■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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OF INTEREST TO MANAGERS

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This issue's IEP Newsletter contains updates on monitoring and research projects, as well as summaries of completed projects. The Quarterly Highlights has updates on Delta water project operations, delta smelt hatchery studies, status and trends of Chinook salmon and estuarine crabs, and the results of Delta juvenile fish monitoring surveys.

The delta smelt population has collapsed over the past decade, motivating researchers and resource managers to take actions to protect this imperiled species. The article by Kathleen Fisch and colleagues describes progress by the UCD Fish Conservation and Culture Lab and USFWS to develop refugial population as a safeguard against extinction. They report on their progress using modern genetic tools to develop a viable refugial population.

Sheila Greene reports relatively grim news on the status of Central Valley salmon. Salmon populations in the ocean catch and Central Valley fell to record levels in 2008, resulting in a well-publicized closure of commercial and recreational salmon fishing. News was somewhat brighter for crabs of the San Francisco estuary, where Kathy Hieb reports that the commercially and recreationally valuable Dungeness crab population improved relative to 2007. Two other important species, brown rock crab, and slender rock crab, also had relatively good years. Another positive trend is that the Chinese mitten crab, a major nuisance invader in the 1990s, has continued to steadily decline.

Also included in the Quarterly Highlights is a review by Paul Miklos on the results of Delta juvenile fish surveys. This sampling provides useful data on how the Delta fish communities have changed over time. For example, one of the longer term surveys is the beach seine, which in 2008 collected field data on over 120,000 fish and 68 species.

Tiffany Brown's article on phytoplankton represents a significant synthesis of how this key food web group has changed radically over the past 30 years. Key changes include a loss of diatoms, generally considered to be "high quality" food sources, and a striking increase in flagellates, which now dominate the phytoplankton community in some areas.

Brianne Noble's review of 2008 dissolved oxygen monitoring in the Stockton Ship Channel highlights a management issue that has often plagued the lower San Joaquin River during fall months. The 2008 dissolved oxygen levels were below the minimum targets set by the State Water Resources Control Board at six stations during two of ten sampling cruises.

The final article in this issue of the IEP Newsletter is by Paul Buchanan, who conducted continuous salinity and temperature sampling in San Francisco Bay during 2006 and 2007. This sampling provides high resolution data that is particularly useful for calibrating hydrodynamic models, and tracking long term changes caused by climate, inflow, and sea levels.

IEP QUARTERLY HIGHLIGHTS

DELTA WATER PROJECT OPERATIONS (April through June 2009)

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During April through June 2009, both the Sacramento River and San Joaquin River flows were low but at typical levels due to a dry spring with minimal precipitation (Figure 1). Sacramento flows ranged between 253 cms and 791 cms, and San Joaquin flows ranged between 27 cms and 65 cms. Net Delta Outflow Index (NDOI) flow patterns were similar to that of Sacramento River throughout this period. For a short period at the end of April, NDOI flow was greater than Sacramento flow, and peaked at a high of about 813 cms in early May due to precipitation events resulting in runoff (Figure 1). Thereafter, NDOI flows dropped as quickly as it increased a week before and then fell below Sacramento flow for the reminder of the period. Flows for NDOI ranged between 132 cms and 813 cms.

April through June 2009 export actions at State Water Project and Central Valley Project were operated to X2 standard and Vernalis Adaptive Management Plan (VAMP) and constrained by delta smelt concerns. During the months of April to June, the X2 objectives were set either at Chipps Island or Collinsville. A similar VAMP target 31-day period occurred during April 17 to May 17. For all three months, pumping at both facilities was constrained by the latest US Fish and Wildlife Services' Biological Opinion dated December 2008 (Figure 2).

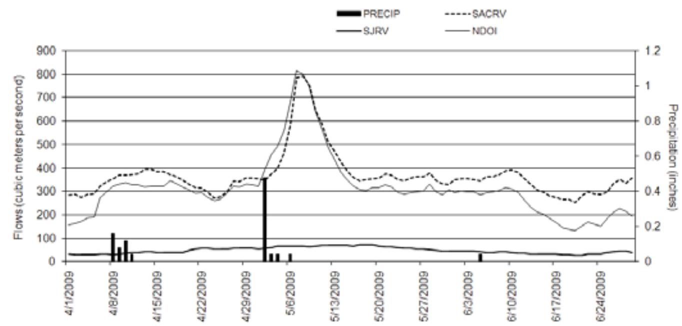

Figure 1 April through June 2009 Sacramento River, San Joaquin River, Net Delta Outflow Index, and Precipitation

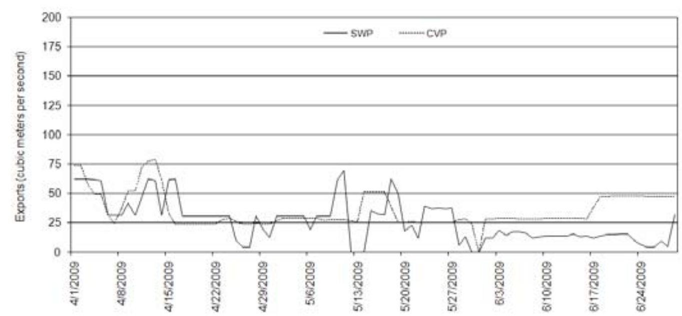

Figure 2 April through June 2009 State Water Project and Central Valley Project Pumping

Delta Smelt Refugial Population Development & Genetic Management- 2009 Season Summary

Kathleen Fisch, Theresa Rettinghouse, Luke Ellison, Galen Tigan, Joan Lindberg, & Bernie May (UC Davis), kmfisch@ucdavis.edu

A refugial population for the endangered delta smelt has been initiated at the Fish Conservation & Culture Laboratory (FCCL), a satellite facility of University of California, Davis (UC Davis), in collaboration with the

Genomic Variation Lab (GVL) at UC Davis, and the US Fish and Wildlife Service in response to a marked decline in delta smelt population abundance indices (Sommer et al., 2007, Baxter et al., 2007, and Feyrer et al. 2007). Over the past decade, the FCCL has developed successful rearing techniques for all life stages of delta smelt. Progeny of wild delta smelt (F_1 generation) from the FCCL were previously reared for research, until the annual collection of sub-adult broodstock was curtailed by regulatory agencies in 2007. To maintain a source of cultured fish and provide a safeguard against species extinction, a refugial population was initiated at the FCCL in the spring of 2008. Natural-origin (NOR) broodfish, birth year 2006 (BY2006), collected in the lower Sacramento River served to initiate the refugial population, the F_1 generation fish (BY2008) through random single-pair crosses of the NOR fish. In 2009, a genetically managed breeding plan was developed to designate single-pair crosses of the F_1 progeny (hatchery origin, HOR) to produce the BY2009 F_2 generation. Seventy wild delta smelt were collected from the lower Sacramento River in December 2008 to supplement the F_1 generation. Tagging methods were developed to uniquely identify individual fish, a critical component to the success of the program (K. Offill, US Fish and Wildlife Service, and FCCL staff, unpublished data).

The genetically managed breeding plan aims to maximize genetic diversity in the refugial population, within the constraints of the existing aquaculture facilities. Parents and progeny were genetically analyzed (GVL, UC Davis) to perform mean kinship selection and determine appropriate single-pair crosses. Additionally, pedigree analysis was used to ensure equal family contribution; and estimations of diversity statistics and relatedness were used to monitor the genetic integrity of the captive population.

The goal of the delta smelt refugial population is to provide a genetic bank of delta smelt that will safeguard the species in the event of extinction in the wild. The refugial population of delta smelt will be genetically managed and monitored to minimize genetic divergence from the wild population. Genetic diversity and effective population size will be maximized within the captive population, and genetic adaptation to captivity will be minimized by equalizing family contributions and using mean kinship selection. The delta smelt refugial population will be managed to be as similar to the wild population as possible, so in the event of species extinction in the wild, delta smelt may be reintroduced into the system contingent upon a thorough reintroduction and habitat remediation plan. Such a reintroduction, however, is not a current goal of the program.

2008 Season Summary

A total of 164 single-pair crosses were made in 2008 from the original 328 natural-origin (NOR) founding population, BY2006. These two-year old NOR delta smelt (captive one year) were randomly crossed (1 male x 1 female), ensuring each fish was used only once. For the F_1 generation (BY2008), embryos from each pair cross (PC) were volumetrically estimated (~1000 embryos/pair cross) and combined into multi-family groups (MFGs). The offspring of 3-6 pair crosses per multifamily group were initially combined into a MFG for larval rearing (in 70L or 130L tanks). Multifamily groups were further combined as necessary, due to tank limitations, into juvenile tanks (400L) and broodfish tanks (1000L) as the fish grew. Delta smelt were reared in intensive closed-system aquaculture. The final F_1 sub-adult broodfish were randomly selected and moved from the FCCL Aquaculture Facility into 18 of 20 broodfish tanks (1000-L) at the new FCCL Delta Smelt Refuge Facility. The final number of full-sibling families per tank ranged from 4-19, with 9.1 PCs per tank on average. A random sample of each of the 18 MFGs (75 fish/tank) were transported to Livingston Stone National Fish Hatchery (USFWS, Redding CA) as a back-up population in case of catastrophic loss.

Development of facilities, tagging methods, and the genetic program progressed simultaneously over the winter of 2008-09 in an effort to preserve the genetic material captured in the F_1 generation of delta smelt. The tight time schedule precluded advanced tagging and analysis of DNA prior to the spawning season. As a result, all work was accomplished in real-time during the spawning season.

Fish preparation for genetic analysis, 2/15/09-6/05/09

Broodfish were checked weekly or bi-weekly with light pressure to the abdomen to express gametes for fish exhibiting mature, or nearly-mature, gametes . Selected fish were fin-clipped for DNA processing, tagged for unique identification (visible-implant alpha-numeric tag, “VI-alpha tag”, inserted near dorsal fin; Northwest Marine Technology, Inc.), and sorted into two same-sex tanks for holding until genetic information on selected pair crosses became available (ca. 1-2 weeks). The number of fish sampled per tank was proportional to the number of full-sibling families held in each tank. Fish were lightly anesthetized (100mg/L, Tricaine Methane Sulphonate) for tag insertion and tissue sampling. Fin clips were divided into two pieces, one for DNA analysis and one which was preserved (95% ETOH). Fish with shed tags were retagged and their DNA was re-analyzed as needed. To help speed DNA processing, fin clip digestion was initiated (Proteinase K in ATL buffer, QIAGEN DNeasy Tissue Kit) and the digested tissue was shipped overnight for analysis (K. Fisch, GVL, UC Davis).

Genetic Analysis, 2/15/09-6/05/09

Genetic analysis of the refugial population was conducted in the Burton Laboratory, at Scripps Institution of Oceanography by K. Fisch, and fragment analysis was performed on an ABI Genetic Analyzer 3730 at the NOAA Southwest Fisheries Science Center. Twelve microsatellite markers, described in Fisch et al. (2009), were amplified for all individuals. The BY2006 NOR broodfish and BY2008 fish were genotyped and analyzed for genetic diversity, population structure, and pairwise relatedness estimates. Parentage analysis was conducted to assign BY2008 HOR individuals to BY2006 NOR pair cross.

Pair crosses of the BY2008 were determined using the method of Mean Kinship (MK) Selection (Ballou & Lacy 1995). Ritland's R, a pairwise relatedness estimator, was calculated among all of the BY2008 fish, the average relatedness value of each individual with all other individuals and itself was calculated, and the mean relatedness values were ranked in ascending order. Fish with the lowest relatedness values were selected as mates. The selection of these mates based on MK selection was cross-referenced with relatedness values calculated using the Allele Sharing Method (Bowcock et al. 1994).

Once an appropriate relatedness value was obtained for an MK selected pair, the parentage of the individuals in the pair was determined to ensure equalization of family representation. If an individual derived from a BY2006 NOR pair cross was over represented, the process was started over again, until an appropriate relatedness value was obtained, and the families were equally represented. This process was repeated for each recommended pair cross. Sixty-three wild fish were tagged, and 54 wild fish were successfully spawned to supplement the captive population. These fish were genotyped and included in the MK Selection procedure. Each wild fish was used only once, as was each captive fish.

Fish handling for genetically recommended pair crosses, 2/15/09-6/05/09

Once pair crosses were determined, the information was transferred to the FCCL. The broodfish for the recommended pair crosses were recovered from tanks (measured for weight and length) and mated (1:1, female:male) by manual expression of gametes. Wild fish (NOR, BY 2008) were crossed with the F_1 generation over the course of the breeding season. Embryos were combined after three days into a column-incubator (clear PVC pipe with upwelling fluidized sand bed). Usually 750 embryos for each of 8 pair crosses were combined in an incubator for a total of 6000 embryos per multi-family group. Upon hatching, larvae swim up and out of the incubator and flow into a retaining bucket; newly-hatched larvae are transferred water-to-water to rearing-tanks. The target population was 250 pair crosses from 500 individuals, with larvae reared in 32 tanks. A population of this size requires the use of both the FCCL's Aquaculture Facility and the Delta Smelt Refuge (Phase I) Facility (each FCCL facility has 20 larval and 20 juvenile tanks). Expected survival to adulthood is about 15 percent with anticipated yield of about 100 adults from each set of parents, or 800 individuals per multifamily group.

2009 Season Summary

Two-hundred eighty-eight unique pair crosses were made this season to obtain 254 successful pair crosses from 508 BY2008 F_1 generation broodfish and BY2008 NOR fish. These 508 fish represent 145 unique BY2006 single-pair crosses, and include 54 wild fish. Recovery rate of individuals deriving from each BY2006 pair cross (PC) in multifamily groups is presented in Table 1. To make these crosses, over 1400 of the BY2008 HOR F_1 generation broodfish were uniquely tagged, fin clipped, and genetically analyzed.

Parentage analysis of the BY2008 fish estimated parentage with 95% confidence for each individual. Crosses were made taking into account the number of times an individual from a particular BY2006 pair cross was used, in order to equalize family contribution. One-hundred forty-five BY2006 pair crosses were ultimately represented once all of the matings were made, each PC was represented an average of 3.1 times, with a range of 1-8 times (Table 1)

Nearly equal representation of each BY2006 pair cross was achieved in the F_2 generation (750 embryos/ pair-cross), with 13.8 percent having fewer than 750 embryos (Table 2). An estimated 184,000 embryos initiated the F_2 generation in 2009 (93% average hatch). The F_2 generation refugial population is currently being reared in 32 larval tanks (130L) housed in either the FCCL's Aquaculture Facility or the FCCL's Delta Smelt Refugial Population Facility (Phase I Facility). The number of alleles per locus, effective alleles per locus, observed and expected heterozygosities for the BY2006 NOR broodfish, BY2008 HOR F_1 broodfish, and BY2008 NOR wild fish are presented in Table 3. The number of alleles per locus ranged from 7 (HtrG116) to 36 (HtrG119), with an average of 24 alleles per locus for the BY2006 NOR broodfish. For the BY2008 HOR F_1 broodfish, the number of alleles per locus ranged from 14 (HtrG104) to 36 (HtrG127), with an average of 24 alleles per locus. The BY2008 NOR wild fish had an average of 16 alleles per locus, ranging from 3 (HtrG116) to 25 (HtrG127).

After calculating pairwise relatedness of the BY2006 population and calculating a cutoff value for full-siblings, an average pairwise relatedness of 0.4 indicated a full sibling relationship. Only 6 out of the 164 pair-crosses made from the BY2006 broodfish fell above this value, and the offspring from these pairs were avoided when recommending pair crosses among the BY2008 fish. Relatedness values of BY2008 fish ranged from 0 to 0.3, and no pairs over 0.4 were recommended. A dendrogram was created with 30 BY2006 fish and the four full sibling families that were used to determine the cutoff relatedness value, to graphically depict the difference between full sibling and unrelated individuals (Figure 1).

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Table 1 Full-sibling families of delta smelt, derived from a single pair cross (PC, or mating of birth year 2008 fish), were combined and reared together in multi-family groups (MFG, Tank #). Individuals from nearly every PC within a multi-family group were recovered (# PCs recovered) to make unique pair crosses with fish from other PCs (# PCs Crossed) during the 2009 spawning season.

MFG (Tank #)	# PCs/MFG	# PCs Recovered	# PCs Crossed
1	5	5	5
2	10	9	9
3	12	12	11
4	10	9	8
5	13	13	12
6	4	4	4
7	19	19	17
8	10	10	10
9	11	10	9
11	10	9	9
12	12	10	10
13	10	7	6
14	5	5	5
15	6	5	4
16	5	5	5
17	2	1	1
18	16	16	16
19	4	4	4
Totals	164	153	145

Table 2 Delta smelt refugial population spawning summary. F1-generation delta smelt were spawned by manual expression of gametes (1 male x 1 female, 1 pair cross, PC) and eggs (usually 750) from each PC were combined to form a multi-family group (MFG) for rearing. Wild delta smelt (Wild) were crossed with the F1-generation throughout the season. Thirty-two total multi-family groups were formed.

