



# ***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, larval survey results, a delta smelt pathology study, delta smelt captive breeding, and status and trends of juvenile sturgeon.

Smelt larva surveys represent a relatively new effort to provide early season information on larval longfin smelt. Now in its second year, the IEP survey is required under the State Water Project Incidental Take Permit for longfin smelt to assess the vulnerability of smelt larvae to entrainment in the south Delta export facilities. A positive sign in 2010 was that few larval longfin smelt were captured near the export facilities despite relatively broad fish distributions.

The collapse of delta smelt remains one of the highest profile resource management issues in the Delta. The Kodiak trawl survey (see article by Julio Adib-Samii, DFG) indicates that delta smelt numbers remained very low in 2010. One of the poorly-understood issues is the

role of disease in the recent fisheries declines. The newsletter includes a study by Scott Foott and John Bigelow, who examined the health of delta smelt during winter and spring 2010. An encouraging finding is that the delta smelt population showed no signs of major disease problems during that period.

Given the dire status of delta smelt, there is substantial interest in protective actions. The article by Kathleen Fisch and colleagues describes continued efforts by the UCD Fish Conservation and Culture Lab and USFWS to develop a refugial population as a safeguard against extinction. They report on their latest progress using modern genetic tools to develop a viable refugial population and a captive breeding plan. This program is designed as a safeguard against species extinction, but the studies also provide a useful source of information about the reproduction, behavior, feeding, and development of smelt.

Also included in the Quarterly Highlights is a summary by Jason DuBois and DFG colleagues on juvenile sturgeon surveys. The white sturgeon is a popular sport fish, but green sturgeon remains a major management concern as illustrated by their listing under the state and federal Endangered Species Acts. The juvenile survey highlighted in this article is one of the few sources of information about the distribution and status of juveniles of either type of sturgeon.

# IEP QUARTERLY HIGHLIGHTS

## Delta Water Project Operations (April - June 2010)

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Precipitation during April through June was enough to bring up the water year type to below normal in the Sacramento River Basin and to above normal in the San Joaquin River Basin. Regulated reservoir releases contributed close to 70% of the Delta inflows from Sacramento and San Joaquin Rivers during these months. Figure 1 shows the Sacramento River flow ranged between 13,000 and 30,000 cfs (370 and 860 cubic meters per second) and the San Joaquin River ranged between 2000 and 6100 cfs (54 and 110 cubic meters per second).

SWRCB Bay Delta habitat protection outflow requirements (also known as X2) and the Vernalis Adaptive Management Program (VAMP) were the primary regulatory constraint for the project operations in the Delta during April through June. In addition, U. S. Fish and Wildlife Service and National Marine Fisheries Service’s Biological Opinions for Fishery Protection, along with the California Department of Fish and Game’s Incidental Take Permit No. 2081 were also more restrictive to further control the project’s export level during the same period. The project’s export restriction was significant in resulting higher outflows throughout this period. As shown in Figure 2, the combined CVP and SWP Projects’ export was as low as 1,500 cfs (42 cubic meters per second) during VAMP (April 25 to May 25) and could peak only as high as 7,500 cfs (213 cubic meters per second) due to fishery protection restrictions. Consequently as shown in Figure 1, Delta outflow peaked at 35,000 cfs (991 cubic meters per second) during VAMP and tapered down to 7500 cfs (212 cubic meters per second) by the end of June. During this period of export restrictions, various outages or maintenance projects at the export facilities were typically scheduled in a way that minimized water operational impacts.

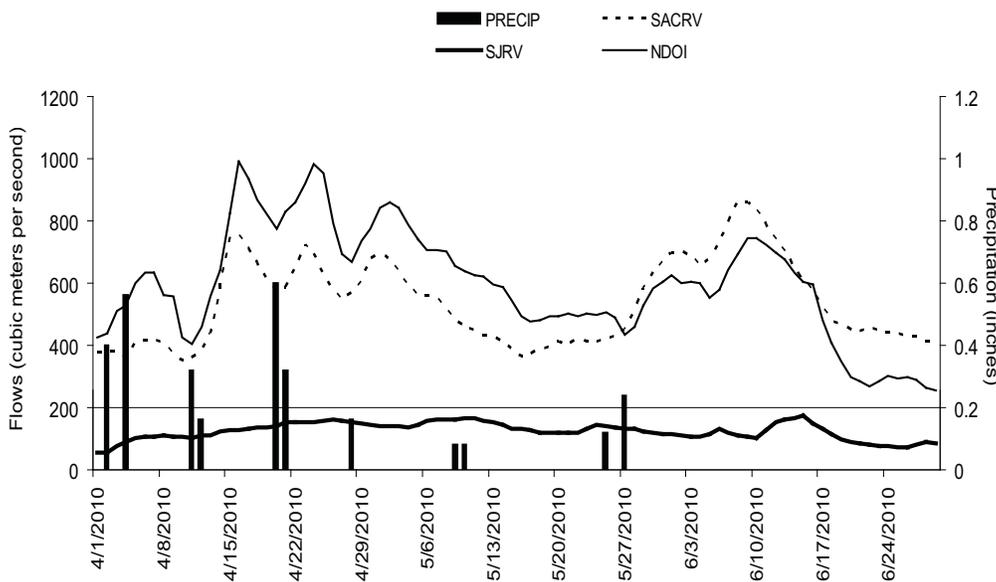


Figure 1 April Through June 2010 Sacramento River, San Joaquin River, Net Delta outflow, and Precipitation

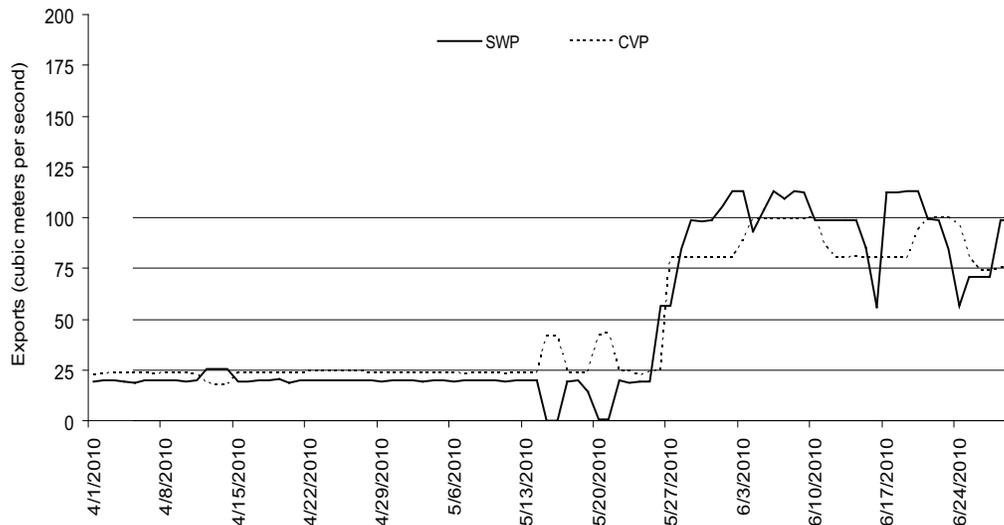


Figure 2 April through June 2010 State water Project and Central Valley Project Exports

