during May. During water year 2009 several historical monthly maximum water temperatures were measured; one location in both June and July in the Suisun Bay, two locations in September in the Delta, and three locations in August in the South Bay. The summer and winter seasons also encompass the warmer and cooler water temperatures (Figure 3). Water temperatures vary by about 10º C over the year.

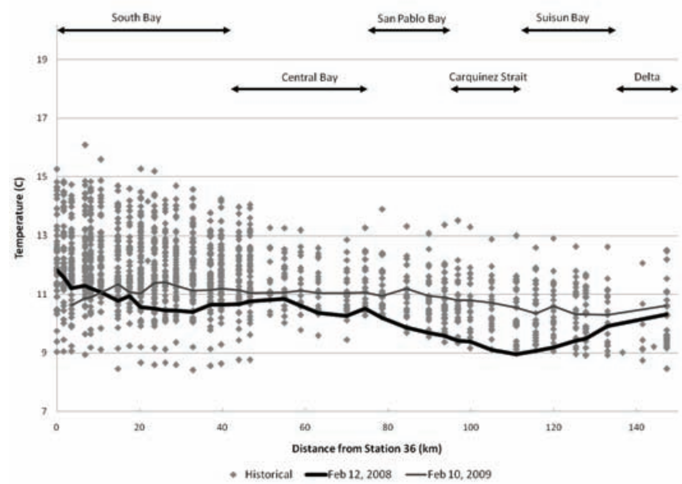

Figure 1 February water temperature, 1 m below the surface, in San Francisco Bay plotted as distance from Station 36, located at Calaveras Point.

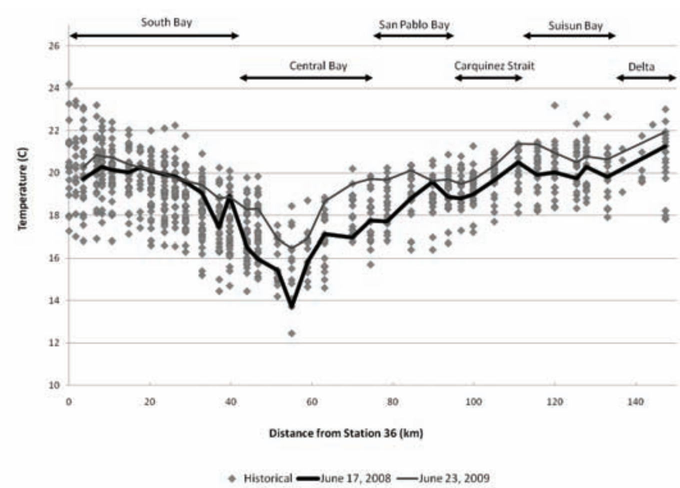

Figure 2 June water temperature, 1 m below the surface, in San Francisco Bay plotted as distance from Station 36, located at Calaveras Point.

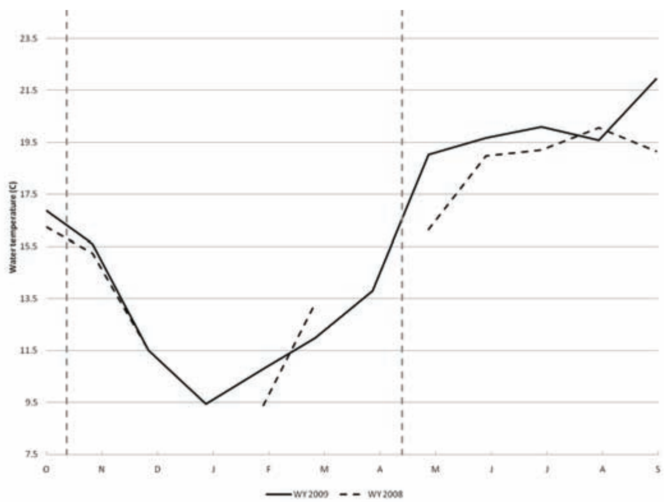

Figure 3 Water year 2008 and 2009 water temperature, 1 m below the surface, in Carquinez Strait, 99.77 km from Station 36 plotted monthly. The dashed vertical lines distinguish between the summer and winter season.

The influence of the Pacific Ocean is evident during the summer season (Figure 2). In water year 2008, the Central Bay was 7.5 º C cooler than the maximum Bay temperature and, in water year 2009 it was 5.5 º C cooler. During the winter season the water temperatures throughout San Francisco Bay are similar (Figure 1), so we do not see the dip in water temperature in the Central Bay like we do in the summer season.

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Chlorophyll in San Francisco Bay, Water Years 2008 and 2009

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Chlorophyll *a* concentration, an approximation used to measure phytoplankton biomass, is monitored throughout San Francisco Bay (SF Bay) because changes in phytoplankton biomass can adversely affect ecosystem function. Unusually low levels of phytoplankton may result in insufficient primary productivity to sustain the food web, while excessive phytoplankton, manifested in phytoplankton blooms, can lead to eutrophication (Cloern et al., 2006).