2009 Spawn date	#PCs per MFG	# of Wild PCs in MFG	MFG ID#	# eggs/ MFG
2/10-2/23	7	3	MF1	7000
2/27-3/5	8	7	MF2	5725
3/5-3/9	5	2	MF3	3531
3/13	8	2	MF4	6000
3/13-3/17	9	3	MF5	6700
3/20-3/26	8	1	MF6	5314
3/23	8	1	MF7	6000
3/30	8	3	MF8	6000
3/30-4/3	6	0	MF9	3887
4/3	8	2	MF10	6000
4/6-4/13	8	3	MF11	6000
4/10	8	2	MF12	6000
4/10-4/13	11	0	MF13	6234
4/13	8	2	MF14	6000
4/14-4/16	8	4	MF15	5800
4/16	8	2	MF16	5688
4/21	8	0	MF17	6000
4/21	8	1	MF18	6000
4/21-4/24	8	0	MF19	5850
4/23	8	1	MF20	5888
4/23	8	3	MF21	5918
4/23-4/24	8	1	MF22	5950
4/24-5/1	8	1	MF23	6000
4/28	8	1	MF24	6000
4/28	8	2	MF25	5957
5/4-5/7	9	3	MF26	4311
5/7-5/11	8	0	MF27	6000
5/11	8	0	MF28	6000
5/15	8	1	MF29	6000
5/15	9	1	MF30	6178
5/18-5/29	7	1	MF31	5250
5/26-6/5	7	1	MF32	4875
Totals	254	54		184056

Table 3 Diversity statistics for birth year 2006 natural-origin broodfish, birth year 2008 hatchery-origin F1 generation broodfish, and birth year 2008 natural-origin broodfish, including sample size (N), number of alleles per locus (A), effective alleles per locus (AE), and observed (HO) and expected heterozygosities (HE).

BY2006 NOR					
Locus	**N**	**A**	**AE**	**HO**	**HE**
HtrG103	145	20	8.4	0.75	0.88
HtrG104	299	10	2.0	0.51	0.51
HtrG109	88	15	8.7	0.82	0.89
HtrG114	314	28	16.4	0.93	0.94
HtrG115	306	30	14.3	0.92	0.93
HtrG116	209	7	2.3	0.59	0.56
HtrG117	251	22	11.5	0.91	0.91
HtrG119	290	36	20.5	0.93	0.95
HtrG120	286	18	5.4	0.85	0.81
HtrG123	304	34	17.3	0.88	0.94
HtrG127	298	33	24.1	0.96	0.96
HtrG131	212	30	18.3	0.93	0.95
BY2008 HOR F1					
Locus	**N**	**A**	**AE**	**HO**	**HE**
HtrG103	389	18	8.3	0.80	0.88
HtrG104	286	14	2.3	0.54	0.56
HtrG109	337	18	10.0	0.86	0.90
HtrG114	365	28	17.8	0.89	0.94
HtrG115	406	25	15.0	0.92	0.93
HtrG116	304	15	2.6	0.64	0.61
HtrG117	419	22	12.4	0.85	0.92
HtrG119	301	33	21.3	0.88	0.95
HtrG120	380	20	5.8	0.88	0.83
HtrG123	401	31	17.9	0.90	0.94
HtrG127	400	36	25.5	0.95	0.96
HtrG131	253	29	18.2	0.94	0.94
BY2008 NOR					
Locus	**N**	**A**	**AE**	**HO**	**HE**
HtrG103	36	15	8.7	0.92	0.89
HtrG104	34	6	2.1	0.62	0.53
HtrG109	22	11	7.2	0.73	0.86
HtrG114	39	22	16.7	0.85	0.94
HtrG115	39	16	12.7	0.85	0.92
HtrG116	20	3	2.0	0.55	0.51
HtrG117	44	14	9.4	0.80	0.89
HtrG119	24	21	14.6	0.92	0.93
HtrG120	48	15	5.1	0.83	0.81
HtrG123	52	21	15.0	0.92	0.93
HtrG127	40	25	20.1	0.95	0.95
HtrG131	19	17	14.4	1.00	0.93

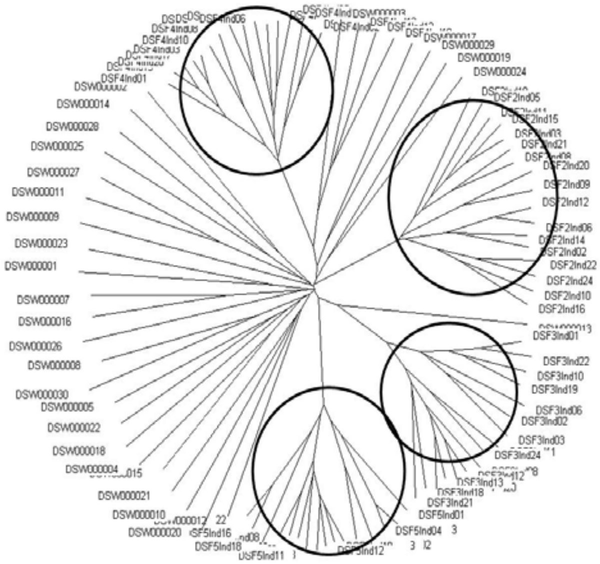

Figure 1 Relatedness dendrogram of 30 birth year 2006 natural-origin fish and four birth year 2008 hatchery-origin F^1 full-sibling families. Full-sibling families circled.

Conclusion

We determined diversity statistics and relatedness estimates for the BY2006 NOR founding population of 328 natural-origin individuals. These fish had low levels of relatedness and were genetically diverse, making them excellent candidates to initiate the refugial population in order to maintain genetic diversity.

Allelic diversity of the BY2008 HOR F_1 generation was not significantly different than that of the BY2006 NOR fish, indicating no loss of genetic diversity between the wild broodfish and the F_1 generation.

Developing embryos, larvae, and/or juveniles from full-sibling families were combined into multi-family rearing groups (from 4-19 full-sibling families per group) as standard operating procedure for intensive culture of delta smelt at the FCCL. At the onset of the study, it was unknown whether all full-sibling families comprising the multi-family groupings would still be present in the adult population. Resolving this unknown was fundamental to species management and facility design using intensive-culture techniques. Only eleven out of 164 BY2006 full-sibling families were not recovered in the BY2008 generation, supporting the practice of combining individual families into multi-family rearing groups, as 93 percent of the families were recovered.

Two-hundred fifty-four successful BY2008 crosses were made this season, which exceeded the goal of an effective population size of 500 for the F_1 generation. These BY2008 pair crosses represent 145 unique BY2006 pair crosses, so the majority of the genetic information from the founding population has been retained.

Prior to spawning season 2010, spawning and genetic management techniques will be refined. Juvenile delta smelt housed in 32 tanks will be randomly sampled and combined into broodfish tanks with a target stock density of 350fish/1000-L tank heading into the spring spawning season. The majority of the fish tagging will be conducted in the fall this year and fin clips will be processed for genetic analysis, well ahead of the 2010 spawning season. After genetically analyzing the sampled fish and assessing sex ratios, another smaller tagging session may be warranted. Wild fish will be collected in the fall to supplement the F_2 generation. We will again aim for an effective population size of 500 individuals in the F_2 generation.

The FCCL has proposed a Phase II expansion of the Delta Smelt Refuge Facility to accommodate an effective population size of 500 individuals within the Facility. Currently, the refugial population is reared at both the Refuge site and at the FCCL's Aquaculture and Research Facility – creating inefficiencies in management, biosecurity problems, and limiting tanks for research. The USFWS has been looking to build a multi-species facility for imperiled Delta fish species, but the facility is still in the planning stages and is not anticipated to go online for 5-7 years. As a result, it is now prudent to create a secure facility for the endangered delta smelt, such as the proposed expansion of the Delta Smelt Refuge Facility. The expanded FCCL Facility can act as the secondary, backup facility to the larger USFWS' facility once it is completed.

In the second year of development of the delta smelt refugial population, we have been successful in reaching our goal of retaining genetic diversity from the founding population, supplementing the captive population with wild fish to prevent genetic divergence from the wild population, and maintaining an effective population size of over 500 individuals. With continued financial support, for both the FCCL and the genetic research, we will be able to continue to effectively manage the delta smelt refugial population as a safeguard against extinction in the wild.

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CENTRAL VALLEY CHINOOK SALMON CATCH AND ESCAPEMENT

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In 2008, the ocean catch of Sacramento River Fall Chinook salmon south of Cape Falcon was the lowest on record because the Pacific Fisheries Management Council (PFMC) closed commercial and recreational fishing due to the low number estimated to return.

The total escapement of Sacramento Valley Chinook salmon was also the lowest on record. Spring-run escapement to Mill and Deer creeks, and winter-run escapement to the Sacramento River were all low.

Sacramento River Fall Chinook ocean harvest index and ocean catch

The PFMC sets spawner escapement goals for Sacramento River system fall-run Chinook and Klamath River fall-run Chinook. They also develop harvest regulations to protect listed Central Valley winter and spring-run Chinook. These include setting minimum size limits, gear restrictions and fishing-season restrictions for fishing south of Cape Falcon.

The PFMC's Sacramento River Fall Chinook harvest index (SI) is an approximate harvest rate. The SI Harvest Index is calculated by dividing the Sacramento River Fall Chinook ocean catch south of Cape Falcon and the inland river catch by the catch plus escapement. In 2008, the SI Harvest Index was the lowest on record due to the lowest catch (no season) and escapement on record (Figure 1). The estimated SI escapement decreased to approximately 66,300 spawners in 2008.

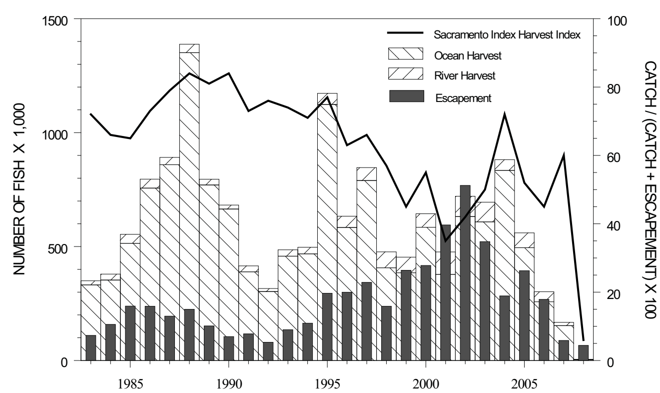

Figure 1 Pacific Fisheries Management Council Fall-Chinook salmon ocean catch, the Sacramento River Fall-Chinook adult spawner escapement, and the Sacramento Index Harvest Index, 1970-2008

California, Oregon and Washington 2008 ocean catches decreased from 2007 catches. For the California and southern Oregon commercial fishery in 2008, the CPUE (fish/boat day) decreased to 3.5, the lowest on record (Figure 2). The mid to northern Oregon and Washington CPUE also decreased to 7.5, the lowest since the early 1990s.

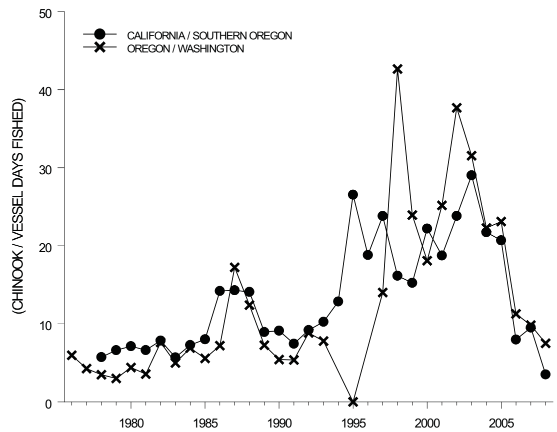

Figure 2 Commercial troll Chinook salmon catch per unit effort (estimated total number of fish caught / total number of boat days fished) in California, Oregon, and Washington, 1970-2008

Central Valley Fall-run Chinook Escapement

Escapement data reported to the PFMC are partitioned into "natural" and "hatchery" categories. Natural escapement includes all fish returning to spawn in natural areas; these fish are of both natural and hatchery origin. Available data indicate that hatchery-produced fish constitute a majority of the natural fall-run Chinook spawners in the Central Valley (PFMC 2007). Hatchery escapement includes all fish returning to the hatcheries; these fish are also of both natural and hatchery origin. These terms, as defined here, are used throughout this paper and in each of the figures.

In 2008, a spawner escapement goal of 122,000 to 180,000 Sacramento River system fall-run Chinook (hatchery and natural adults combined) guided PFMC management for this stock. The estimated number of spawners was the lowest on record, 70,325 (Figure 3).

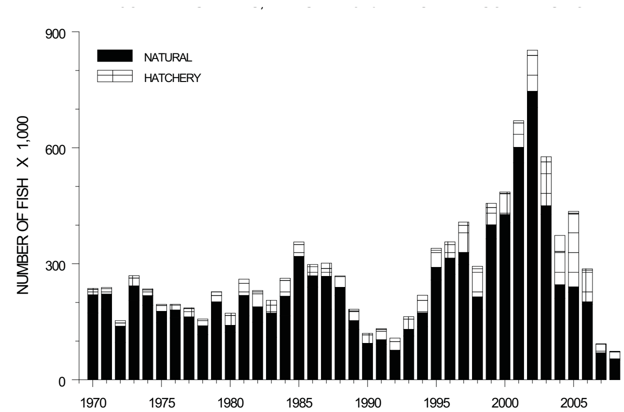

Figure 3 Annual natural and hatchery fall-run Chinook escapement to the Sacramento River and major tributaries, 1970-2008

Natural spawner escapement to the Sacramento Valley decreased from about 700,000 in 2002 to about 51,100 in 2008, the lowest on record (Figure 4). Natural spawner escapement in the American River decreased from about 180,000 in 2001 to about 1,884 in 2008, the lowest on record (Figure 4). In the Feather River, the estimated escapement decreased from about 180,000 in 2001 to about 8,200 in 2008, the lowest on record (Figure 4). The estimated Yuba River fall-run escapement decreased from 28,000 in 2003 to about 3,600 in 2008, and was the second lowest on record. The lowest on record was in 2007 (Figure 4).

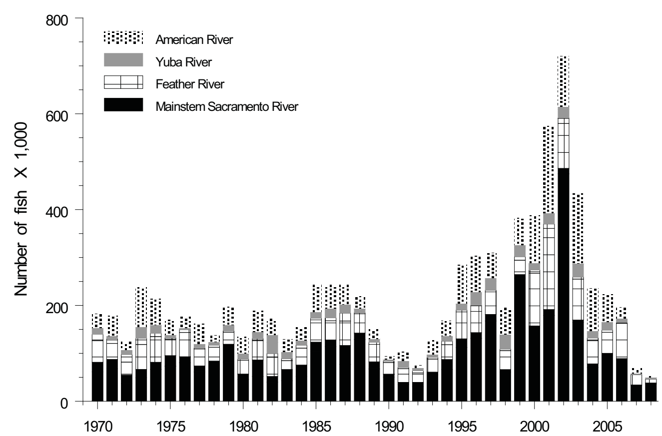

Figure 4 Annual natural fall-run Chinook escapement to the mainstem Sacramento River and major tributaries, 1970-2008

On the San Joaquin River system the estimated natural spawner escapement decreased from about 40,000 in 2000 to 2,466 in 2008, but was not the lowest on record (Figure 5). The lowest San Joaquin River natural spawner escapement occurred in the early 1990's.

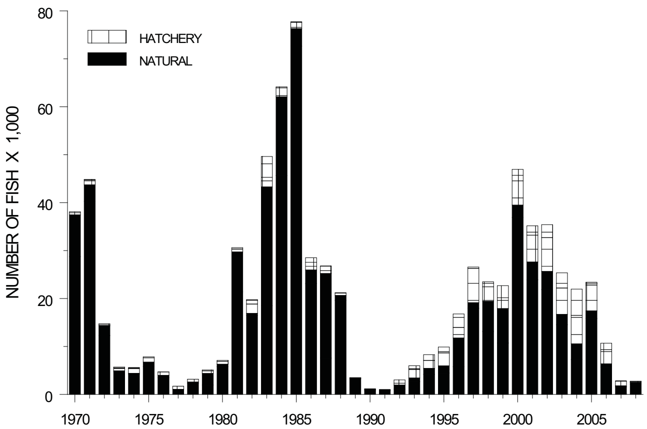

Figure 5 Annual natural and hatchery fall-run Chinook escapement to the San Joaquin River system, 1970-2008

Sacramento River system spring-run Chinook escapement

The number of natural spawners on Mill Creek decreased from about 1,600 in 2002 to 362 in 2008 (Figure 6). In 2008, the escapement to Deer Creek decreased to approximately 140 natural spawners, the fourth lowest on record (Figure 6).

The Butte Creek escapement decreased from about 10,600 in 2005 to 3,900 in 2008, based on the snorkel survey methodology, but remained well above escapement levels of the 1980s and early 1990s (Figure 6). The estimated escapement to Butte Creek continues to surpass the other spring-run tributaries and the mainstem Sacramento River (Figure 6).

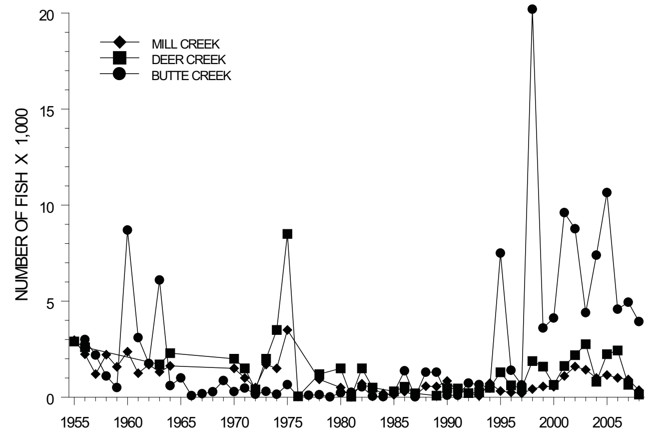

Figure 6 Annual spring-run Chinook escapement to Mill, Deer, and Butte creeks, 1955-2008

Winter-run escapement to the Sacramento River below Keswick Dam

DFG has been using mark-recapture carcass survey methodology to estimate winter-run Chinook escapement since 2001. The estimated in-river escapement of winter-run Chinook was 2,850 in 2008, but was not the lowest on record (Figure 7). The escapement was the lowest in the early 1990s (Figure 7).