## 2010 Smelt Larva Survey

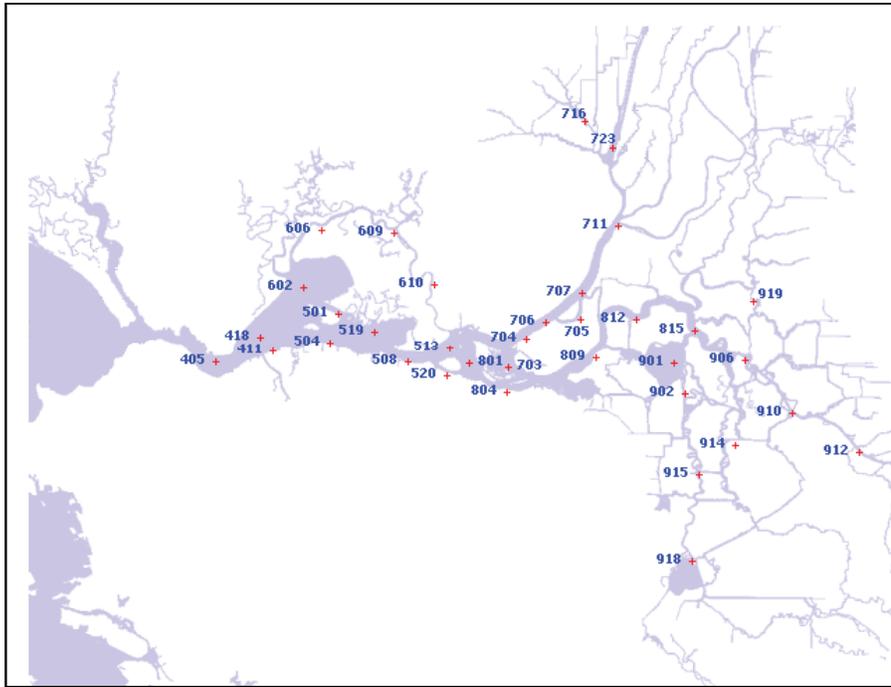
Julio Adib-Samii (CDFG), jadibsamii@dfg.ca.gov

The California Department of Fish and Game (DFG) successfully completed the second field season of the Smelt Larva Survey (SLS) in late March. Initiated in 2009, the SLS monitors the distribution and relative abundance of larval longfin smelt (*Spirinchus thaleichthys*) in near real-time. These data are used to assess the vulnerability of larva to entrainment at south Delta water-export facilities. Longfin smelt are the focus of this program because of their recent listing as threatened under the California Endangered Species Act (CESA).

From January 4 until March 24, 2010, we conducted 6 bi-weekly Delta-wide surveys consisting of a single sample (one 10-minute stepped oblique tow) taken at 35 locations (Figure 1). The net (length = 3.35 m, mouth area = 0.37 m<sup>2</sup>, mesh size = 505 μm) is mounted to a rigid steel frame. Skis are attached to the frame to prevent the frame and net from digging into the substrate during deployment. Once a tow is complete, all larval fish are preserved in 10% buffered formalin and returned to our Stockton laboratory for positive identification. A full description of methods and protocol is available through this author.

A total of 31,385 fish representing 16 species (Table 1) were collected. Longfin smelt, prickly sculpin (*Cottus asper*), and Pacific herring (*Clupea pallasii*) were the most-abundant and most-widely distributed fishes encountered. Yellowfin gobies (*Acanthogobius flavimanus*) was fourth most abundant and the remaining 12 species comprised less than 5% of total catch.

Longfin smelt showed broad distributions throughout each survey and were collected in 88.4% (183 of 207) of all the samples taken (Figure 2). Samples with no longfin smelt were located in the central or south Delta. Highest densities of longfin smelt occurred at or downstream of the Sacramento-San Joaquin confluence in every survey, and average lengths (Figure 3) consistently show that older (larger) larvae occur there more than upstream. Coincident to a 3°C rise in average water temperature from the previous survey (Figure 4) and an increase in average lengths Delta-wide, total catch peaked in Survey 4 (Figure 5) with 4078 longfin larvae collected from 31 of the 35 stations sampled.



**Figure 1 Station locations sampled by the Department of Fish and Game's Smelt Larva Survey**

**Table 1 Total species catch from the Department of Fish and Game's Smelt Larva Survey, 2010**

2010 Smelt Larva Survey: Species Catch		
Common Name	n	% of Catch
Longfin Smelt	14241	45.38%
Prickly Sculpin	9531	30.37%
Pacific Herring	6289	20.04%
Yellowfin Goby	1147	3.65%
Arrow Goby	107	0.34%
Northern Anchovy	26	0.08%
Three Spine Stickleback	12	0.04%
Pacific Staghorn Sculpin	8	0.03%
Delta Smelt	6	0.02%
Bigscale Logperch	6	0.02%
Jacksmelt	3	0.01%
Chinook Salmon	3	0.01%
Shokihaze Goby	2	0.01%
Shimofuri Goby	2	0.01%
White Catfish	1	0.003%
Cyprinids (Unid)	1	0.003%

The SLS proved to be a useful tool for resource management. We provided weekly catch reports (distribution and abundance) to the Smelt Working Group (SWG) for its use in assessing entrainment risk to delta smelt and longfin smelt larvae. Our data, coupled with that of other agencies, allowed the SWG to make informed recommendations to the U.S. Fish and Wildlife Service regarding larval delta smelt, and to DFG's Director regarding the impact of water export operations on larval longfin smelt. Such recommendations to DFG's Director are required by Section 5.2 of the *California Endangered Species Act Incidental Take Permit No. 2081-2009-001-03*, which states: "To protect larval and juvenile longfin smelt during the January through June period, the SWG or DFG SWG personnel shall provide OMR (Old and Middle River) flow advice to the WOMT (Water Operations Management Team) and to the Director weekly." Further, "When a single Smelt Larva Survey (SLS) or 20 mm Survey (20 mm) sampling period results in: 1) longfin smelt larvae or juveniles found in 8 or more of the 12 SLS or 20 mm stations in the south Delta (Stations 809, 812, 815, 901, 902, 906, 910, 912, 914, 915, 918, 919) or, 2) catch per tow exceeds 15 longfin smelt larvae or juveniles in 4 or more of the 12 survey stations listed above, OMR flow advice shall be warranted" (available at <http://www.dfg.ca.gov/delta/data/longfinsmelt/documents/ITP-Longfin-1a.pdf>).