In contrast to most phytoplankton populations, which are limited by nutrient input, algal growth in the SF Bay is limited by sunlight (Jassby et al., 2002). (For information on other factors that influence SF Bay phytoplankton dynamics such as, suspended sediment, tidal mixing, etc., see Cloern et al. 2006). The SF Bay is considered a high nutrient low chlorophyll estuary because phytoplankton biomass is low most of the year, except during annual spring blooms (Cloern, 2001). Recently, a documented regime shift from 1999-2005 was presented by Cloern et al. (2006), where larger spring blooms, unusual blooms during other seasons, and an increase in the baseline minimum Chlorophyll *a* values were observed in the South Bay, Central Bay and San Pablo Bay. Here an analysis of Chlorophyll *a* concentrations in these three subembayments is presented for water year (WY) 2008 and WY 2009. Suisun Bay and the Sacramento River were not included because the purpose of this article is to provide a summary of highlights and not an in depth analysis.

Monthly data gathered by the United States Geological Survey (USGS), *RV Polaris*, can be analyzed to track the temporal and spatial changes in Chlorophyll *a* concentration throughout the SF Bay. Chlorophyll *a* concentration, measured in mg/m^3, is recorded at various stations from the South Bay to the Sacramento-San Joaquin Delta. In this analysis, stations 27, 18, and 13 were used as representative stations to capture changes in the South Bay, Central Bay and San Pablo Bay, respectively (see Schoellhamer, this issue, Figure 3 for locations of these subembayments). Station 27 was the same station used in Cloern et al. (2006) article. At station 27, for WY 2008 and WY 2009 there were small spring blooms (less than 20 mg/m^3), but they were not unusually large and no unusual off season blooms were observed (Figure 1A). Alternatively, the Chlorophyll *a* concentrations throughout the rest of both water years were relatively high compared to the historical values (Figure 1A).

In Figure 1B, there were two spring blooms that occured in May for WY 2008 and WY 2009 in the Central Bay. These blooms are small compared to blooms in the South Bay, but are large for the Central Bay. In fact, the largest spring bloom recorded for May at Station 18 was observed in WY 2008 (Figure 1B). Most of the Chlorophyll *a* concentrations are high compared to historical values, WY 2008 had a small increase in Chlorophyll *a* concentration in August and was at the top of the historical range for most other months that water year. Similarly, WY 2009 was at the top of the historical range for December, January, February, and August. These observations further support the trend of increasing Chlorophyll *a* concentration levels and high Chlorophyll *a* concentrations in non-spring seasons in the Central Bay.

San Pablo Bay does not normally experience the large blooms seen in other bays (Cloern et al., 2006), however a small increase in Chlorophyll *a* concentration was observed in May and August of WY 2009 and July of WY 2008 (Figure 1C). Chlorophyll *a* concentrations in San Pablo Bay are also consistently on the high end of historical concentrations, again consistent with observations that Chlorophyll *a* concentrations are increasing in the North Bay.

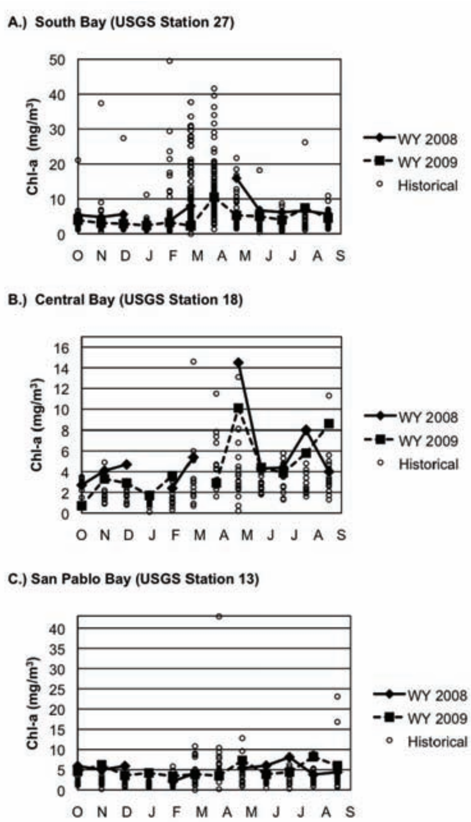

Figure 1 A Chlorophyll a concentrations in mg/m3 for WY 2008, WY 2009, and historical (1968-2009) for USGS station 27 in the South Bay. B.) Chlorophyll a concentrations in mg/m3 for WY 2008, WY 2009, and historical (1968-2009) for USGS station 18 in the Central Bay. C.) Chlorophyll a concentrations in mg/m3 for WY 2008, WY 2009, and historical (1968-2009) for USGS station 13 in the San Pablo Bay.

Although, no particularly large spring blooms nor many autumn or winter blooms were observed at these stations, they may have occurred at other stations in these subembayments. Other stations were not analyzed here, which is outside the scope of this article. All data is publicly available for USGS stations at the USGS Water Quality of the San Francisco Bay website (USGS 2009). This analysis is most useful in portraying the continued increased baseline Chlorophyll *a* concentrations that are occurring in all three subembayments. This increase may partially be attributable to the East Pacific "cold phase" that caused an increase in bivalve predators, which caused a decrease in the bivalve mollusk populations that are the main consumers of phytoplankton (Cloern et al., 2007). Another hypothesis is that phytoplankton biomass may be increasing in response to improved wastewater treatment processes, because pollutants can inhibit algal growth (Cloern et al., 2006). The trends observed in WY 2008 and WY 2009 in these three subembayments are aligned with Cloern et al.'s 2006 finding that the SF Bay is becoming an estuary with primary productivity more typical of temperate-latitude estuaries. To expose the causes for these observations, and other changes that are occurring in phytoplankton dynamics of the SF Bay, further trend analyses and studies should be considered.

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