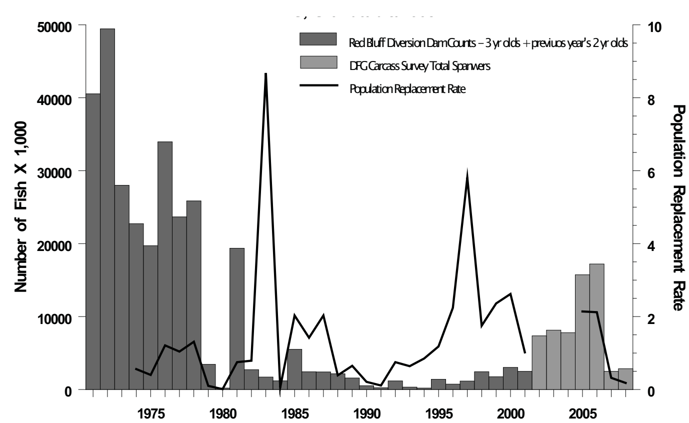

Figure 7 Annual winter-run Chinook escapement to the upper Sacramento River based on Red Bluff Diversion Dam data from 1980 to 2001 and DFG carcass survey data from 2002 to 2008, and the population replacement rates

Most of the data presented in this article is published in the PFMC's *Review of the 2007 Ocean Salmon Fisheries* and the PFMC's 2008 Preseason report. A copy of the report is available by calling (503) 820-2280 or on-line at www.pcouncil.org. I thank Colleen Harvey Arrison (DFG) for providing the spring-run Chinook escapement data for Mill and Deer creeks and Tracy McReynolds (DFG) for providing the spring-run Chinook escapement data for Butte Creek.

References

Pacific Fishery Management Council. 2007. Review of 2006 Ocean Salmon Fisheries. (Document prepared for the Council and its advisory entities). PFMC, 7700 NE Ambassador Place Suite 101, Portland, Oregon, 97220-1384. Report is also located at: http://www.pcouncil.org/salmon/salsafe08/salsafe08.html

2008 Status and Trends Report Common Crabs of the San Francisco Estuary

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This report summarizes abundance trends and distributional patterns of the most common *Cancer* crabs and *Eriocheir sinensis,* the Chinese mitten crab, through 2008 in the San Francisco Estuary. Most of the data is from the San Francisco Bay Study (Bay Study) otter trawl, with additional *E. sinensis* data from UC Davis Suisun Marsh otter trawls and the CVP and SWP fish salvage facilities.

Cancer crabs

Cancer magister, the Dungeness crab, is a valuable sport and commercial species that reproduces in the ocean in winter and rears in nearshore coastal areas and estuaries. Small juvenile *C. magister,* 5-10 mm carapace width (CW), immigrate to San Francisco Estuary in spring, rear for 8-10 months, and then emigrate from the estuary when approximately 100 mm CW. Estuary-reared crabs reach legal size at the end of their third year, 1 to 2 years before ocean-reared crabs. This faster growth is hypothesized to be due to warmer temperatures and more abundant prey resources in the estuary (Tasto 1983).

The 2008 abundance index of age-0 *Cancer magister* was slightly higher than the 2007 index (Figure 1), but still much lower than the 2001 to 2004 indices. When larval *C. magister* were hatching and rearing in the Gulf of the Farallones in winter 2007-08, sea surface temperatures (SSTs) were 1 to 2°C cooler than the long-term average (see the Physical Settings section of the Fishes Status and Trends report). Infrequent winter storms should have resulted in a weak northward-flowing Davidson Current and retention of *C. magister* larvae in the Gulf of the Farallones. This combination of favorable SSTs and nearshore surface currents was expected to increase larval survival and retention, and therefore age-0 crab abundance. However, *C. magister* juvenile abundance was lower than expected in 2008. Relatively strong upwelling in March and April 2008, before the normal transition to upwelling season, may have caused a portion of the year class to settle too far offshore to enter the San Francisco Estuary for rearing. In addition, small juvenile *C. magister* entered the estuary very late in 2008, with the majority in June. This late entry was also probably due to the strong March and April upwelling; the portion of the year class that did settle nearshore were far offshore as late-stage larvae and megalopae, and therefore required more time to return nearshore and settle.

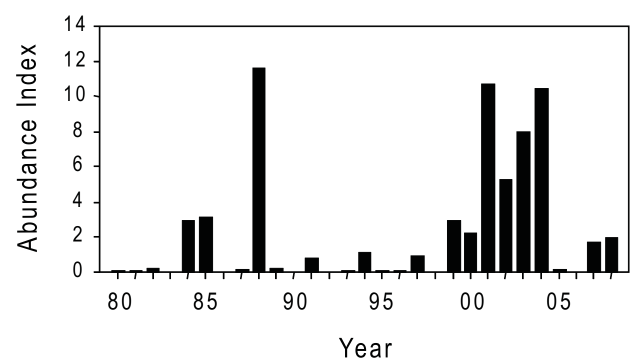

Figure 1 Annual abundance indices of age-0 *Cancer magister*, Bay Study otter trawl, May to July, 1980-2008

The strong *C. magister* year classes earlier this decade were reflected in the commercial landings. Central California landings surpassed 5 million pounds annually from the 2002-03 to 2006-07 fishing seasons, and approximately 3.4 million pounds were landed in 2007-08, but only 0.86 million pounds were landed in the 2008-09 season through mid June 2009 (B. McVeigh). The strong year classes of estuary-reared crabs from 2001 to 2004 reached legal size and entered the fishery consecutively from the 2003-04 to 2006-07 fishing seasons, while primarily the weak 2005 and 2006 year classes contributed to the fishery in 2008-09.

Age-0 *C. magister* were collected from South Bay, near San Leandro, to western Suisun Bay in 2008. A distinct group of age-0 crabs migrated upstream to rear, ultimately in eastern San Pablo Bay, Carquinez Strait, and western Suisun Bay. Another group of crabs appeared to remain in Central Bay or was composed of crabs that moved between the ocean and Central Bay. Since 1999, there has been a general trend of more age-0 *C. magister* collected in Central Bay in summer and fall, especially at the Alcatraz Island station. In 2008, 49% of the age-0 catch from June to December was from the Alcatraz Island station. By December, the group that reared upstream had a mean size of 90 mm CW, while the group that remained in Central Bay had a mean size of 57 mm CW.

Just over 70% of *C. magister* were collected at channel stations in 2008, although this was largely driven by the Alcatraz Island station collections. Excluding this station, 60% of the *C. magister* <50mm CW (n=226) were collected at shoal stations, while 76% of the crabs ≥50 mm CW (n=75) were collected from channel stations.

The following 3 *Cancer* species reproduce in both the nearshore ocean and higher salinity areas of the estuary in winter. Therefore, estuary and ocean conditions may control larval survival and year-class strength.

Cancer antennarius, the brown rock crab, is common to rocky areas and other areas with structure. It and *C. productus*, the red rock crab, are targeted by sport anglers fishing from piers and jetties in the higher salinity areas of the estuary. In 2008, the age-0 *C. antennarius* abundance index was similar to the 2004 index, the record high for the study period (Table 1). *C. antennarius* abundance in the estuary appears to be partially related to ocean temperatures, with the highest abundance often in years with the coldest winter-spring SSTs. In 2008, peak abundance occurred in July and August, when a large number of small juveniles <20 mm CW were collected.

In 2008, *C. antennarius* was collected from South Bay, near the Dumbarton Bridge, to upper San Pablo Bay. This was a slightly broader distribution than in 2007. The highest age-0 catches were from the channel station near Hunter's Point in South Bay and the shoal stations off Alameda, near Berkeley Marina, and just downstream of Point Pinole. All but 2 age-1+ *C. antennarius* were collected at the Hunter's Point and Alcatraz Island channel stations in 2008. The smallest age-0 crabs (<10 mm CW, n=107) were evenly distributed between the channel and shoal stations and 68% of the crabs 10-34 mm CW (n=458) were collected from shoal stations. However, all but 2 of the *C. antennarius* ≥35 mm CW (n=36) were collected at channel stations.

Table 1 Annual abundance indices of age-0 Cancer crabs from the Bay Study otter trawl, 1980-2008. The index period is from May to October for *C. antennarius* and *C. gracilis* and from April to October for *C. productus*.

Year	*C. antennarius*	*C. gracilis*	*C. productus*
	age-0	age-0	age-0
1980	102	17	0
1981	76	152	6
1982	0	87	4
1983	28	151	4
1984	50	154	41
1985	20	216	38
1986	0	59	89
1987	71	93	79
1988	21	223	138
1989	29	203	30
1990	113	159	160
1991	171	656	128
1992	60	371	62
1993	398	616	71
1994	*603*	*1,017*	*166*
1995	*367*	*227*	*40*
1996	*1,126*	*411*	*198*
1997	*351*	*1,131*	*86*
1998	*718*	*1,621*	*149*
1999	*90*	*222*	*249*
2000	*849*	*251*	*93*
2001	*276*	*1,921*	*142*
2002	*119*	*796*	*238*
2003	*424*	*522*	*140*
2004	*1,765*	*112*	*139*
2005	*144*	*132*	*57*
2006	*46*	*81*	*71*
2007	*987*	*418*	*58*
2008	*1,703*	*543*	*50*

Cancer gracilis, the slender crab, is the smallest of the 4 *Cancer* crab species reported, rarely exceeding 85 mm CW. It is common in open sandy or sand-mud habitats rather than rocky areas; researchers have hypothesized that because of its small size it cannot compete with the rock crabs for the more “preferred” protected habitats with structure. The 2008 abundance index of age-0 *C. gracilis* increased somewhat from 2007 and was the highest index since 2002 (Table 1). Age-0 abundance peaked in June and November; both peaks were comprised of crabs from 25-39 mm CW. Most small, recently settled juveniles <20 mm CW were collected in March and April and were likely also abundant in May (not sampled) based on the June size frequency.

C. gracilis was collected from the shoal station near Candlestick Park in South Bay to lower San Pablo Bay in 2008, with 98% (n=504) of all crabs collected from Central Bay. The highest catches were from the channel stations just south of the Bay Bridge and near Angel Island and the shoal stations near Treasure Island and at Southampton Shoal. The smallest *C. gracilis* (<20 mm CW) slightly favored the channels, while crabs 20-49 mm CW were collected at the channel and shoal stations at almost the same frequency. In contrast, 71% of *C. gracilis* >49 mm CW (n=156) were collected at channel stations.

Cancer productus is overall the least common of the 4 *Cancer* crabs collected by the otter trawl in the estuary, reflecting its strong preference for rocky intertidal and subtidal marine habitats not sampled by the trawl rather than its actual abundance. In a survey conducted by CDFG from 1982 to 1994 with baited ringnets at piers, it was the second most common *Cancer* crab in the estuary. The 2008 age-0 *C. productus* abundance index decreased slightly from the 2007 index, resulting in 4 consecutive years of relatively low abundance (Table 1). Abundance peaked in October, with no age-0 crabs collected from February through July. Catch of the smallest *C. productus* was very scattered in 2008, with several collected in January, October, and December. It is not unusual for recruitment of *C. productus* to be sporadic in the San Francisco Estuary.

C. productus was collected from near Hunter's Point in South Bay to western San Pablo Bay in 2008, with 95% (n=40) collected from Central Bay. Deeper water was also favored, with 98% collected from channel stations. It has been reported that juvenile *C. productus* settle on spatially complex substrates and move to areas with more open space as they grow (Orensanz and Gallucci 1988), but our sampling did not detect a seasonal movement in 2008. Most likely we collected too few of the smallest crabs to detect a pattern.

Ocean conditions, with cooler winter temperatures and fewer storms, should have been favorable for recruitment of *C. antennarius, C. gracilis, and C. productus* to the estuary in 2008. However, only *C. antennarius* abundance increased substantially and *C. gracilis* abundance moderately. Slight differences in larval hatching and development may have contributed to the recruitment patterns, especially with the unusually strong upwelling in March and April 2008 that would have transported planktonic larvae offshore. A large number of small juvenile *C. antennarius* entered the estuary in July and August 2008, when upwelling was somewhat weaker. Most small juvenile *C. gracilis* entered the estuary from March through May, a period with some of the strongest upwelling indices for the year. If most *C. gracilis* larvae settled from March to May of 2008, a large proportion of the small juveniles were likely offshore, not near the mouth of San Francisco Estuary.

Eriocheir sinensis

Eriocheir sinensis, the Chinese mitten crab, was first collected in the estuary in the early 1990s, but likely introduced to South Bay in the late 1980s. After several years of rapid population growth and expanding distribution, the *E. sinensis* population peaked in 1998 (Table 2). All data sources indicate that the population has steadily declined since 2001. In fall and winter 2008-09, no adult *E. sinensis* were collected at either fish facility or by the San Francisco Bay Study and UC Davis Suisun Marsh (T. O'Rear, personal communication) trawl surveys in the northern estuary. There were also no reports of adult *E. sinensis* in South Bay trawls (M. Seiff, personal communication), the second consecutive year that none were collected there.

Table 2 Annual adult *Eriocheir sinensis* CPUE and estimated total salvage, 1996-2008. Bay Study CPUE is from October (year) to March (year+1), Suisun Marsh CPUE is from July to December, and Central Valley Project (CVP) and State Water Project (SWP) fish facilities salvage is from September to November.

Year	Bay Study CPUE	Suisun Marsh CPUE	CVP salvage	SWP salvage
	(#/tow)	(#/tow)	est. total	est. total
1996	0.02	0.00	50	
1997	0.34	0.07	20,000	
1998	2.51	0.89	750,000	
1999	0.96	1.08	90,000	34,000
2000	0.93	0.02	2,500	4,700
2001	3.25	0.17	27,500	7,300
2002	1.07	0.04	2,400	1,200
2003	0.15	0.00	650	90
2004	0.12	0.00	750	370
2005	0.01	0.00	0	18
2006	0.00	0.00	12	0
2007	0.00	0.00	0	0
2008	0.00	0.00	0	0

There were also no public reports of *E. sinensis* sightings made to the toll-free reporting line, the web page reporting form, or from the postage-paid mailer in 2008 (J. Thompson, personal communication). One impact of *E. sinensis* commonly reported is bait stealing from sport anglers in the delta and Suisun and San Pablo bays. From such public reports, we may learn of an increase in the *E. sinensis* population before it is detected by our surveys.

What controls the *E. sinensis* population in the San Francisco Estuary is still not well understood, although winter and spring water temperatures and outflow are hypothesized to control survival and growth of larvae and timing of juvenile settlement (Rudnick et al. 2005). The planktonic larvae hatch in winter in the lower estuary and have minimal or no retention mechanisms (Hanson and Sytsma 2008), so high freshwater outflow can readily transport them from the estuary to the ocean. Based on laboratory growth experiments, successful development of *E. sinensis* larvae from hatching to metamorphosis occurred only at temperatures ≥12°C, with the highest survival at 18°C (Anger 1991). Under these circumstances, ocean conditions may control larval survival in years with high freshwater outflow, with ocean temperatures often more favorable than lower San Francisco Estuary temperatures (Figures 2A and 2B). The largest *E. sinensis* year classes possibly recruited from 1995-1998, when a series of El Niño events resulted in mean monthly SSTs consistently >12°C during the larval development period. There was also very high freshwater outflow these years that would have transported *E. sinensis* larvae from the estuary to the coastal ocean (Figure 2C). Late winter and spring SSTs have been <12°C in the Gulf of the Farallones most years since 1998 (Figure 2B). In 2006, the most recent year with high outflow, mean SSTs were near 12°C and mean lower estuary temperatures were near 11.4°C.

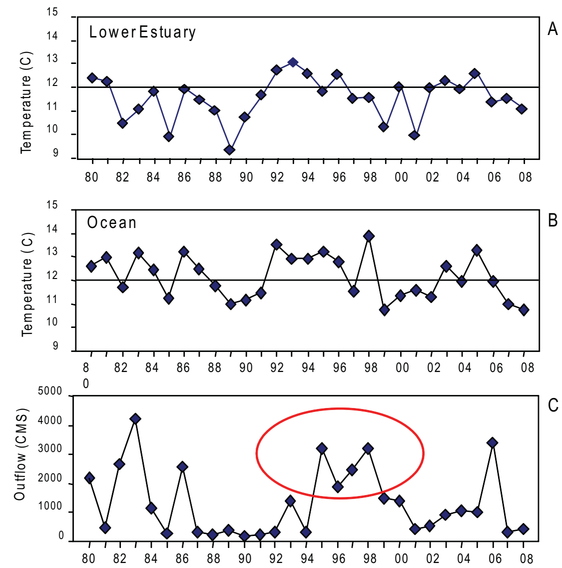

Figure 2 Annual physical data related to *Eriocheir sinensis* abundance: A)Mean annual surface water temperature in South, Central and San Pablo bays, January - March, 1980-2008; B) Mean annual Sea Surface Temperature(SST) in the Gulf of the Farallones, January - March, 1980-2008; C) Mean annual freshwater outflow at Chipps Island, January - March, 1980-2008. Highest outflow in years with warmer SSTS are circled.

Acknowledgements

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Notes

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Delta Juvenile Fish Monitoring Program

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Introduction

The goal of the Delta Juvenile Fish Monitoring Program (DJFMP) at the Stockton Fish and Wildlife Office is to monitor juvenile fish populations throughout the Sacramento and San Joaquin rivers and the San Francisco Estuary. The program was established in the late 1970s to monitor juvenile Chinook salmon *Oncorhynchus tshawytscha* (Brandes & McLain, 2001), but the program quickly expanded in response to water-management actions and endangered species listings and now monitors all juvenile fish. The objective of this report is to summarize results from trawling and beach seining efforts from January 4, 2009 through September 27, 2009.