The next bi-weekly SLS is scheduled to begin in early January 2011 and conclude in March or April (depending on water year). All data is available through our FTP site (<ftp://ftp.delta.dfg.ca.gov/Delta%20Smelt/>), and fish distribution maps are available on our project web-page

(<http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SLS>).

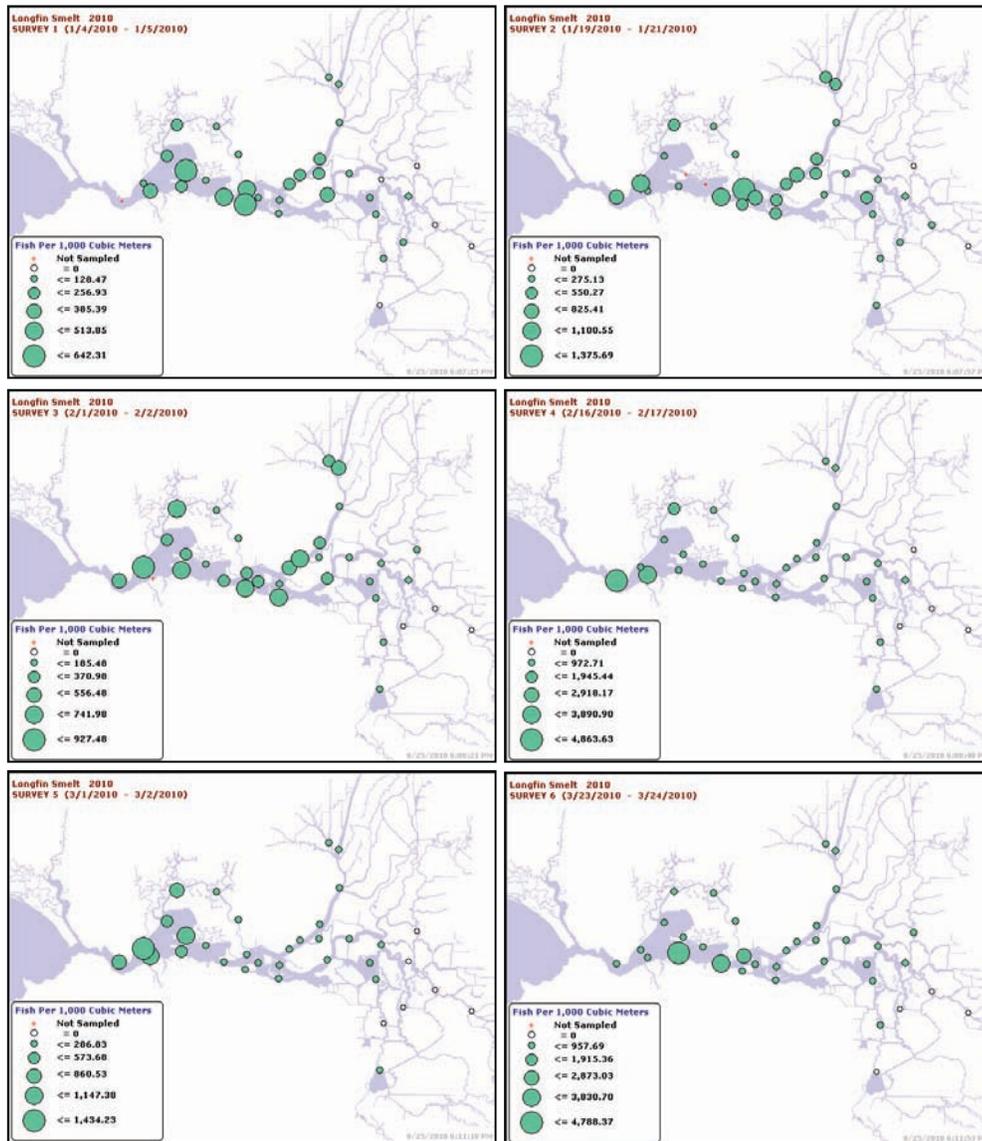
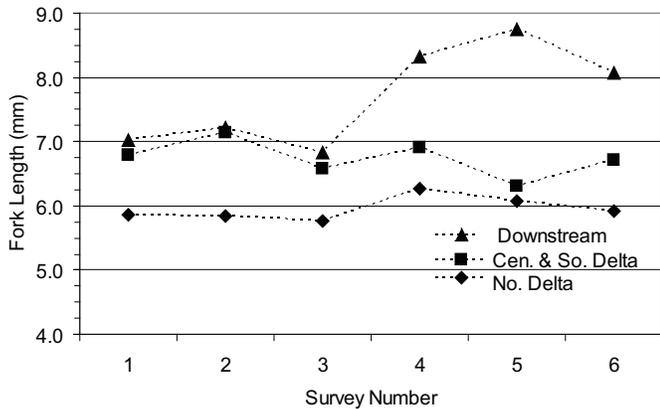
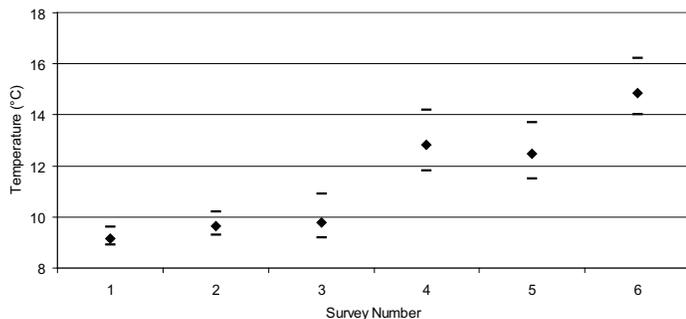


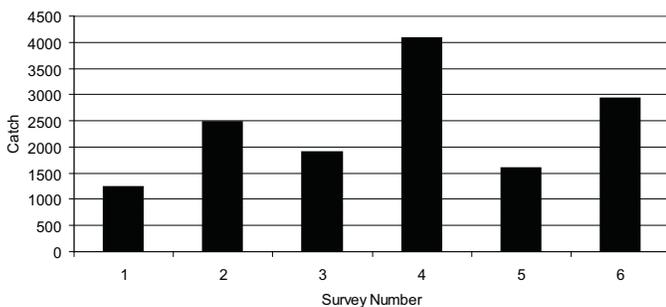
Figure 2 Geographical distribution and catch per unit effort of longfin smelt collected by the Department of Fish and Game's Smelt Larva Survey, 2010. Bubble plots are taken from the Smelt Larva Survey web-page (<http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SLS>).