Trawling

For the reporting period of January 4, 2009 through September 27, 2009, all trawls were conducted in ten 20-minute time intervals. Kodiak trawls were conducted three days a week at Mossdale Landing (San Joaquin River, river mile [RM] 54). Midwater trawls were conducted at Sherwood Harbor (Sacramento River RM55) from the beginning of April through September, twice weekly from May through June and three times a week for the month of April and from July through September. Kodiak trawls were conducted at Sherwood Harbor three days a week during the months of January through March. Midwater trawls were also conducted three days a week at Chipps Island (Suisun Bay RM 18) throughout the reporting period. In addition, trawl efforts were increased for the month of April through May 8, 2009 when three sets of 24-hour net efficiency studies were conducted at Sherwood Harbor and Chipps Island. These were conducted to provide estimates of relative abundance and patterns in distribution of migrating juvenile salmon, and to determine catch efficiencies of our midwater and Kodiak trawls (Wilder & Ingram, 2006). It is also important to mention that state and federal hatcheries conducted large scale fish releases at designated locations along the Sacramento River from late December 2008 through April 2009, which resulted in increased numbers of Chinook salmon captured during this period.

The greatest number of unmarked Chinook salmon (n = 2,083 fish) was captured at Chipps Island: 1,572 fall-run sized, 9 late fall-run sized, 430 spring-run sized and 72 winter-run sized. Sampling at Mossdale resulted in the capture of 649 fall-run sized unmarked Chinook salmon. Kodiak trawling at Sherwood Harbor between January 4, 2009 and March 31, 2009 resulted in the catch of 516 unmarked Chinook salmon: 497 fall-run, 4 spring-run and 15 winter-run. A total of 1,508 unmarked Chinook salmon was caught in midwater trawls at Sherwood harbor between April 1, 2009 and September 30, 2009: 1,287 fall-run, 1 late fall-run, and 220 winter-run. For this reporting period, 1,831 adipose fin-clipped Chinook salmon were recovered: 1,092 at Chipps Island, 725 in the midwater trawls at Sherwood harbor and 14 in Kodiak trawls at Sherwood Harbor. No marked Chinook salmon were recovered at Mossdale. The total average of weekly catch-per-unit effort (CPUE), expressed as fish / 10000m^3, was calculated for each sampling location for fish species and salmon races (Table 1).

Table 1 The mean weekly catch per unit effort (fish / 10,000 m³) of eight species of interest captured via Kodiak and midwater trawls, between January 4, 2009 through September 27, 2009. The 95% confidence interval is represented in parenthesis.

Region Sampled	American Shad	Treadfin Shad	Delta Smelt	Longfin Smelt	Fall-run sized Chinook Salmon	Late fall-run sized Chinook Salmon	Spring-run sized Chinook Salmon	Winter-run sized Chinook Salmon	Striped Bass
Sherwood Harbor MWTR	0.04 (0.03)	0.04 (0.04)	0	0	2.71 (2.84)	<0.01 (<0.01)	0.34 (0.31)	0	<0.01 (<0.01)
Sherwood Harbor KDTR	0	0.21 (0.32)	0	0	1.79 (2.17)	0	0.02 (0.02)	0.05 (0.07)	<0.01 (<0.01)
Chipps Island	2.90 (1.21)	0.01 (0.01)	0.08 (0.03)	0.08 (0.04)	0.48 (0.43)	<0.01 (<0.01)	0.11 (0.09)	0.03 (0.02)	0.20 (0.05)
Mossdale	0.01 (0.01)	5.23 (2.42)	0	0	0.47 (0.34)	0	0	0	1.29 (1.16)

For the reporting period, we captured 24,446 fishes (excluding marked salmon): 1,541 fishes representing nine species at Sherwood Harbor via midwater trawling, 1,053 fishes representing 16 species at Sherwood Harbor via Kodiak trawling, 10,986 fishes representing 28 species at Chipps Island, and 10,866 fishes representing 29 species at Mossdale Landing. Unmarked Chinook salmon compromised almost 98% of the catch in midwater trawls at Sherwood Harbor. Mean weekly CPUE of unmarked Chinook salmon were highest in April and May in midwater trawls at Sherwood Harbor, which was likely due to the increased number of salmon being released and an increase in our trawling effort for the net efficiency study (Table 2). Unmarked Chinook salmon compromised 49% of the catch via Kodiak trawling at Sherwood Harbor. Inland silversides *Menidia beryllina* comprised 26% of the catch and Pacific lamprey *Lampetra tridentate* comprised 8% of the catch in the Kodiak trawls at Sherwood Harbor. At Chipps Island 65% of the total catch was comprised of American Shad *Alosa sapidissima*, and 19% of the catch were unmarked Chinook salmon. At Mossdale Landing inland silversides and threadfin shad *Dorosoma petenense* combined to make up 70% of the catch, while unmarked Chinook salmon only comprised 6% of the catch and had the lowest CPUE (0.47 x 10^{-4} fish/m³, Table 1).

Beach Seining

For the reporting period, The DJFMP conducted 1,381 beach seine hauls at 58 sites. We conducted 274 seine hauls in the central Delta (9 sites) and 244 seine hauls in the southern Delta (9 sites). Sampling intensity increased between October and January with an additional seine run (Sacramento region) to improve detection of less common races and life stages of Chinook salmon entering the delta. During the month of January we conducted 32 seine hauls in the Sacramento region (8 sites). We conducted 192 seine surveys on the lower Sacramento River (7 sites) and 363 seine hauls in the northern Delta (10 sites) from January through September 27, 2009. We conducted 127 seine hauls on the San Joaquin River (9-sites). During low flow conditions alternate sampling sites were used on the San Joaquin River. Additionally, we conducted 149 seine hauls in San Pablo and San Francisco bays (a total of 9 sites, collectively referred to as Bay seines). The Sacramento and San Joaquin rivers and Delta sites were typically sampled once per week, and Bay sites were sampled every other week.

During the sampling period 1,927 unmarked Chinook salmon were captured in the beach seine: 1,841 fall-run sized, 5 late fall-run sized, 59 spring-run sized and 22 winter-run sized. A total of 275 marked Chinook salmon were captured in beach seine during the sampling period. We captured 4 marked salmon from the central delta, 219 from the lower Sacramento River and 52 from the northern delta. No marked or unmarked salmon were captured in the San Joaquin River or in the Bay seine during the reporting period.

Table 2 The mean weekly catch per unit effort (fish / 10,000 m³) of three salmon runs and three species of interest captured via midwater trawl at Sherwood Harbor between January 4, 2009 through September 27, 2009.

	Fall-run Chinook salmon	Late fall-run Chinook salmon	Spring-run Chinook salmon	American Shad	Striped Bass	Threadfin Shad
Sample Week						
3/29/2009	0	0	0.33	0	0	0
4/5/2009	0.47	0	0.72	0	0	0.06
4/12/2009	2.74	0	3.46	0	0	0
4/19/2009	8.05	0	2.02	0	0	0
4/26/2009	17.9	0	0.59	0.03	0	0
5/3/2009	35.5	0	2.05	0.33	0	0
5/10/2009	2.06	0	0	0	0	0
5/17/2009	1.27	0	0	0	0	0
5/24/2009	0.25	0	0	0	0	0
5/31/2009	0.31	0	0	0	0	0
6/7/2009	1.9	0	0	0	0	0
6/14/2009	2.06	0	0	0	0	0
6/21/2009	0	0	0	0	0	0.11
6/28/2009	0	0	0	0	0	0
7/5/2009	0.28	0	0	0	0	0
7/12/2009	0.1	0	0	0	0	0
7/19/2009	0	0	0	0	0	0
7/26/2009	0.06	0	0	0	0	0
8/2/2009	0.06	0.06	0	0.06	0	0
8/9/2009	0	0	0	0.22	0	0
8/16/2009	0	0	0	0.14	0	0.49
8/23/2009	0	0	0	0.15	0	0.07
8/30/2009	0	0	0	0	0	0.27
9/6/2009	0	0	0	0	0	0
9/13/2009	0	0	0	0	0.09	0
9/20/2009	0	0	0	0.07	0	0
9/27/2009	0	0	0	0	0	0
Average	2.71	0.00	0.34	0.04	0.00	0.04
SD	7.52	0.01	0.83	0.08	0.02	0.11
95% CI	2.84	0.00	0.31	0.03	0.01	0.04

A total of 122,734 fish representing 68 species were captured using the beach seine during the reporting period: 18,459 fishes from the lower Sacramento River, 218 fishes from the Sacramento region, 15,661 fishes from the northern Delta, 31,075 fishes from the central Delta, 24,883 from the southern Delta, 28,309 fishes from the San Joaquin River, and 4,178 fishes from the Bay. Sacramento suckers *Catostomus occidentalis* (CPUE = 10,300 fish/10^4 m³) and Sacramento pikeminnow *Ptychocheilus grandis* (CPUE = 1600 fish/ 10^4 m³) represented 48% of the total catch in the lower Sacramento River. Native fishes accounted for 60% of the total catch in the lower Sacramento River. In the Sacramento, northern Delta, central Delta, and southern Delta regions, the inland silverside comprised over 79% of the catch, whereas native species were represented in less than 5% of the catch. In the San Joaquin River, red shiner *Cyprinella lutrensis*, inland silverside and western mosquitofish *Gambusia affinis* comprised approximately 94% of the catch. Top smelt *Antherinops affinis* was the predominate species captured in the Bay representing 53% of the total catch and had the highest total CPUE for this region (2028 fish/ 10^4 m^3, Table 3).

Table 3 The mean weekly catch per unit effort (fish / 10,000 m³) of eight species of interest caught via beach seine for all sampling regions, between January 4, 2009 through September 27. The 95% confidence interval is represented in parenthesis.

Region Sampled	Threadfin shad	Striped Bass	Delta Smelt	Fall-run sized Chinook salmon	Late fall-run sized Chinook salmon	Spring-run sized Chinook salmon	Winter-run sized Chinook salmon	Sacramento Pikeminnow	Sacramento Sucker	Splittail	Wakasagi	Topsmelt	Inland Silverside
Sacramento	0	0	0	160 (291)	0	4.73 (9.28)	0	0	278 (324)	0	0	0	880 (557)
Lower Sacramento	807 (464)	6.63 (5.82)	0	1400 (1100)	2.44 (3.35)	50.1 (45.3)	26.6 (30.6)	1600 (603)	10300 (4890)	1260 (1290)	80.6 (126)	0	3740 (1770)
Northern Delta	5.87 (5.01)	0	5.48 (5.55)	581 (416)	1.67 (1.85)	13.0 (7.61)	3.19 (3.32)	224 (81.4)	3120 (2100)	1840 (2020)	32.1 (33.1)	0	5620 (2500)
Central Delta	65.6 (61.1)	107 (91.2)	5.47 (7.92)	76.7 (75.5)	0	1.11 (1.63)	0	234 (117)	54.5 (48.4)	113 (106)	14.0 (17.3)	0	43100 (22500)
Southern Delta	244 (299)	10.6 (8.43)	0	3.14 (6.09)	0	0	0	61.8 (29.9)	82.8 (108)	0	0	0	19000 (8300)
San Joaquin	172 (135)	117 (140)	0	0	0	0	0	1.16 (2.27)	483 (388)	144 (195)	0	0	19100 (8600)
SP and SF Bays	0	1.14 (2.23)	0	0	0	0	0	0	0	0	0	2030 (793)	6.70 (8.76)

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CONTRIBUTED

Phytoplankton Community Composition:The Rise of the Flagellates

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Abstract

Phytoplankton are an important component of the food web in the San Francisco Estuary. Species composition is also important; shifts in the phytoplankton community can have significant effects on the larger ecosystem. Recent increases in phytoplankton biomass in parts of the estuary have not been accompanied by corresponding increases in pelagic species. This suggests that species composition of the phytoplankton may be playing a role. Phytoplankton community composition was examined at several long-term monitoring stations in the estuary. Changes in community composition were significant, and primarily due to just a handful of taxa. Historically, the delta has been dominated by diatoms, but some areas are now dominated by flagellate taxa. The implications of these changes are discussed, and areas of further study identified.

Introduction

Phytoplankton are an important part of the pelagic food web in the San Francisco Estuary, serving as the dominant food source for higher trophic levels (Sobczak et al. 2002, Jassby et al. 1993, Müller-Solger et. al. 2002). The nutritional quality of phytoplankton varies by taxonomic group: diatoms and cryptomonads are considered good food sources, while cyanobacteria are not (Lehman et al. 2005; Lehman 2007; Cloern and Dufford 2005). Cryptomonads in particular are considered an optimal or near optimal food for zooplankton (Kugrens and Clay 2003). Diatoms are also a primary food source for copepods (Lehman 1992; Orsi 1995) and *Neomysis mercedis* (Cloern et al. 1983) in the Estuary. Copepods and *N. mercedis* are important food items for larval and juvenile fish in the Estuary (Cloern et al. 1983; Obreski et al. 1992; Orsi 1995).

Phytoplankton species composition and biomass can be influenced by many factors including climate, stream flow, water temperature and transparency, specific conductance, introduced species, water diversions, and the presence of inhibiting factors such as ammonium (Mahood et al. 1986; Lehman 2000a, 2004, 2007; Wilkerson et al. 2006; Dugdale et. al. 2007). The community tends to vary with water year type (Lehman 2000a), with wet, cool years being dominated by diatoms, and warm, dry years having more flagellates. Recently there has been an increase in phytoplankton biomass in the Sacramento-San Joaquin Delta, the upstream portion of the estuary (Jassby 2006, 2008). However, this increase in biomass has not been accompanied by similar increases in zooplankton or pelagic fish that are dependent on the upper estuary (Jassby 2006, 2008). This suggests that phytoplankton species composition may be playing a role in trophic transfer independent of biomass (Jassby 2006, 2008). Previous analyses of the phytoplankton community showed decreases in diatoms and increases in flagellate taxa due to climate shifts and species introductions (Lehman 1998, 2000a, 2000b); however, an updated analysis of the phytoplankton community is needed to determine what role individual taxa may be playing in food web dynamics (Jassby 2008).

Materials and Methods

Data for this analysis were provided by the Department of Water Resources' (DWR's) Environmental Monitoring Program (EMP). Phytoplankton samples were collected once or twice monthly from 1975 through 2007 at fixed monitoring stations in the Estuary (Figure 1). Samples were collected from 1 m below the surface using a Van Dorn sampler or a submersible pump. Samples were preserved with Lugol's solution in 50-mL brown bottles and processed according to the Utermöhl method (Utermöhl 1958). Phytoplankton were identified to the lowest possible taxonomic level using an inverted microscope at a magnification of 350X to 700X, and counted.

Counts were used to determine abundance, which was calculated as organisms per mL. Data from two stations in Suisun Bay (D7 and D8) and five stations in the interior Delta (D19, D26, D28A, MD10A and P8) were used for subsequent analyses. In order to study the overall community (including rare species) without the dominating effects of bloom events, the abundance data were transformed to presence/absence (0 = absent, 1 = present) prior to analysis. Community analysis was performed at the genus level, as most taxa were able to be identified to this level. Heterotrophic taxa were not routinely speciated, so these species were lumped together as “miscellaneous flagellates.”

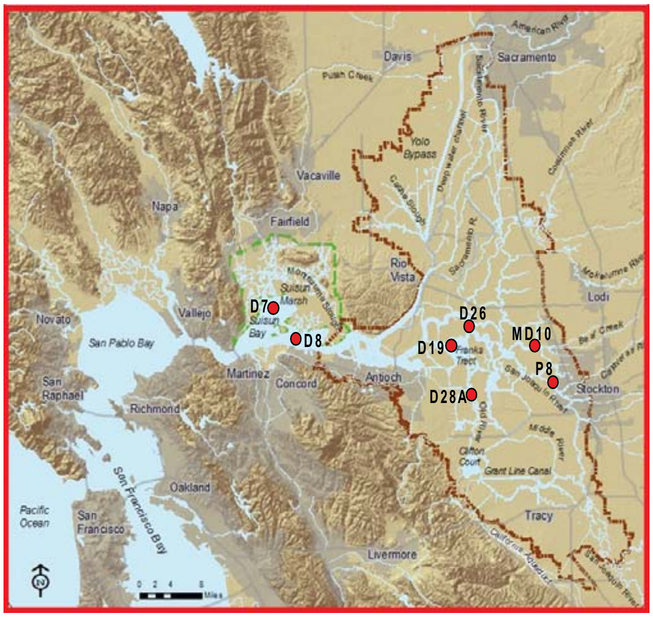

Figure 1 Map of stations used in analysis. D7 & D8 = Suisun Bay; D19, D26, D28A, MD10 & P8 = interior Delta

Statistical analyses were performed using the non-parametric routines in the PRIMER software package (Clarke 1993; Clarke and Warwick 2001; PRIMER-E version 6.1.11). Three routines were performed: Analysis of Similarities (ANOSIM), Similarity Percentages (SIMPER), and Non-metric Multi-dimensional Scaling (NMDS). The ANOSIM procedure is a permutation/randomization test analogous to a non-parametric multivariate ANOVA (Clarke 1993). The test statistic, R, is scaled to lie between 0 and 1 (0 = no separation of groups, 1 = complete separation). The data for each region (Suisun Bay or Delta) was split into groups by decade (1970s, 1980s, 1990s, and 2000s) and analyzed with a 1-way ANOSIM. If significant differences between decades were found, the SIMPER routine identified those taxa responsible for the observed difference. This procedure breaks down Bray-Curtis dissimilarities to determine which variables (in this case, phytoplankton genera) typify a group (Clarke 1993; Clarke and Warwick 2001). The dissimilarity takes a value between 0 and 100 (0 = completely similar, 100 = completely dissimilar). To examine yearly changes in community composition, the transformed abundances were averaged by year and input into the NMDS procedure. By using presence/absence data, the yearly average abundance of a taxon becomes a percentage of samples in which the taxon was present. If the organism is present in every sample, the average tends towards 1 (100%). Conversely, if the organism is very rare, the average tends towards zero. The “fit” of the ordination is assessed by the stress value, with values < 0.20 indicating a useful ordination. For each region, yearly average abundances of the top contributors from the SIMPER routine were overlaid onto the yearly NMDS map to examine how their abundance (in terms of presence/absence) had changed.

Results

Suisun Bay

The ANOSIM test found a significant difference between the 1970s and 2000s ($R = 0.539$; $p<0.001$). SIMPER identified 28 taxa responsible for 90.01% of the observed difference (not shown), with the first five contributing 49.92% (Table 1). Three of the five taxa (*Thalassiosira* sp.,*Cyclotella* sp., and *Skeletonema* sp.) are centric diatoms belonging to the order Thalassiosirales, and they have declined significantly. A cryptomonad flagellate, *Cryptomonas* sp., has also declined. The miscellaneous flagellates, on the other hand, have increased. Historically, the centric diatom taxa were present in 50% to 90% of the samples, and *Cryptomonas* sp. was present in 33%. By the 2000s, these taxa have virtually disappeared. The NMDS (Figure 2) shows a distinct change in the abundance pattern after 1987, the year that the Asian clam *Corbula amurensis* became established in the estuary. The low stress (0.13) indicates a good ordination of the data. The decline of the diatoms and *Cryptomonas* sp. begins with the introduction of the clam (Figures 3, 4, 6 and 7), while the miscellaneous flagellates began their increase in the early 1980s (Figure 5). In 1995, a wet year, the abundances of *Thalassiosira* sp. and *Skeletonema* sp. increase, but do not reach pre-clam levels. *Cryptomonas* sp. increased to pre-clam levels in the wetter years of the 1990s, but declined again after 1997.

Table 1 SIMPER Results for Suisun Bay stations and statistically dissimilar decades, 1970s & 2000s. Average dissimilarity is 90.07. Ave. Abund = fraction of samples in which taxon is present (0=absent; 1=present); Ave. Diss = average dissimilarity, with higher dissimilarity indicating taxa that contribute more to the observed difference; % Contrib. = percent contribution by that taxon; % Cumulative = cumulative percent contribution for all taxa.

	Group 1970s	*Group 2000s*			
Species	*Ave. Abund*	*Ave. Abund*	*Ave. Diss*	*% Contri.*	*% Cumulative*
Thalassiosira sp.	0.90	0.10	13.13	14.57	14.57
Cyclotella sp.	0.70	0.17	9.82	10.90	25.47
Misc. Flagellates	0.08	0.56	8.85	9.83	35.30
Skeletonema sp.	0.51	0.10	7.16	7.95	43.25
Cryptomonas sp.	0.33	0.19	6.01	6.67	49.92

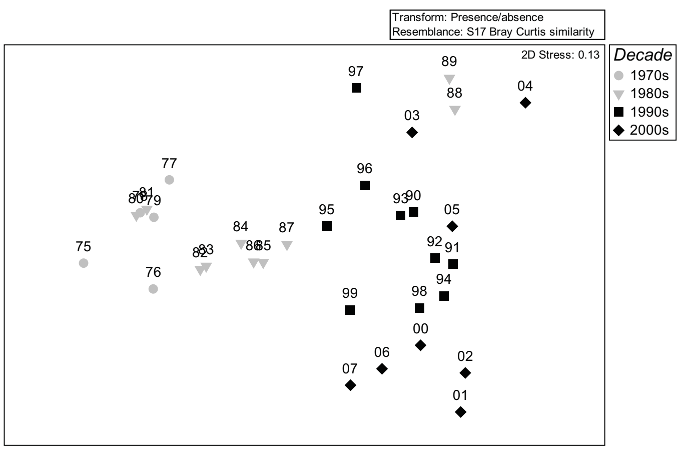

Figure 2 Suisun Bay Year NMDS

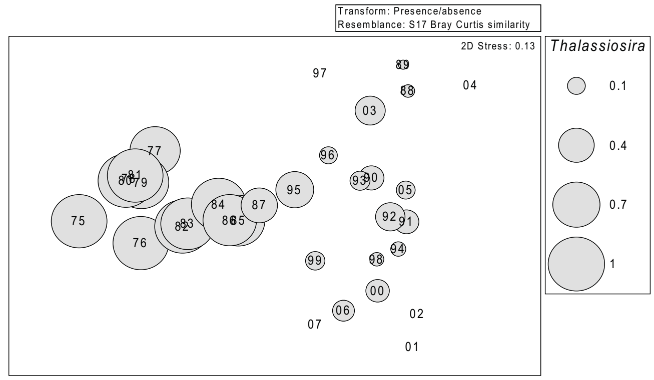

Figure 3 NMDS of Suisun Bay *Thalassiosira* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

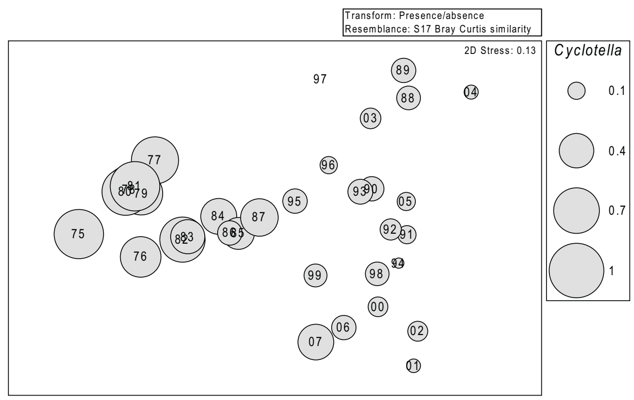

Figure 4 NMDS of Suisun Bay *Cyclotella* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round).

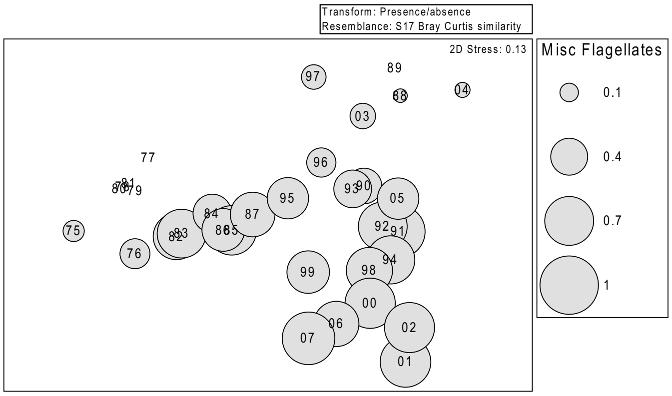

Figure 5 NMDS of Suisun Bay miscellaneous flagellate abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round).

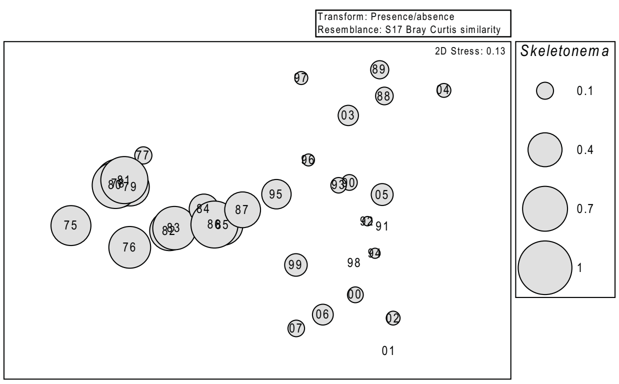

Figure 6 NMDS of Suisun Bay *Skeletonema* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round).

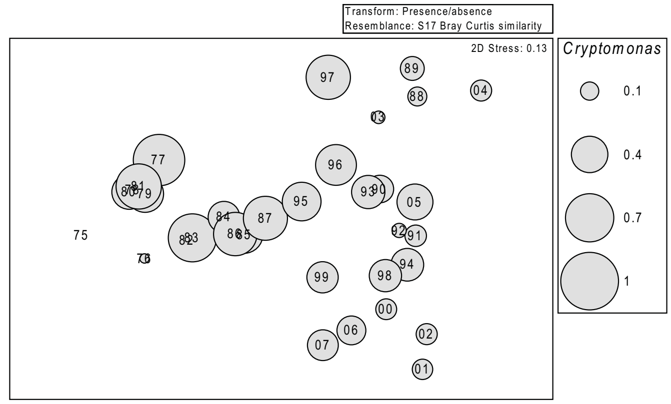

Figure 7 Suisun Bay *Cryptomonas* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round).

Interior Delta

The ANOSIM test found significant differences between the 1970s and the 1990s ($R = 0.427$; $p<0.001$), and between the 1970s and 2000s ($R = 0.405$; $p<0.001$). This suggests that any changes that occurred in the 1990s are continuing into the 2000s. SIMPER identified 28 taxa responsible for 90.29% of the difference between the 1970s and the 1990s, and 35 taxa responsible for 90.21% of the difference between the 1970s and the 2000s (not shown). In both cases, the top seven taxa contributed over 47% to the observed differences (Tables 2 and 3). The top four taxa are the same for both comparisons, and three of the four are the same taxa responsible for the observed differences in Suisun Bay as well. As in Suisun Bay, there have been severe declines in centric diatoms, and increases in flagellate taxa (Tables 2 and 3; Figures 8 through 15). A single pennate diatom, *Nitzschia* sp., was common in 1975-76, but has appeared only sporadically since then (Figure 16). The stress for the NMDS is low (0.12), and shows the declines of the diatoms beginning in the late 1980s (*Melosira* sp.) and 1990s: early 1990s for *Cyclotella* sp. and late 1990s for *Thalassiosira* sp. and *Skeletonema* sp. (Figures 9, 11, 14 and 15). The flagellate taxa began to increase in the late 1970s (*Cryptomonas* sp.) or in the 1980s: early 1980s for miscellaneous flagellates and late 1980s for *Rhodomonas* sp., another cryptomonad flagellate (Figures 10, 12 and 13). While the miscellaneous flagellates have remained relatively abundant, *Cryptomonas* sp. and *Rhodomonas* sp. declined sharply after 1996 and again after 1998, and resurged briefly again in 2003-04.

Table 2 SIMPER Results for Interior Delta and statistically dissimlar decades, 1970s & 1990s. Average dissimilarity is 78.67. Abbreviations as for Table 1

	Group 1970s	Group 1990s			
Species	Ave. Abund	Ave. Abund	Ave. Diss	% Contrib.	% Cumulative
Cyclotella sp.	*0.88*	*0.18*	*7.37*	*9.36*	*9.36*
Misc. Flagellates	*0.17*	*0.78*	*6.90*	*8.77*	*18.14*
Thalassiosira sp.	*0.74*	*0.48*	*5.29*	*6.73*	*24.87*
Cryptomonas sp.	*0.45*	*0.47*	*4.85*	*6.17*	*31.03*
Rhodomonas sp.	*0.00*	*0.54*	*4.80*	*6.10*	*37.13*
Melosira sp.	*0.50*	*0.13*	*4.60*	*5.84*	*42.98*
Skeletonema sp.	*0.41*	*0.42*	*4.46*	*5.67*	*48.65*

Table 3 SIMPER Results for Interior Delta and statistically dissimilar decades, 1970s & 2000s. Average dissimilarity is 83.39. Abbreviations as for Table 1

	Group 1970s	Group 2000s			
Species	Ave. Abund	Ave. Abund	Ave. Diss	% Contrib .	% Cumulative
Cyclotella sp.	*0.88*	*0.29*	*7.49*	*8.98*	*8.98*
Misc Flagellates	*0.17*	*0.67*	*6.85*	*8.21*	*17.19*
Thalassiosira sp.	*0.74*	*0.25*	*6.77*	*8.12*	*25.31*
Cryptomonas sp.	*0.45*	*0.25*	*5.05*	*6.05*	*31.36*
Melosira sp.	*0.50*	*0.15*	*5.05*	*6.05*	*37.41*
Nitzschia sp.	*0.46*	*0.04*	*4.31*	*5.17*	*42.58*
Skeletonema sp.	*0.41*	*0.14*	*4.13*	*4.96*	*47.54*

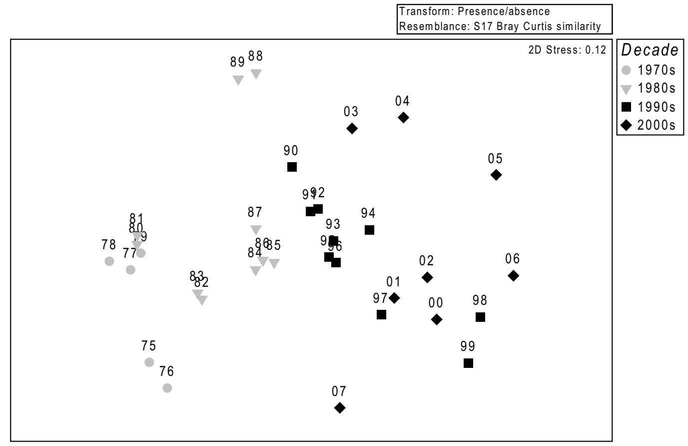

Figure 8 Interior Delta Year NMDS

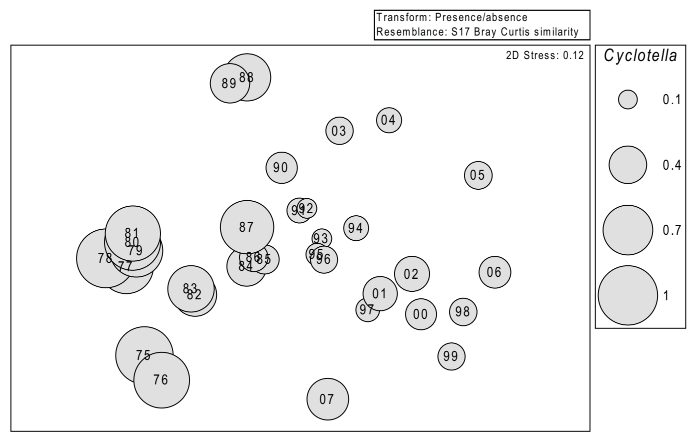

Figure 9 NMDS of Interior Delta *Cyclotella* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

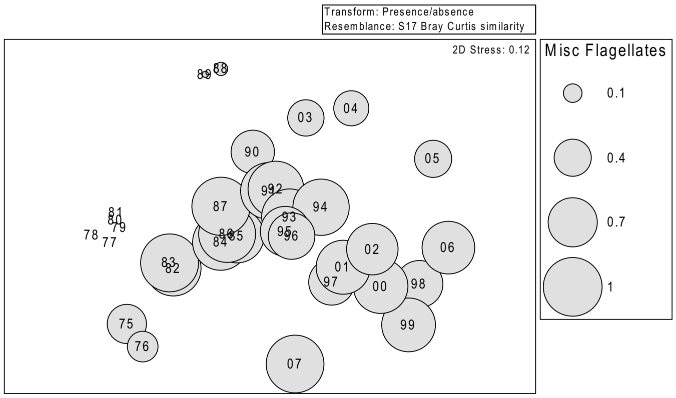

Figure 10 NMDS of Interior Delta miscellaneous flagellate abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

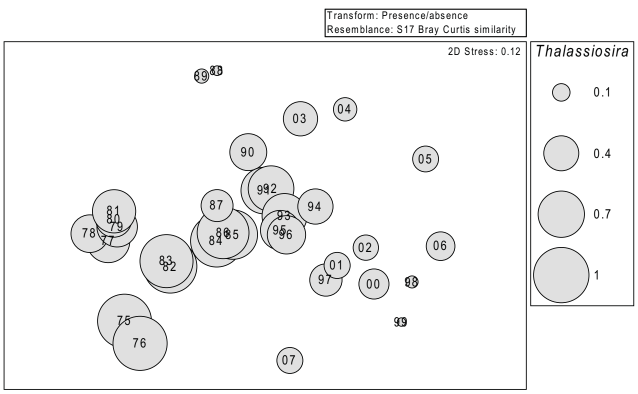

Figure 11 NMDS of Interior Delta *Thalassiosira* sp. abundance. Abundance is fraction of samples for year in which taxon is present (0=completely absent; 1=present year round)

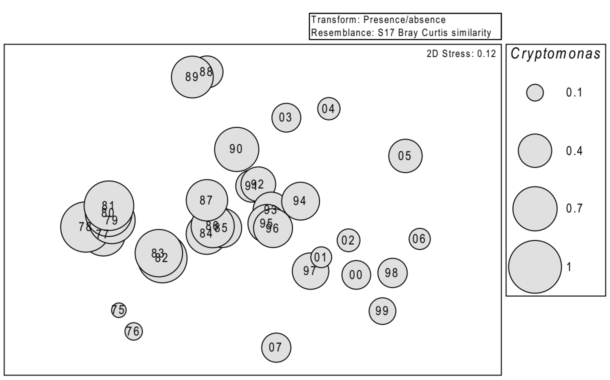

Figure 12 NMDS of Interior Delta *Cryptomonas* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

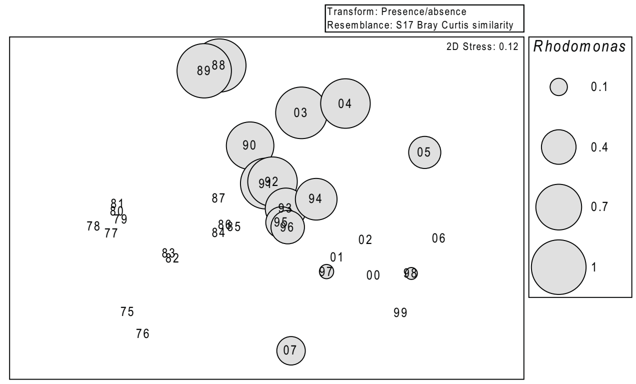

Figure 13 NMDS of Interior Delta *Rhodomonas* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