**Figure 3 Average fork lengths of longfin smelt collected in DFG's Smelt Larva Survey, 2010. Fork lengths are grouped by survey number for 3 distinct geographic regions. Downstream refers to fish collected below Decker Island on the Sacramento River and below Jersey Point on the San Joaquin River. Cen. & So. Delta refers to stations within the Central and South Delta. No. Delta refers to stations above Decker Island on the Sacramento River.**



**Figure 4 High, low, and average temperatures for each survey of DFG's Smelt Larva Survey, 2010.**



**Figure 5 Summed catch (by survey) of longfin smelt collected by DFG's Smelt Larva Survey, 2010.**

## Disease Occurance in Adult Delta Smelt Captured in Sacramento River Kodiak Trawl, 2010

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### Abstract

Delta smelt abundance has declined drastically and the species was listed as threatened in 1993. The role of disease in this decline is largely unknown. One hundred and five adult smelt, collected from the lower Sacramento River between January and May 2010, were surveyed for infectious agents, blood leukocyte profile, and gill Na-K-ATPase activity. Few tissue changes or significant parasitic infections were observed in histological specimens and there was a low incidence of bacterial isolations. Asymptomatic *Mycobacterium sp.* infection was detected in 54% of the samples by PCR; however, this bacterial group was not isolated in culture. Gill Na-K-ATPase activity was lower in the January sample than subsequent month collections. The number of blood granulocytes increased between March and May. Disease did not appear to be an overt influence on the surveyed population in the spring of 2010.

### Introduction

The delta smelt (*Hypomesus transpacificus*) was listed as threatened under the Endangered Species Act in 1993 and is endemic to the upper San Francisco Bay Estuary (Moyle et al. 1992). In the last decade, a clade of pelagic organisms in the delta has declined in abundance (Feyrer et al. 2007). Potential factors associated with these declines in delta smelt include reduction in freshwater flows, entrainment losses at diversions and power plants, inadequate food base and competition for food from exotic species, environmental contaminants, and predation by exotic fishes. Only limited work has been reported on smelt disease (Antonio et al. 2000, Teh 2007). Our objective was to determine the presence of infectious pathogens (virus, bacteria, or parasites), tissue abnormalities (gill, liver, intestinal tract), peripheral blood cell profile, and gill Na-K-ATPase activity in adult smelt captured in the lower Sacramento River between January and May 2010.

## Methods

One hundred and five adult smelt were sampled from the California Department of Fish and Game (CDFG) Bay-Delta Kodiak trawl collections in the Sacramento River between January–May 2010 (Table 1). After initial evaluation of maturity by a CDFG biologist, the following actions were taken: (1) fish were euthanized in 100 mg/L benzocaine; (2) measured by caliper (standard length; mm), weighed (Pesola micro-line 20010 hanging balance, 0.1g), and condition factor calculated ( $(\text{g}/\text{mm}^3) \times 10^5$ ); (3) caudal peduncle severed and blood collected in microhematocrit tube; (4) blood was transferred into cold L-15 separation solution or smeared directly onto glass slides; (5) gill tissue placed into 100  $\mu\text{L}$  Sucrose-EDTA-Imidazole solution and frozen on dry ice; (6) liver aseptically removed with half placed into Brain Heart Infusion (BHI) broth transport media and the other half placed into a tube and frozen on dry ice; (7) anterior kidney removed and placed into cold antibiotic-antimycotic solution; and, (8) gill and viscera placed into Davidson's fixative for 24 h and processed for 6  $\mu\text{m}$  histological sections. The remaining carcass (head into ethanol, body and gonad into 10% formalin) was given to CDFG for other researchers.

Anterior kidney was pooled (1 to 5 fish) in 1 mL antibiotic/mycotic solution and held on ice for 18–24 h until processed (American Fisheries Society-Fish Health Section 2007). The samples were sonicated (Heat system Microson XL2005, Farmingdale NY) for 10 s at #3 setting to disrupt the tissue, centrifuged at  $10,000 \times g$  at 4 °C, supernatant diluted 2x and 4x in Hanks Buffered Salt Solution, and 100  $\mu\text{L}$  samples inoculated onto duplicate wells of EPC, CHSE214, BF2, and SSN1 cell cultures maintained in 48 well plates. Cultures were incubated for 18 d at either 15 °C (EPC and CHSE214) or 25 °C (BF2 and SSN1) and examined every 3 or 4 days.

Liver in BHI broth was inoculated onto BHI agar and incubated at 20–25 °C for 48–72 h as well as Middlebrook 7H10 media. For the 05 May collection, Lowenstein-Jensen 5% NaCl media was also inoculated. Both Middlebrook and Lowenstein-Jensen media were incubated at 25 °C for 18–20 d. Any colony obtained from either Middlebrook or Lowenstein-Jensen media was acid-fast stained to presumptively identify *Mycobacterium* (Antonio et al. 2000, Stine et al. 2010). An ATCC culture of *Mycobacterium marinum* (ATCC 11565) was grown on Middlebrook 7H10 media to verify its suitability for the survey. Isolates from BHIA were identified to genus or clade (American Fisheries Society-Fish Health Section 2007). DNA from frozen liver was extracted with

a Qiagen Cube using the manufacturer's procedure (<http://www.qiagen.com/qiacube>) and sent to the Real-time PCR Research and Diagnostics Core Facility, School of Veterinary Medicine, Department of Medicine and Epidemiology, University of California, Davis to be analyzed in their proprietary MTC assay for multiple *Mycobacterium* species ([http://www.vetmed.ucdavis.edu/vme/taqman-service/Bacteria\\_assays.html](http://www.vetmed.ucdavis.edu/vme/taqman-service/Bacteria_assays.html)).

Fixed tissue was processed for 6  $\mu\text{m}$  paraffin sections and stained with hematoxylin and eosin (H&E). Sagittal sections, of a 30 mm larvae collected on 05 May, were stained by both H&E and Nissel stain for neurons ([www.ihcworld.com/protocols/special\\_stains](http://www.ihcworld.com/protocols/special_stains)). Tissues examined microscopically included gill, liver, intestine, adipose tissue, pancreatic acinar cells, spleen, and heart. Not all tissues were sectioned for each fish.

In March, blood smears were immediately prepared using a cover slip, air-dried, fixed in cold methanol for 5 minutes, and protected from light until further processing. During April and May, blood was dispensed from the hematocrit tubes into Eppendorf tubes containing L-15 separation solution (1,000  $\mu\text{L}$  of Lebowitz L-15 media, 75  $\mu\text{L}$  of 7.5% fetal bovine serum, and 2  $\mu\text{L}$  of 5 KU / mL heparin). Blood smears were then prepared 4–8 h later by brief vortexing, placing 200  $\mu\text{L}$  of the suspension into a single well cyto-spin chamber, centrifuged at 1,600 rpm for 4 min in a StatSpin Cytofuge (StatSpin, Inc., Norwood, MA), air-dried and fixed in cold methanol for 5 minutes. For panoptical staining, blood smears were treated according to a modified Leishman-Giemsa staining protocol of Yasutake and Wales (1983). For each peripheral blood smear, 81–115 leukocytes were classified as lymphocytes, granulocytes, or thrombocytes on the basis of panoptical staining characteristics (Blaxhall and Daisley 1973) by examination at 100x magnification and expressed as a proportion of the total number of leukocytes classified. A lymphocyte to granulocyte ratio was calculated for each sample (Modra et al. 1998). Gill Sodium-Potassium-Adenosine Triphosphatase activity (ATPase =  $\text{mmoles ADP}/\text{mg protein}/\text{hr}$ ) was assayed by the method of McCormick and Bern (1989). Statistical analysis was performed with SigmaStat 3.1 software on raw data. Normality was tested by the Kolmogorov–Smirnov method at the  $P=0.05$  level. One-way ANOVA or T-test (data with normal distribution, reported with F or t value) or Kruskal-Wallis ANOVA or Mann-Whitney U test with subsequent multiple comparison procedures (Holm-Sidak or Dunns method respectively,  $\alpha \leq 0.05$ ) was used to compare groups.

## Results

Male smelt averaged 62 mm in standard length (SL) while the mean female SL was 66 mm (Table 2). Similarly, female wet weight and condition factor was higher than males due to their gravid condition. No abnormalities (cytopathic effects) were observed in the 4 cell lines over the 18 d incubation periods (Table 3). The eighteen anterior kidney pools (1-5 fish / pool) tested contained a total of 79 smelt. It was necessary to add fresh media to SSN1 and BF2 cultures to maintain them for the full 18 days. Liver samples inoculated onto the general purpose media, Brain Heart Infusion Agar, isolated a low incidence of aquatic bacteria (*Aeromonas* / *Pseudomonas* sp. and *Staphylococcus* / *Micrococcus* sp.). Middlebrook cultures, collected on 13 January, were contaminated with fungi and environmental bacteria related to the outside inoculation conditions and discarded. On subsequent trips, fish dissection and tissue collection were done within the boat's cabin. No acid-fast bacteria were isolated from either the Middlebrook 7H10 or Lowenstein-Jensen 5% NaCl media (Table 3). In contrast, 54% of the livers tested positive for *Mycobacterium* sp. DNA by PCR assay. These *Mycobacterium* data indicate a high incidence of asymptomatic, carrier-state infections but not a significant health problem for the sample population.

Few tissue abnormalities and no overt infectious disease was observed in 72 histological specimens (Table 4) Helminth parasites (nematode and trematode) were seen in < 10% of intestine, visceral adipose, or liver sections. No lesions were associated with the parasites. No parasitic infection was seen in gill sections. Focal liquefactive necrosis was observed in 7% of the liver sections and occurred primarily in the 10 February collection. The cause of the lesion is unclear as there was no association with bacterial or parasitic infection. Post-mortem artifact cannot be ruled out. No acid-fast bacteria (e.g. *Mycobacterium*) were observed in a pancreatic acinar tissue granuloma from a 13 January sample. Spleen contained multifocal regions of endogenous pigments / melanomacrophage centers. Small foci of lipofuscin were seen in the visceral adipose tissue of 2 fish. No necrotic neurons were seen in the brain and retina (Nissel stain) of the 30 mm larvae collected on 05 May.

Gill Na-K-ATPase activity was significantly lower in the 13 January samples compared to subsequent collection groups, however, low sample numbers reduce our confidence in its biological significance (Table 5, ANOVA  $F=6.984$ ,  $P=0.001$ ). Twenty-five percent of the samples did not produce enzymatic activity. Protein con-

centrations of these “no activity” samples were similar to the other samples. We suspect the quantity of muscle and bone was in excess of gill filament in these samples but cannot rule out other explanations. Eight of the ten “no activity” samples occurred in the January and February collection groups. Mean activities of smelt ranged from 10.7 to 20.9; in comparison, mean gill Na-K-ATPase activity ranges of juvenile Chinook smolts assayed by the same methods ranged from 7.0 – 11.2  $\mu\text{mole ADP/mg protein/hr}$  (Foott et al. 2007).

Thrombocytes, lymphocytes, and granulocytes were present in proportions of 0.876, 0.119, and 0.006 in males, of which 8 of 9 males were captured during March (Figure 1, Table 6). Females displayed the same order of prevalence (Thrombocyte>lymphocyte>granulocyte) in peripheral blood leukocyte types as males during March, April, and May. Granulocyte numbers increased over time in the females resulting in a lower Lymphocyte: Granulocyte ratio in May compared to March or April.

**Table 1 Adult delta smelt collection dates in 2010, site numbers and associated fish numbers per site.**

SITE	13-Jan	10-Feb	10-Mar	11-Mar	7-Apr	5-May
606	NT	NT	NT	2	NT	NT
704	8	NT	5	NT	12	2
706	6	1	4	NT	NT	NT
707	NT	NT	2	NT	NT	NT
713	1	NT	4	NT	NT	NT
715	3	7	7	NT	NT	1
716	NT	2	6	NT	NT	1
719	5	2	12	NT	25	2 <sup>a</sup>

a including a 30mm larvae sampled for histology

**Table 2 Mean (SE) standard length, weight, and condition factor ((g/mm<sup>3</sup>) x 105) of male and female delta smelt during January, February, March, April, and May of 2010. Sample number for fish identified to sex is less than total number of fish collected in 2010.**

	Male	Female
<b>Standard length (mm)</b>	62 (4)	66 (4)
sample number	30	60
<b>Weight (g)</b>	2.1 (0.3)	2.7 (0.6)
sample number	26	59
<b>Condition factor</b>	0.895 (0.119)	0.936 (0.115)
sample number	26	59

**Table 3 Viral assay, bacterial culture (Brain heart infusion agar [BHIA] and mycobacterium media Middlebrook 7H10 [MB]), and Mycobacterium sp. [Mycob] PCR results. Data reported as number positive / monthly sample number (or viral pools) collected in Kodiak trawls from 13 Jan to 05 May 2010 and incidence (total positive / total samples (%)). If sample was not performed or collected it is designated as "ND".**