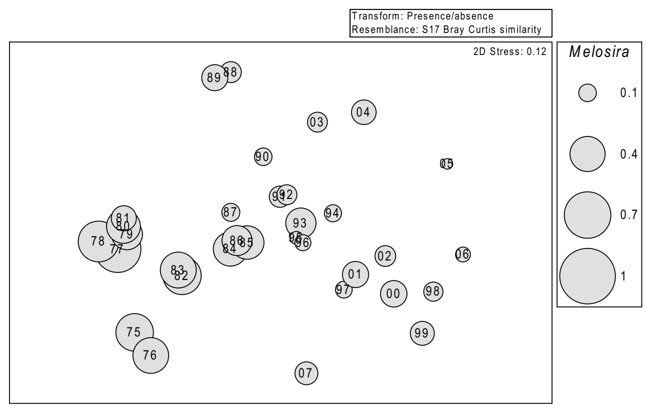

Figure 14 NMDS of Interior Delta *Melosira* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

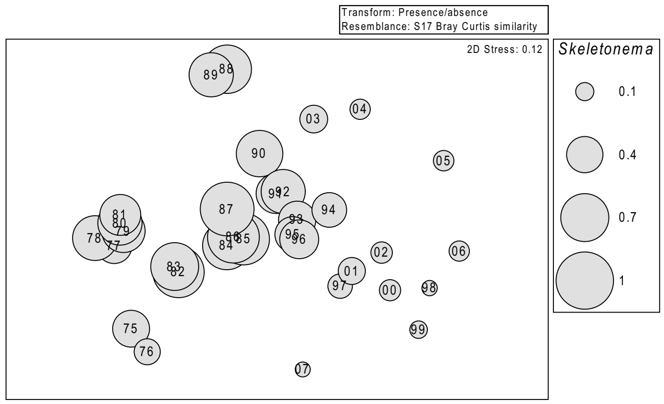

Figure 15 NMDS of Interior Delta *Skeletonema* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

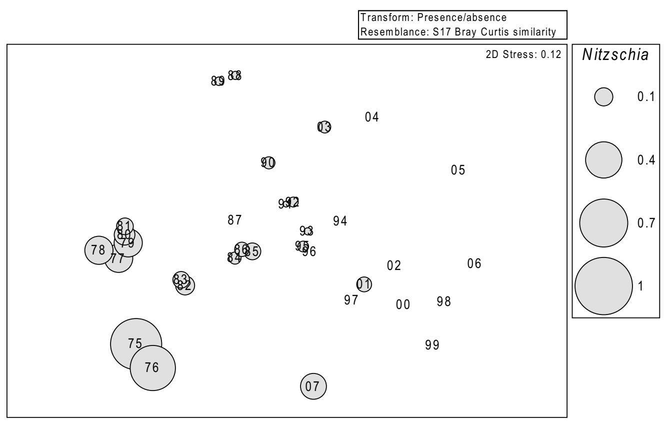

Figure 16 NMDS of Interior Delta *Nitzschia* sp. abundance. Abundance is fraction of samples for that year in which taxon is present (0=completely absent; 1=present year round)

Discussion

A previous study showed a shift from a diatom-dominated community to a flagellate-dominated one during 1975-1993 (Lehman 2000a). This analysis includes data collected since 1993, and shows that this shift remains despite the return of wetter years in the late 1990s (which would favor diatoms over flagellates), and more normal water years since 2000. The onset of the El Nino-Southern Oscillation (ENSO) in 1997 may be playing a role; such events are known to influence water year type through their effect on climate (Lehman 2000a). The magnitude of such events is also important, and the 1997-1999 ENSO was one of the largest in the historical record (Menkes et al. 2005). More extreme events tend to show a greater impact on coastal and estuarine species (Zamon and Welch 2005).

Three of the five diatom genera that have declined in Suisun Bay and the interior Delta belong to the same order, Thalassiosirales, which is a diverse and ecologically important order (Stoermer and Julius 2003). *Thalassiosira* sp. in particular was the dominant taxon historically, especially in Suisun Bay (Arthur and Ball 1980, Mahood et al. 1986). While this genus and its respective order may still be dominant in the estuary as a whole (Cloern and Dufford 2005), it has virtually disappeared from Suisun Bay and the interior Delta. Diatoms are an important food for the calanoid copepods *Eurytemora affinis* and *Sinocalanus doerrii* in the estuary, where they constituted >90% of the volume of gut contents for these two species (Orsi 1995). *Thalassiosira* sp. was volumetrically the most abundant taxon in the guts of *E. affinis* and *S. doerrii* (Orsi 1995), so the virtual loss of this taxon likely had an impact on the food web. Additionally, the size selectivity of calanoid copepods limits their ability to prey on small, but potentially nutritious, organisms (Hansen et al. 1994) such as the miscellaneous flagellates. The supply of phytoplankton biomass in Suisun Bay has always been dominated by allochthonous sources, and this has become even more pronounced since the introduction of *C. amurensis* (Jassby 2008). Thus, the loss of diatoms and cryptomonads in the interior Delta in the late 1990s may have had an effect on the food web in Suisun Bay, as there were less of the “good food” groups being transported downstream. Zooplankton in the estuary are routinely food-limited (Müller-Solger et al. 2002; Sobczak et al. 2002), and the disappearance of a major food item like *Thalassiosira* sp. likely increased this limitation, at least for calanoid copepods. Food limitation may also increase reliance on the microbial loop as a source of production, which is an inefficient pathway for higher trophic levels (Azam et. al. 1983).

Inhibiting factors may influence the phytoplankton community as well. Ammonium in the estuary is regularly at levels that inhibit phytoplankton blooms (Wilkerson et. al. 2006, Dugdale et. al. 2007). The phytoplankton community in Suisun Bay is highly structured by *C. amurensis* grazing (Lehman 2000b), but the near constant presence of ammonium at bloom-inhibiting levels may prevent a return to a diatom-dominated community elsewhere in the estuary as diatoms are out-competed by flagellates. Diatoms generally grow better on nitrate, while microflagellates are better at utilizing ammonium (Dortch 1990), though they may not actually form a bloom.

Herbicides can also structure the phytoplankton community by inhibiting sensitive species such as diatoms, and favoring more tolerant species like cyanobacteria (Edmunds et al. 1999; Peterson et. al. 1997). Pyrethroids could play a role too, though not necessarily in the water column. They are regularly pulled into the sediment where they degrade sediment quality and cause toxicity (Amweg et al. 2005). Many diatoms produce benthic resting stages, or have the ability to survive periodic and prolonged entrainment and burial in the sediment (McQuoid and Godhe 2004; Stoermer and Julius 2003; McQuoid et al. 2002). Toxic compounds in the sediment could potentially impair the viability of diatom cells in the benthos; these cells often serve as inocula for blooms (Cloern and Dufford 2005, McQuoid and Godhe 2004, McQuoid et al. 2002).

The ecological importance of the Thalassiosirales in the Estuary is clear; historically, the Estuary was dominated by species in this order, and by *Thalassiosira* sp. in particular (Arthur and Ball 1980, Mahood et. al. 1986). Now, certain regions are dominated by other taxa, such as flagellates, green algae and cyanobacteria (Lehman 2000 a, b). The factors regulating the phytoplankton community at the class level or higher are relatively well understood (Cloern and Dufford 2005; Lehman 2000a), but "the rules of phytoplankton community assembly at the species level remain elusive" (Cloern and Dufford 2005). Species-level descriptions and analyses of phytoplankton are crucial to understanding the roles of individual taxa in the phytoplankton community, their importance in food web production for higher trophic levels, and their overall effects on the estuary.

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2008 Dissolved Oxygen Monitoring in the Stockton Ship Channel

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Introduction

The Department of Water Resources (DWR) Bay-Delta Monitoring and Analysis Section has been monitoring dissolved oxygen (DO) levels in the Stockton Ship Channel (channel) during the late summer and fall since 1968. Due to a variety of factors, DO levels have historically fallen in the central and eastern portions of the channel during this period. Some of the factors responsible include low San Joaquin River inflows, warm water temperatures, high biochemical oxygen demand (BOD), reduced tidal circulation, and intermittent reverse flow in the San Joaquin River at Stockton.

Because low DO levels can have adverse impacts on fisheries and other beneficial uses of the waters within the Bay-Delta, the State Water Resources Control Board (SWRCB) established specific water quality objectives to protect these uses. Within the channel, two separate DO objectives have been established. The most recent Basin Plan (1998) of the Central Valley Regional Water Quality Control Board establishes a baseline objective of 5.0 mg/L DO for the entire Delta region (including the Stockton Ship Channel) throughout the year. However, an objective of 6.0 mg/L was adopted for the period from September through November by the SWRCB in its latest Bay-Delta Plan (1995). This objective is established to protect fall-run Chinook salmon and applies to the lower San Joaquin River between Stockton and Turner Cut, which includes the eastern channel.

As part of a 1969 Memorandum of Understanding between DWR, the U.S. Fish and Wildlife Service, the U.S. Bureau of Reclamation, and the Department of Fish and Game, DWR has installed a rock barrier across the upstream entrance (head) to Old River during periods of projected low San Joaquin River outflow. The head of Old River barrier (barrier) increases net flows down the San Joaquin River past Stockton. The higher flows can contribute to improving DO levels. The barrier is usually installed temporarily in the fall and spring when average daily San Joaquin River flows past Vernalis are projected to be approximately 2,000 cubic feet per second (cfs) or less.

This article describes DO monitoring results during the period of June through November 2008, which includes an instance when San Joaquin River net flow at Stockton reached a minimum of -79 cfs. Installation of the barrier began on October 1 and was completed on October 16. Barrier removal began on November 3 and was completed by November 9, 2008.

Methods

Monitoring was conducted approximately every two weeks by vessel on 12 monitoring cruises from June 16 to November 25, 2008. During each of the monitoring cruises, 14 sites were sampled at low water slack, beginning at Prisoners Point (station 1) in the central Delta and ending at the Stockton turning basin at the terminus of the Stockton Ship Channel (station 14; Figure 1). For geographic reference and simplicity of reporting, the sampling stations are keyed to channel light markers. Because monitoring results differ along the channel, sampling stations are grouped into western, central, and eastern regions. These regions are highlighted in Figure 1.

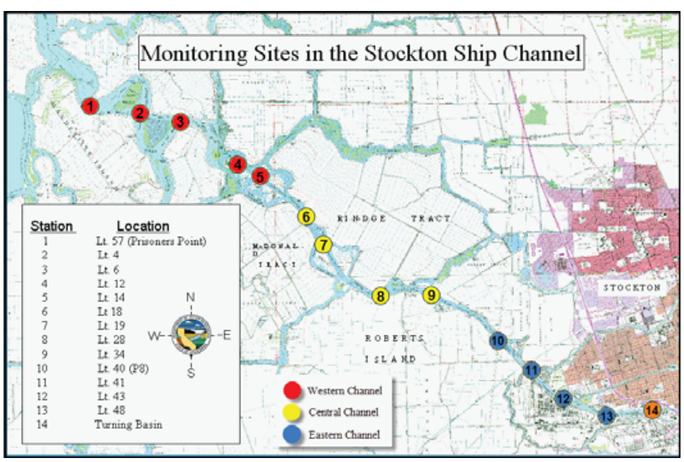

Figure 1 Monitoring sites in the Stockton Ship Channel

Discrete samples were taken from the top (1 meter from the surface) and bottom (1 meter from the bottom) of the water column at each station at low water slack, and analyzed for DO concentrations and temperature. Top DO samples were collected using a through-hull pump and were analyzed with the modified Winkler titration method (APHA 1998). Bottom DO samples were obtained using a Seabird submersible sampler and measured using a YSI polarographic electrode (model no. 5739) with a Seabird CTD 911+ data logger. Surface and bottom water temperatures were measured using a Seabird SBE3 temperature probe or a YSI 6600 sonde equipped with a model no. 6560 thermistor temperature probe.

Flow data for the San Joaquin River at Vernalis were obtained from station data recorded at the Vernalis monitoring station, operated jointly by the U.S. Geological Survey (USGS) and DWR. Average daily flows on the San Joaquin River near Vernalis were obtained by averaging 15-minute data for a daily average flow rate. Tidal cycles of ebb and flood are not seen in flows at Vernalis, and flow proceeds downstream (positive flow) throughout the year.

Flows of the San Joaquin River past Stockton used in this report were obtained from data recorded by the USGS flow monitoring station northeast of Rough and Ready Island. Flow rates in the San Joaquin River at Stockton are heavily influenced by tidal action, with daily ebb and flood tidal flows of 3,000 cfs or greater in either direction. To calculate net daily flows, the tidal pulse is removed from the USGS 15-minute flow data with a Butterworth filter[1]. Due to low inflows, upstream agricultural diversions, and export pumping, net daily flows at Stockton can frequently approach zero and can sometimes reverse direction. During July 2008, net flow at Stockton reached a minimum of -79 cfs.

Results

During the period of this study, DO levels varied by season and between regions within the channel (excluding the turning basin). Overall study period range was 4.5 to 10.3 mg/L at the surface and 4.3 to 9.8 mg/L at the bottom. In the western channel, DO concentrations were relatively high and stable, ranging from 6.9 to 8.5 mg/L at the surface and 6.7 to 8.4 mg/L at the bottom. In the central portion of the channel, DO concentrations were variable, ranging from 5.5 to 8.4 mg/L at the surface and 5.4 to 8.2

1. The USGS uses a Butterworth bandpass filter to remove frequencies (tidal cycles) from 15-minute flow data that occur on less than a 30-hour period. The resulting 15-minute time-series is then averaged to provide a single daily value which represents net river flow exclusive of tidal cycles.

mg/L at the bottom. In the eastern channel, DO levels were the lowest and tended to be more stratified than the other stations, ranging from 4.5 to 10.3 mg/L at the surface and 4.3 to 9.8 mg/L at the bottom.

During the study period, flows on the San Joaquin River near Vernalis ranged from a high of 1,325 cfs in October to a low of 584 cfs in September. Net daily flow on the San Joaquin River past Stockton, exclusive of tidal pulses, ranged from a high of 1,070 cfs in October to a low of -79 cfs in July (Figure 2).

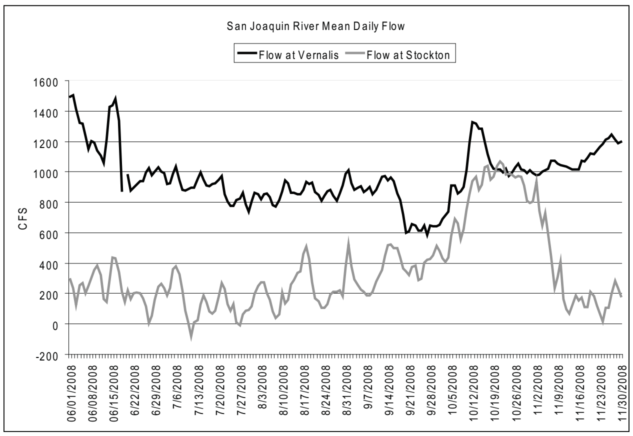

Figure 2 San Joaquin River mean daily flow

The findings for the summer and fall of 2008 are briefly summarized by month as follows. Because of the unique hydro-morphology of station 14, the findings for this station are discussed separately from those of the other channel stations.

June

Monitoring was conducted on June 16th. Surface DO levels ranged from 4.5 mg/L at station 13 to 7.4 mg/L at station 1. Bottom DO levels ranged from 4.3 mg/L at station 12 to 7.2 mg/L at station 1. Dissolved oxygen values fell below the 5.0 mg/L objective at station 13 at the surface and stations 11-13 at the bottom (Figure 3).

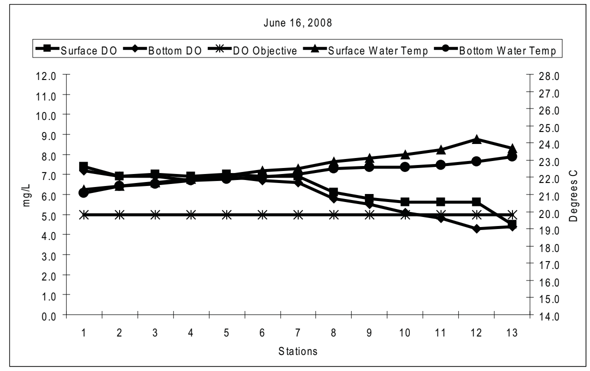

Figure 3 DO and water temperature during one monitoring cruise in June 2008

Water temperatures ranged from 21.3 ^{o}C (station 1) to 24.2 ^{o}C (station 12) at the surface and 21.1 ^{o}C (station 1) to 23.2 ^{o}C (station 13) at the bottom (Figure 3).

Flows on the San Joaquin River near Vernalis during the month of June ranged from 875 to 1,502 cfs. Net flow in the San Joaquin River near Stockton during June ranged from 4.1 to 435 cfs (Figure 2).

July

Monitoring cruises were conducted on July 1, 16 and 30. Surface DO levels ranged from 5.1 mg/L at station 13 to 7.6 mg/L at station 1. Bottom DO levels ranged from 5.1 mg/L at stations 12 and 13 to 7.4 mg/L at station 1 (Figure 4).

Water temperatures ranged from 21.6 ^{o}C (station 1) to 26.7 ^{o}C (station 12) at the surface and 21.6 ^{o}C (station 1) to 26.1 ^{o}C (station 13) at the bottom (Figure 4).