Assay	13-Jan	5-Feb	10-Mar	11-Mar	7-Apr	5-May	Incidence
Viral (pools)	0 / 5	0 / 3	ND	0 / 1	0 / 8	0 / 1	0 / 18 (0)
BHIA AP <sup>a</sup>	5 / 23	0 / 12	ND	0 / 2	2 / 33	0 / 5	7 / 75 (9)
BHIA SM <sup>b</sup>	0 / 23	0 / 12	ND	0 / 2	2 / 33	0 / 5	2 / 75 (3)
MB	ND	0 / 12	ND	0 / 2	0 / 33	0 / 5 <sup>c</sup>	0 / 19 (0)
Mycob-PCR	18 / 23	6 / 11	ND	2 / 2	9 / 27	1 / 4	36 / 67 (54)

a Aeromonas-Pseudomonas clade

b Staphylococcus - Micrococcus clade

c Lowenstein - Jenson 5% NaCl media also used for Mycobacterium isolation

**Table 4 Histological observation of parasites (para) or tissue abnormalities (abn) such as nematode (nem), trematode (trm), granulomatous foci (grn), inflammatory cell foci (icf), liquefactive necrosis foci (lqn), and endogenous brown pigment foci (bpf). Reported as number of specific tissues positive for either parasites or abnormality / total sections by date of collection and incidence (total positive / total samples (%)). If there are no specific tissues in sections of a given collection it is designated as "NT".**

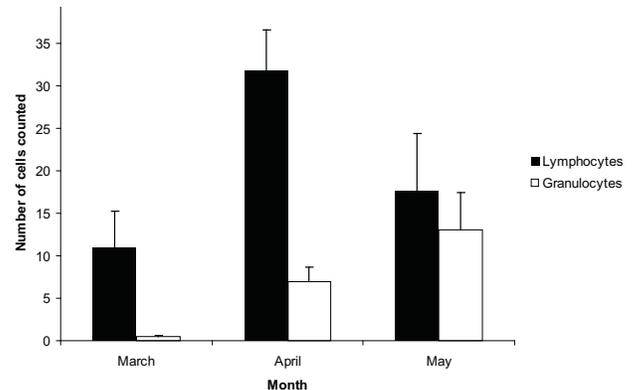
Tissue	para / abn	13-Jan	10-Feb	10-Mar	11-Mar	7-Apr	5-May	Incidence (%)
Gill		0 / 12	0 / 12	0 / 21	0 / 2	0 / 14 <sup>a</sup>	0 / 4	0 / 65 (0)
Heart		0 / 6	0 / 4	0 / 6	NT	0 / 5	NT	0 / 21 (0)
Intestine	nem	15-Feb	0 / 12	0 / 23	0 / 2	0 / 16	0 / 4	2 / 72 (3)
Stomach		0 / 16	0 / 12	0 / 19	0 / 2	0 / 16	0 / 4	0 / 64 (0)
Acinar	grn	1 / 15 <sup>b</sup>	NT	0 / 21	NT	0 / 12	0 / 3	1 / 51 (2)
Adipose	nem	0 / 15	0 / 11	1 / 21	0 / 1	1 / 11	0 / 3	2 / 62 (3)
	trm	0 / 15	0 / 11	0 / 21	0 / 1	0 / 11	1 / 3	1 / 63 (2)
Liver	icf	1 / 15	0 / 7	0 / 21	0 / 1	0 / 2	0 / 3	1 / 59 (2)
	lqn	0 / 15	4 / 7	0 / 21	0 / 1	0 / 2	0 / 3	4 / 59 (7)
	trm	0 / 15	0 / 7	1 / 21	0 / 1	0 / 2	0 / 3	1 / 59 (2)
Spleen	bpf	3 / 3	2 / 2	NT	NT	2 / 2	NT	7 / 7 (100)

a late fixation resulted variable levels of post-mortem changes in gill morphology

b no acid fast bacteria observed within the granuloma

**Table 5 Mean (SE) Gill Na-K-ATPase activity ( $\mu$ mole ADP/mg protein/hr), total gill sample set and number of samples showing no activity (not included in analysis) from adult delta smelt by sample date. Letters in common indicate the differences were not significant. The single 11 Mar sample was not compared to other groups.**

	13-Jan	10-Feb	11-Mar	7-Apr	5-May
<b>Mean (SE)</b>	10.7 (1.2) a	20.9 (2.8) b	8.6	17.6 (0.9) b	19.0 (2.4) b
<b>Total</b>	13	12	2	8	5
<b>No activity</b>	3	5	1	1	0



**Figure 1 Mean number of lymphocytes and granulocytes counted (bar = SE) in peripheral blood of female delta smelt. Insufficient male samples excluded them from temporal analysis.**

**Table 6 Proportion of leukocytes [mean (SE); minimum and maximum; and coefficient of variation] for male, female, and combined sexes in delta smelt peripheral blood.**

Leukocyte Type	Male	Female	Both sexes
<b>Sample number</b>	9	24	33
<b>Lymphocytes</b>			
mean (SE)	0.119 (0.029)	0.167 (0.034)	0.154 (0.026)
Min. - Max.	(0.030 - 0.300)	(0.000 - 0.610)	(0.000 - 0.610)
Coef. Variation	0.719	0.989	0.962
<b>Granulocytes</b>			
mean (SE)	0.006 (0.002)	0.045 (0.014)	0.034 (0.0105)
Min. - Max.	(0.000 - 0.020)	(0.000 - 0.291)	(0.000 - 0.291)
Coef. Variation	1.308	1.526	1.78
<b>Thrombocytes</b>			
mean (SE)	0.876 (0.030)	0.879 (0.042)	0.813 (0.032)
Min. - Max.	(0.690 - 0.970)	(0.301 - 1.000)	(0.301 - 1.000)
Coef. Variation	0.103	0.258	0.225

## Discussion

Adult delta smelt, collected from the lower Sacramento River in the spring of 2010, were apparently healthy as demonstrated by lack of clinical signs or morbidity, few tissue changes or significant parasitic infections observed in histological specimens, or microbiological isolations. While a high incidence of asymptomatic *Mycobacterium* sp. infection was detected by PCR, this bacterial group was not isolated in culture. Antonio et al. (2000) reported the occurrence of *Mycobac-*

*terium* disease in delta smelt broodstock held at  $\geq 16^\circ\text{C}$  and stressed by handling. Similar mycobacteria disease has occurred in captive post-spawning smelt held at Livingston Stone National Fish Hatchery. In contrast to a stressful culture situation, Antonio et al. (2000) were not able to culture *Mycobacterium* in recently caught smelt. Similar to the histological data, Teh (2007) reported no significant disease or parasitic infection observed in 385 adult smelt collected from all regions of the Delta in 2005. Teh (2007) stated that liver abnormalities (glycogen

depletion, cytoplasm eosinophilic inclusion, fat vacuoles, single cell necrosis, and inflammation) were common observations.

The occurrence of melanomacrophage foci in the spleen has been reported in other fish. Melanomacrophage centers are common in fish hematopoietic tissues and act as depositories of oxidized materials, scavenged iron, and some micro-parasites (Aguis and Roberts 2003). The macrophages contain a mixture of endogenous pigments such as lipofuscin or ceroid, melanin, and hemosiderin. The extent of such foci has been associated with contaminate exposure or hypoxic conditions (Fournie et al. 2001).

We do not have an adequate explanation for the “no activity” gill Na-K-ATPase samples collected in January and February. While collection, storage, and processing error could be the cause, metal exposure has been reported to impair Na-K-ATPase activity (Lauren and McDonald 1985, Roger et al. 2003). Delta smelt are exposed to a variety of contaminants that could affect their health and physiology (Kuivila and Moon 2004, Foe 1995).

Increased granulocyte numbers in the blood between March and May are counter to that observed by other workers where lymphocyte numbers and overall specific immune function tend to increase with increasing seasonal temperature. Alcorn et al. (2002) report temperature influence on lymphocyte to granulocyte ratios with greater numbers of peripheral blood lymphocytes in Sockeye salmon reared at 12 °C than 8 °C. Similarly, Luskova (1998) states the white blood cell count (leukocyte) increases with higher seasonal water temperatures in brown trout. Higher granulocyte counts result in low L : G ratio values and can indicate infection, tissue damage, or seasonal blood cell changes (Modra et al 1998). It is unclear what influenced the higher granulocyte numbers in the May collection given that water temperature increased throughout the spring and we did not detect clinical infections or tissue lesions in the gill or viscera.

The extreme stress of capture and handling associated with the Kodiak trawl would likely influence blood measurements. Delta smelt are extremely sensitive to handling stress (Swanson et al. 1996) and the effect on peripheral blood cells could induce an artifact. It is unlikely that leukocyte evaluation will be a valid biomarker for captured smelt. Physiological measurements, that utilize tissue or blood, are limited by the small size of smelt. The use of sentinel fish is one option for examining the effects of water quality on the health and physiology of these fish.

## Acknowledgements

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## Captive Breeding Plan for the Endangered Delta Smelt: Genetic Management and Fish Rearing Modifications for 2010

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### Introduction

The following constitutes an update for the captive breeding plan for the delta smelt refugial population at the Fish Conservation and Culture Lab (FCCL of University of California, Davis, UCD; located near Byron, California) in collaboration with the Genomic Variation Laboratory of UCD. The population is considered “refugial” in the sense that we have sequestered a portion of an endangered natural population to a manmade refugium (the FCCL) that, under proper genetic management, could serve as source material to replenish the natural population if necessary. The captive refugial population (or simply: refugial population) was initiated in 2008 with wild-caught captive 2-year-old delta smelt (Fisch et al. 2009a)

in rapid response to alarmingly low population abundance estimates (Sommer et al. 2007; Baxter et al. 2007; Feyrer et al. 2007) and has progressed to the F<sub>3</sub> generation in 2010. A representative sub-group of captive delta smelt is transferred to Livingston Stone National Fish Hatchery, Shasta Lake, California (U.S. Fish and Wildlife Service) annually to protect against catastrophic loss at either facility.

The goal of the delta smelt refugial population program is to provide a genetic bank of delta smelt that is representative of the wild population, as a safeguard against species extinction. To date, the refugial population is genetically managed each year and wild fish are incorporated to preserve gene diversity and the evolutionary potential of the species. Current breeding practices are reviewed and the following recent changes in methodologies are assessed in light of this goal:

- Testing new methods to consolidate broodfish for space and fish handling efficiencies
- Tagging and fin clipping a large sub-sample of the captive population prior to the spring spawning period to expedite parentage analysis
- Developing a software program to recommend pair crosses that minimizes mean kinship among offspring
- Improving larval and juvenile rearing systems, feeding, and fish handling practices

A review of data for the delta smelt captive refugial population over the past 2 years is generally positive, however, survival to adulthood of fish spawned late in the year appears to be compromised. Impacts of this late-spawning group of fish on the captive refugial population and breeding plan will be discussed.

### Methods for spawning the F<sub>2</sub> generation and rearing the F<sub>3</sub> larval through sub-adult life stages

#### General rearing plan, terminology and facilities

A large population of delta smelt is spawned and reared each year in captivity to maintain an effective population size of approximately 500 individuals. More than 500 broodfish are selected through genetic analysis to

make approximately 250 single-pair crosses per year. Fin clips and fish tag identification numbers are sent to the Genomic Variation Laboratory at UCD for genetic analysis, pedigree reconstruction, and mate selection. Recommended pair crosses are relayed back to the FCCL, where gametes are manually expressed to produce the desired full-sibling families. Currently, a target number of 750 full-sibling fertile eggs from each pair cross are combined with 7 other full-sibling egg sets to give an initial multi-family rearing group of 6000 eggs. Multi-family groups (MFGs) are reared in 32 of the 40 larval- and juvenile-sized tanks currently available, to give a starting population size of about 200 000; expected survival is about 10-20% to adulthood. Additional delta smelt are reared to meet various research needs. A target population of 50 wild broodfish is collected to become part of the refugial population each year. Facility size and design constrains total capacity and rearing techniques employed. Currently, the facility designated to hold the refugial population ("refuge facility"), is undersized and nearly the entire aquaculture facility (adjacent facility of similar size at FCCL) is also required to rear the delta smelt refugial population each year (see Fisch et al. 2009). As a result, plans are underway to initiate an expansion (Phase II of construction) of the current refugial facility.