Flows on the San Joaquin River near Vernalis during the month of July ranged from 737 to 1,035 cfs. Net flow in the San Joaquin River near Stockton during July ranged from -79 to 379 cfs (Figure 2).

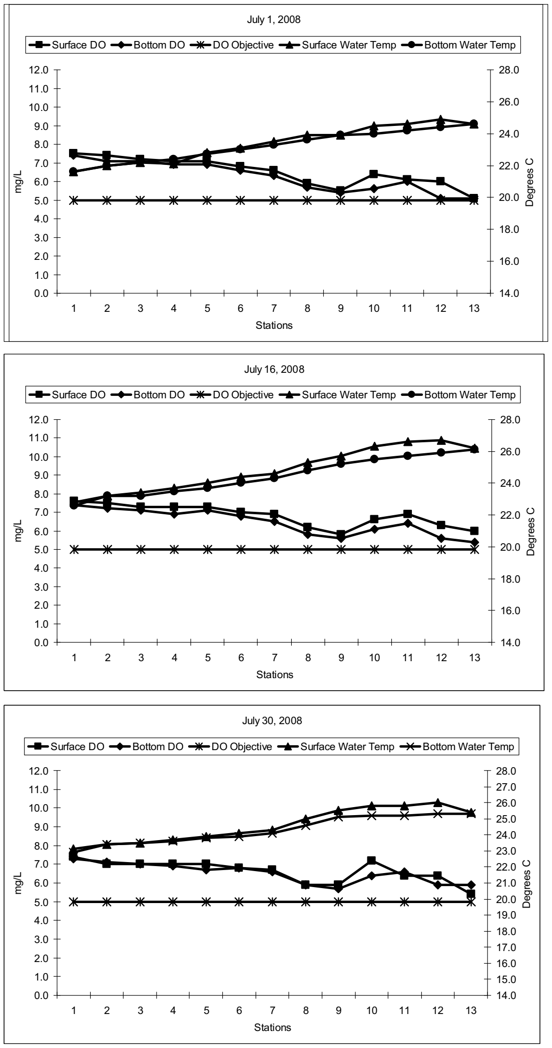

Figure 4 DO and water temperature during three monitoring cruises in July 2008

August

Monitoring cruises were conducted on August 14 and 28. Surface DO levels ranged from 5.5 mg/L at station 9 to 7.6 mg/L at station 12. Bottom DO levels ranged from 5.1 mg/L at station 12 to 7.3 mg/L at station 1 (Figure 5).

Water temperatures ranged from 23.7 ^{o}C (station 1) to 26.5 ^{o}C (station 12) at the surface and 23.5 ^{o}C (station 1) to 25.9 ^{o}C (station 13) at the bottom (Figure 5).

Flows on the San Joaquin River near Vernalis during the month of August ranged from 771 to 987 cfs. Net flow in the San Joaquin River near Stockton during August ranged from 40 to 508 cfs (Figure 2).

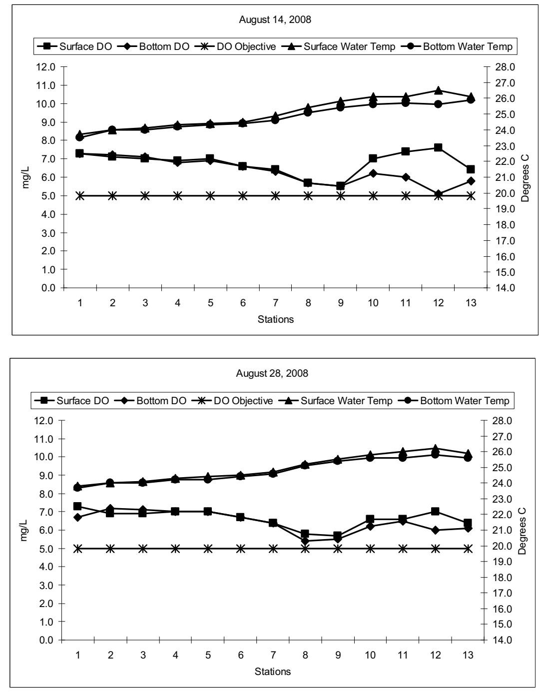

Figure 5 DO and water temperature during two monitoring cruises in August 2008

September

Monitoring cruises were conducted on September 12 and 29. Surface DO levels ranged from 5.7 mg/L at station 9 to 7.8 mg/L at station 1. Bottom DO levels ranged from 5.2 mg/L at station 12 to 8.0 mg/L at station 2 (Figure 6). However, the DO objective increased to 6 mg/L and six stations fell below the objective on September 12, but all met the objective on September 29.

Water temperatures ranged from 21.3 ^{o}C (station 1) to 24.7 ^{o}C (station 12) at the surface and 21.3 ^{o}C (station 1) to 24.5 ^{o}C (station 12) at the bottom (Figure 6).

Flows on the San Joaquin River near Vernalis during the month of September ranged from 584 to 1,011 cfs. Net flow in the San Joaquin River near Stockton during September ranged from 188 to 524 cfs (Figure 2).

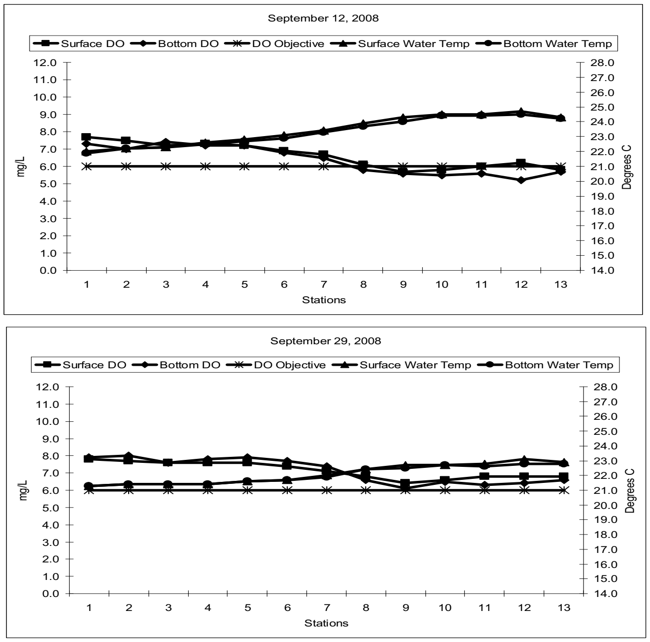

Figure 6 DO and water temperature during two monitoring cruises in September 2008

October

Monitoring cruises were conducted on October 10 and 24. Surface DO levels ranged from 6.2 mg/L at station 9 to 10.3 mg/L at station 13. Bottom DO levels ranged from 6.3 mg/L at stations 9 and 10 to 9.8 mg/L at station 13 (Figure 7).

Water temperatures ranged from 17.0 ^{o}C (stations 1 and 8) to 20.5 ^{o}C (stations 9 -12) at the surface and 17.0 ^{o}C (stations 1, 8 and 9) to 20.4 ^{o}C (stations 10 and 11) at the bottom (Figure 7).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 635 to 1,325 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 406 to 1,070 cfs (Figure 2).

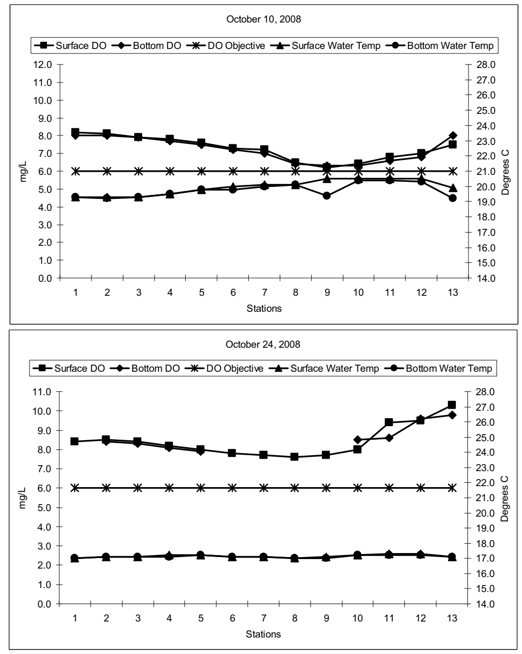

Figure 7 DO and water temperature during two monitoring cruises in October 2008

November

Monitoring cruises were conducted on November 11 and 25. Surface DO levels ranged from 7.2 mg/L at station 10 to 8.4 mg/L at station 7. Bottom DO levels ranged from 7.0 mg/L at station 11 to 8.3 mg/L at station 13 (Figure 8).

Water temperatures ranged from 14.4 ^{o}C (stations 1 - 5) to 16.1 ^{o}C (station 12) at the surface and 14.4 ^{o}C (stations 1, 8 and 9) to 15.6 ^{o}C (station 8) at the bottom (Figure 8).

Flows on the San Joaquin River near Vernalis during the month of October ranged from 976 to 1,245 cfs. Net flow in the San Joaquin River near Stockton during October ranged from 15 to 936 cfs (Figure 2).

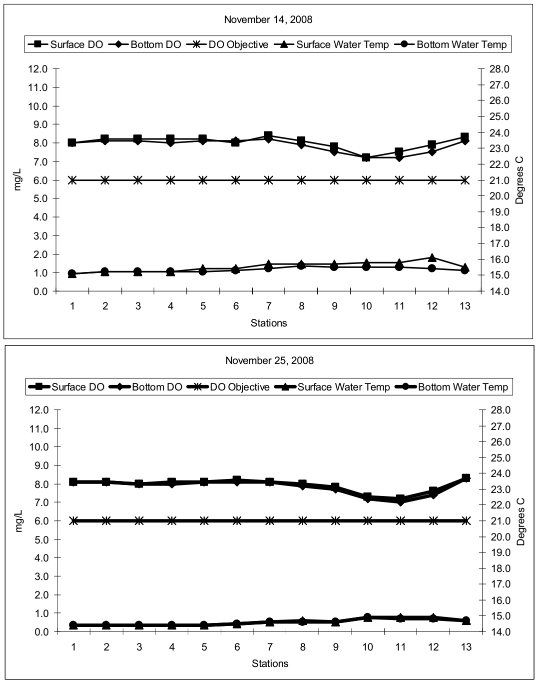

Figure 8 DO and water temperature during two monitoring cruises in November 2008

Stockton Turning Basin

DO levels at the surface in the Stockton turning basin were below SWRCB objectives on only one occasion in October during the study period, and bottom DO levels dropped below the SWRCB standards during eight of ten monitoring cruises from June through October. DO levels in June ranged from 12.4 mg/L at the surface to 4.9 mg/L at the bottom (Figure 9). DO levels in July ranged from 10.3 mg/L at the surface to 2.3 mg/L at the bottom. DO levels in August ranged from 12.7 mg/L at the surface to 1.7 mg/L at the bottom. September DO levels at the surface and bottom ranged from 10.7 to 3.7 mg/L, respectively. DO levels in October ranged from 9.6 mg/L at the surface to 5.9 mg/L at the bottom. November DO readings ranged from 9.5 mg/L at the surface to 7.5 mg/L at the bottom (Figure 9).

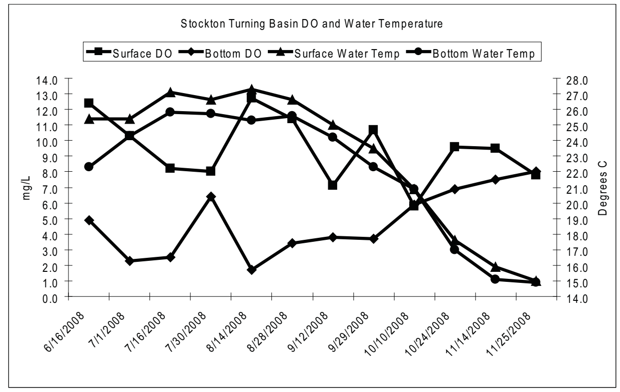

Figure 9 DO and water temperature in the Stockton Turning Basin from June through November 2008

Summary

DO concentrations in the Stockton Ship Channel fell below the SWRCB's 5.0 mg/L and 6.0 mg/L objectives at six stations (excluding the Stockton turning basin) during two of ten monitoring cruises during the study period. The Stockton turning basin was below DO objectives during eight of ten monitoring cruises.

Flows on the San Joaquin River near Vernalis ranged from a low of 584 cfs in July to a high of 1,325 cfs in September. Net daily flow on the San Joaquin River past Stockton ranged from a low of -79 cfs in July to a high of 1,070 cfs in October. The head of Old River barrier was installed by October 16^{th} and completely removed by November 9^{th}.

Further monitoring operations for the summer and fall 2008 special study were suspended after November 25, 2008.

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Specific-Conductance and Water-Temperature Data, San Francisco Bay, California, for Water Years 2006, 2007

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Introduction

This article presents time-series graphs of specific-conductance and water-temperature data collected in San Francisco Bay during water years 2006 and 2007 (October 1, 2005, through September 30, 2007). Specific-conductance and water-temperature data were recorded at 15-minute intervals at seven U.S. Geological Survey (USGS) locations (Figure 1, Table 1).

Specific-conductance and water-temperature data from monitoring stations PSP and SMB were recorded by the California Department of Water Resources (DWR) before 1988, by the USGS National Research Program from 1988 to 1989, and by the USGS-DWR cooperative program since 1990. Monitoring stations BEN and CARQ were established in 1998 by the USGS. The monitoring station at ALC was established in 2003 by the USGS to replace the discontinued monitoring station San Francisco Bay at Presidio Military Reservation. Monitoring station HAM was established in 2005 by the USGS in cooperation with the U.S. Army Corps of Engineers. Both HAM and PSP were discontinued at the end of WY 2006. Monitoring station RICH was established in 2006 by the USGS to replace the discontinued monitoring station PSP.

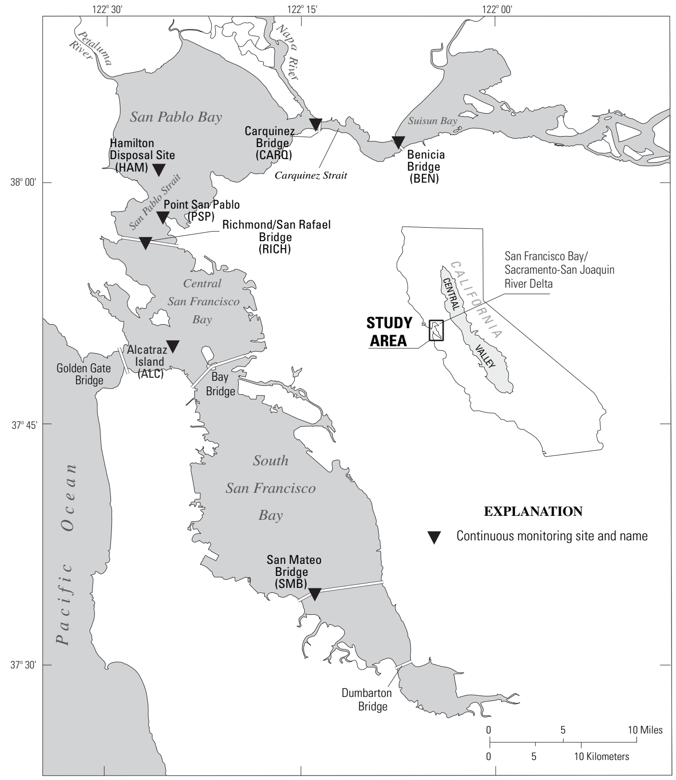

Figure 1 Location of continuous monitoring sites in San Francisco Bay, California

Table 1 Sensor depths (in feet) below mean lower low water 1 (MLLW), San Francisco Bay, California, water years 2006, 2007

Site	Abbreviation	Station No.	Latitude (NAD 1983)	Longitude (NAD 1983)	Sensor depth	Depth below MLLW	Water depth at MLLW[1]
Suisun Bay at Benicia Bridge,					Near-surface	6	
near Benicia, Ca.	BEN	11455780	38°02’42”	122°07’36”	Near-bottom	55	80
Carquinez Strait at Carquinez Bridge, near					Mid-depth	40	
Crockett, Ca.	CARQ	11455820	38°03’41”	122°13’32”	Near-bottom	83	88
San Pablo Bay at Hamilton Disposal near San							
Rafael, Ca.	HAM	380109122250401	38°01’09”	122°25’04”	Mid-depth	10	16
						15	
San Francisco Bay at Richmond/San Rafael					Mid-depth	40	
Bridge near San Rafael, Ca.	RICH	375607122264701	37°56’07”	122°26’47”	Near-bottom		45
					Mid-depth	13	
San Pablo Strait at Point San Pablo, Ca.	PSP	11181360	37°57’53”	122°25’46”	Near-bottom	23	26
San Francisco Bay at NE shore Alcatraz							
Island, Ca.	ALC	374938122251801	37°49’38”	122°25’18”	Mid-depth	6	16
San Francisco Bay at San Mateo Bridge, near					Near-surface	4	
Foster City, Ca.	SMB	11162765	37°35’04”	122°15’03”	Near-bottom	38	48

[a] [1]The mean lower -low water depth is the average of the lower -low water height above bottom of each tidal day observed during the National Tidal Datum Epoch (NTDE). The NTDE is the specific 19-year period (1960-1978 for values given in this report) adopted by the National Ocean Service as the official time segment during which tidal observations are made and reduced to obtain mean values (Hicks, 1983).

Data Collection

Specific-conductance and water-temperature data were collected at two depths in the water column (Table 1) to help define the vertical variability. However, at the shallow ALC and HAM sites, data were collected only at one depth.

Several types of instrumentation were used to measure specific-conductance and water-temperature data in San Francisco Bay. Specific conductance [reported in microsiemens per centimeter at 25°Celsius (C)] was measured using either a Foxboro[1] electrochemical analyzer (calibrated accuracy ± 0.5%), or a YSI 6920-M multi-parameter water quality logger (conductivity cell calibrated accuracy ± 0.5%). Water temperature (reported in degrees Celsius) was measured using a Campbell Scientific thermister (accuracy ± 0.2°C), or a YSI 6920-M multi-parameter water quality logger (temperature probe accuracy ± 0.2°C). The calibrated accuracies stated here are manufacturer specifications and do not reflect the accuracy of collected data. In an environmental monitoring program, potential sources of introduced error include but are not limited to electronic drift, calibration standard inconsistencies, and fouling of sensors.

Monitoring instrument calibrations were checked every two to three weeks. Calibration of the Foxboro specific-conductance instrument was checked using a WTW model 197 conductivity meter (calibrated accuracy ±1%) which was calibrated to a known specific-conductance standard. Direct checks against a known standard are not possible with the Foxboro large-bore probe because of the large volume of standard needed. Calibration of the YSI specific-conductance instrument was checked using a range of known specific-conductance standards. Calibration of the water-temperature instruments were checked using a NIST traceable Cole Parmer thermister (accuracy ± 0.2 °C). Data corrections required as a result of biological fouling or instrument electronic drift were applied to the record following the guidelines described by Wagner and others (2000).

1.The use of firm, trade, and brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey or California Department of Water Resources.

Data Presentation

Figures 2 through 13 show time-series graphs of the specific-conductance and water-temperature data measured at the seven sites in San Francisco Bay. Gaps in the data primarily are caused by equipment malfunctions and fouling. Tidal variability (ebb and flood) affects specific conductance and water temperature (Cloern and others, 1989; Ruhl and Schoellhamer, 2001). To illustrate how tides affect variability of specific conductance, Figure 14 shows the near-surface and near-bottom specific conductance and the corresponding water-level data at the BEN site for the 24 hours of August 6, 2006. The water-level data are not published or referenced to a known datum and are shown only to detail how specific conductance varies with tidal change. Tidal variability was greater in San Pablo Bay than in South San Francisco Bay (Figures 3, 4, 7, 9, 10, 13; Schoellhamer, 1997).

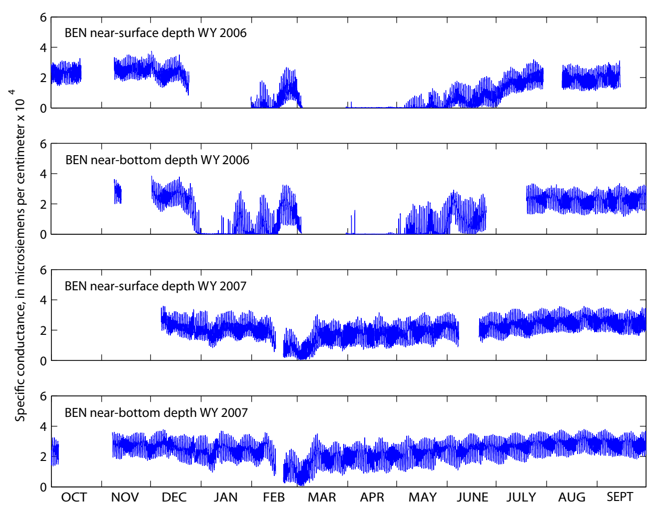

Figure 2 Measurements of specific conductance at Benicia Bridge (BEN), Suisun Bay, water years 2006, 2007. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4).

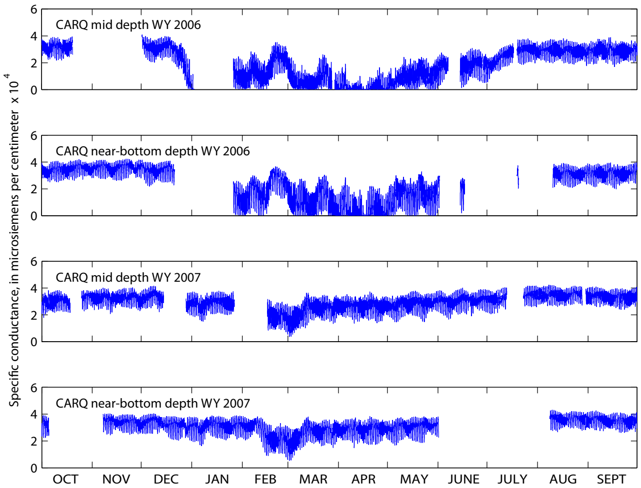

Figure 3 Measurements of specific conductance at Carquinez Bridge (CARQ), San Pablo Bay, water years 2006, 2007. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

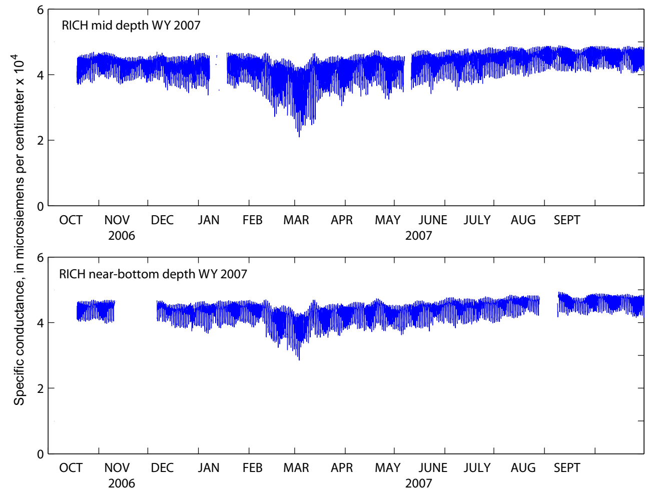

Figure 5 Measurements of specific conductance at Richmond/San Rafael Bridge (RICH), Central San Francisco Bay, water year 2007. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

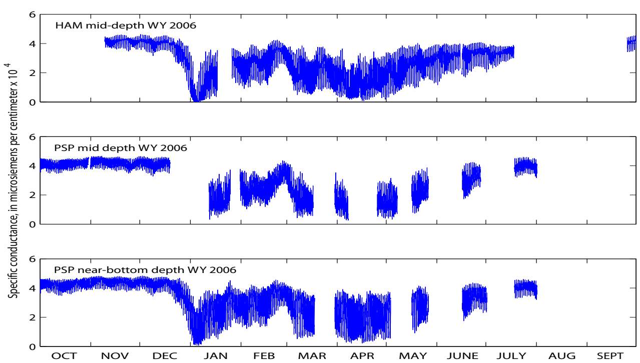

Figure 4 Measurements of specific conductance at Hamilton Disposal Site (HAM), and, Point San Pablo (PSP), San Pablo Bay and Central San Francisco Bay, respectively, water year 2006. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

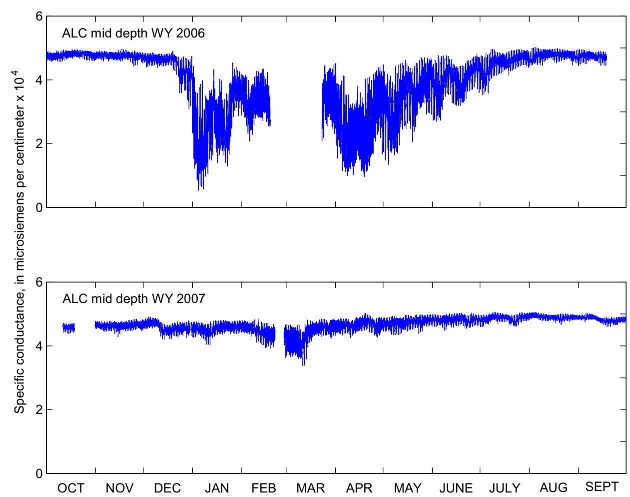

Figure 6 Measurements of specific conductance at Alcatraz Island (ALC), Central San Francisco Bay, water years 2006, 2007. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

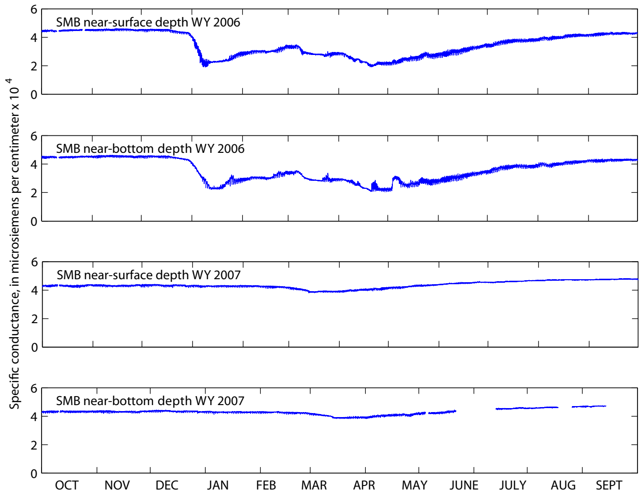

Figure 7 Measurements of specific conductance at San Mateo Bridge (SMB), South San Francisco Bay, water years 2006, 2007. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

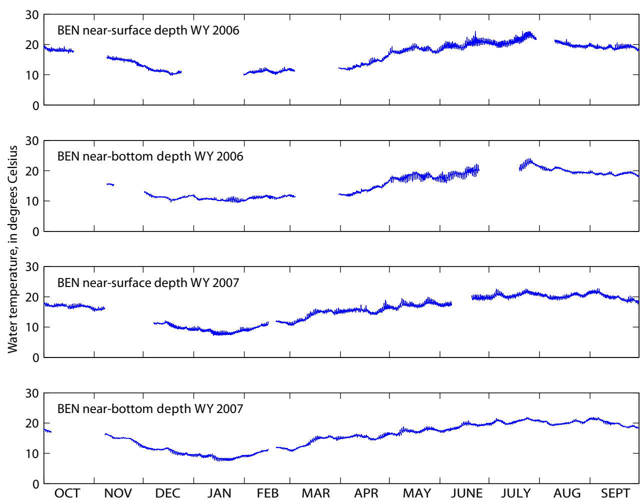

Figure 8 Measurements of water temperature at Benicia Bridge (BEN), Suisun Bay, water years 2006, 2007

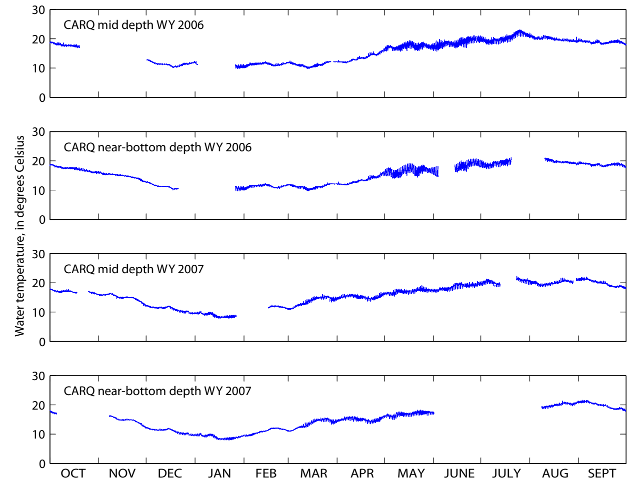

Figure 9 Measurements of water temperature at Carquinez Bridge (CARQ), San Pablo Bay, water years 2006, 2007

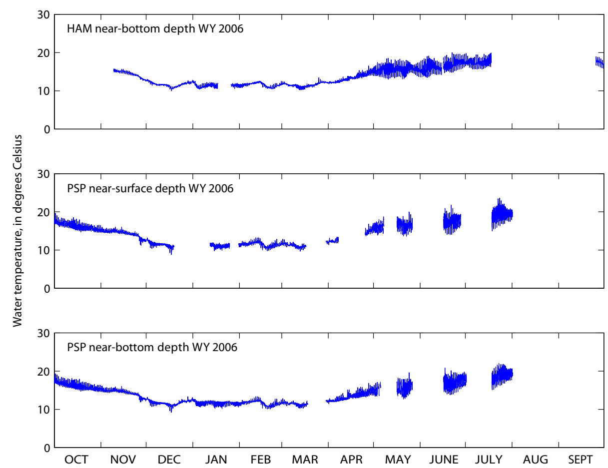

Figure 10 Measurements of water temperature at Hamilton Disposal Site (HAM), and, Point San Pablo (PSP), San Pablo Bay and Central San Francisco Bay, respectively, water year 2006

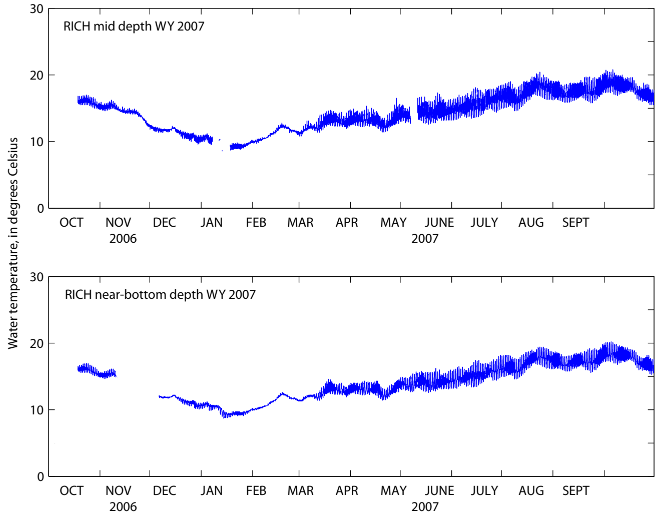

Figure 11 Measurements of water temperature at Richmond/San Rafael Bridge (RICH), Central San Francisco Bay, water year 2007

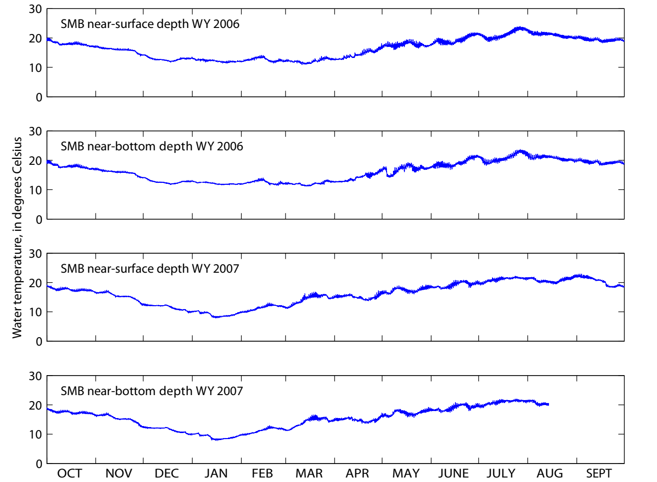

Figure 13 Measurements of water temperature at San Mateo Bridge (SMB), South San Francisco Bay, water years 2006, 2007

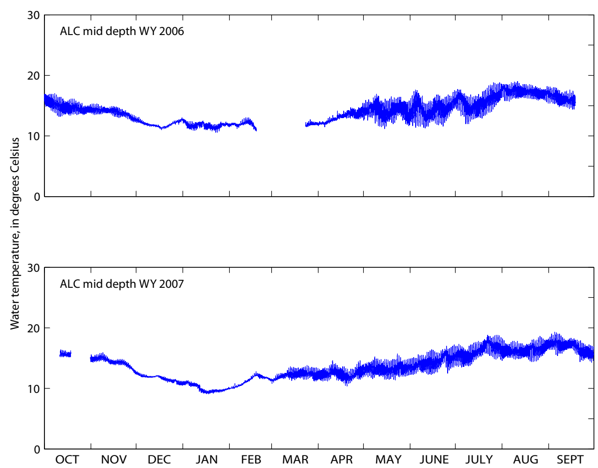

Figure 12 Measurements of water temperature at Alcatraz Island (ALC), Central San Francisco Bay, water years 2006, 2007

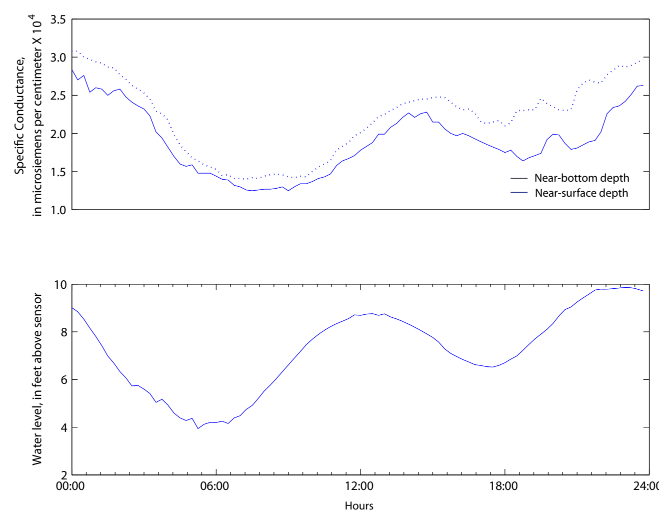

Figure 14 Near-surface and near-bottom measurements of specific conductance and water levels at Benicia Bridge, Suisun Bay, August 6, 2006. For reference, seawater has a specific conductance of about 53,000 microsiemens per centimeter (5.3 x 10^4)

Daily maximum and minimum values of specific-conductance and water-temperature data for the six sites are published annually in the USGS Water Resources Data, California, series, which is available on the USGS website http://ca.water.usgs.gov/archive/waterdata/ (USGS, accessed April 15, 2009). The complete data sets through September 30, 2007, also are available http://sfbay.wr.usgs.gov/sediment/cont monitoring/index.html (USGS, accessed April 15, 2009).

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