Fish handling, rearing techniques and facilities were similar to 2009 (Fisch et al. 2009a). The majority of changes for 2010 are indicated below. New marking and tagging methodologies were implemented with the F<sub>2</sub> young-adult fish (ca. 50mm) in 2009-2010. An adipose fin clip was administered in October 2009 to 1 of the 2 multifamily groups, which allowed unique identification of the 2 multifamily groups (200 randomly selected fish/group; 1 group with mark) once combined into a single tank (1000L; adult-sized tank). In this way, almost the entire captive broodfish population (of 31 MFGs) was consolidated into 16 tanks (1000L) at the refugial facility. Younger broodfish, spawned late in the previous year (fish with higher MFG ID numbers), appeared to be compromised in terms of survival and growth, and were held separately, and at lower density, in indoor adult tanks at the aquaculture facility. Tagging and fin clipping of fish proceeded as in 2009, except it was initiated more than a month earlier in 2010 (tagged January 5-13, measured January 26 -27) to allow more time for tagging process, and for the genetic analysis and pedigree reconstruction of the adult F<sub>2</sub> generation prior to the spawning season. Delta smelt were tagged, weighed, and measured (20 randomly selected fish/MFG) totaling about 600 fish for the

January effort. Another length measurement was obtained in April (7-9) from each multi-family group to estimate growth. As the marked fish matured, they were transferred to sex-specific tanks and their ID information was given to the Genomic Variation Lab to recommend best pair crosses. Additional F<sub>2</sub> broodfish were tagged, fin clipped, and identified throughout the spawning season as needed, to improve representation of the F<sub>1</sub> and F<sub>2</sub> generations in the F<sub>3</sub> generation. Wild delta smelt were collected in December 2009 (75 wild fish; 77% survival at 72 hrs) to supplement the captive refugial population.

Refugial facility rearing systems were reconfigured during late 2009 and early 2010 to separate larvae and juveniles into independent re-circulating rearing systems, which benefit each life stage. Elevated head tanks (supplying system water pressure) were placed on the floor, as a safety measure, and the systems were pressurized. Early juvenile fish (ca. 40-80 DPH) were then reared under lower incident light (ca. 1-2 μmoles/m<sup>2</sup>/sec) than in 2009 (ca. 4-5 μmoles/m<sup>2</sup>/sec), in an attempt to reduce stress. Bead filters, which help remove excess particles, were added to each system to improve water quality.

Several feeding and rearing changes were implemented in 2010 for the larval and juvenile life stages and are briefly described here: (1) culturing rotifers (*Brachionus plicatus*) with "RotiGrow Plus" (omega fatty acid and algal blend) instead of the micro-algae, *Nannochloropsis*, used in 2009 (both from Reed Mariculture, Campbell, California) and feeding rotifers at a higher density in 2010 (10L rotifers/6000larvae/130L-tank/day vs. 6L/6000 larvae/tank in 2009); (2) feeding the more nutritious stage (newly-hatched stage) of the brine shrimp prey (*Artemia* sp.) to larvae through juvenile fish stage; (3) delay in feeding prepared diet mixture (Cyclop-eeze® from Argent Lab, Redmond, Washington, and EPAC/NRD 4/6 from "INVE Aquaculture", 50:50 mixture) to juvenile fish until they reach 120 days post hatch (DPH; vs. Cyclop-eeze® initiated at about 70 DPH in 2009); (4) moving the older juveniles to adult tanks earlier (to avoid crowding) and allowing them to rear in the indoor environment longer than in 2009. The last modification (#4) involved transferring fish at a target age of 80 DPH to indoor adult tanks (1000L) until 120 DPH, before moving them to the final outdoor adult tanks (located under an awning) at the refugial facility. In contrast, in 2009 most multi-family groups of juveniles were first split between two juvenile tanks (to reduce crowding, but adding handling stress), and then transferred directly to outdoor adult tanks at a median age of 110 DPH. In 2010, light levels of the outdoor adult

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tanks were further reduced at the refuge facility by adding double-layer (vs. single) shade-cloth covers over each tank and adding a shade-cloth drape to awning perimeter to help the juvenile fish transition to the brighter outdoor environment.

### Genetic Analysis

Laboratory work for the genetic analysis portion of the operation is conducted in the Genomic Variation Laboratory at UCD. DNA from fin clips of tagged fish are isolated using the Qiagen DNeasy 96 tissue kit. Multiplex polymerase chain reactions (PCRs) are then performed on all individuals to amplify twelve microsatellite loci (Table 1) with primers and conditions described in Fisch et al. (2009a,b).

### Pedigree Reconstruction & Mate Selection

In each generation, the captive delta smelt pedigree is reconstructed to enable kinship calculations between fish. As full-sibling family groups are combined and reared together (8 families/group), the family identity of an individual is unknown. After tagging and genetic analysis, pedigree reconstruction is employed using the software program CERVUS 3.0 (Kalinowski *et al.* 2007). This program assigns parent pairs to each fish and provides a statistical means to evaluate the results with 95% confidence.

Fish are selected to reproduce based on the method of minimal kinship (MK) selection (Ballou and Lacy 1995). MK selection aims to minimize the average relatedness of a population by breeding genetically underrepresented individuals with low mean kinships (*mk*). Using a software program written in the C programming language that calculates *mk* and recommends crosses, breeding recommendations for the F<sub>2</sub> generation are generated using the pedigree-based MK approach to preserve the long-term genetic potential of the species. Wild fish are incorporated into the captive population annually to maintain an open system that allows gene flow between the captive and wild populations. In 2010, wild fish were preferentially mated to one another to create additional founders for the captive population. The sex ratio of the collected wild fish was highly skewed towards males, so wild males that were unable to be paired with wild females were paired with F<sub>2</sub> generation fish using MK selection.

### Genetic Monitoring

Genetic diversity is estimated for each captive generation and the incorporated wild fish in each generation (Wild in F<sub>1</sub> and Wild in F<sub>2</sub>) as the number of alleles per locus (*A*), observed heterozygosity (*H<sub>O</sub>*), and expected

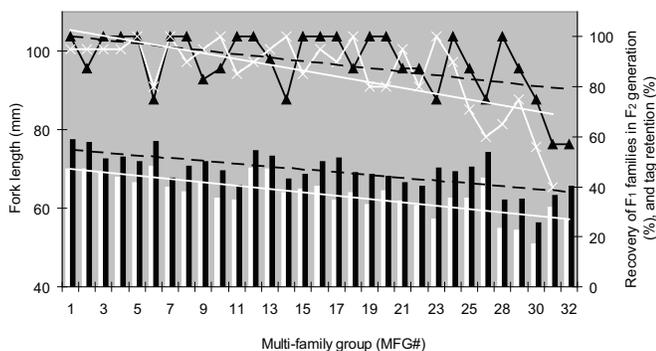
heterozygosity (*H<sub>E</sub>*) using Cervus 3.0 (Kalinowski et al. 2007). To compare populations with different sample sizes, allelic richness (*A<sub>R</sub>*) is calculated as a measure of the number of alleles independent of sample size using FSTAT 2.9.3 (Goudet 1995, 2001). Statistical significance is determined using the Wilcoxon signed-rank test. Population pairwise comparisons of *F<sub>ST</sub>*, a measure of genetic differentiation, are calculated and tested for statistical significance with 10 000 permutations in Arlequin 3.1 (Excoffier et al. 2005).

## Results

### Fish handling and rearing techniques, and fish-facilities

The new adipose fin clip procedure proved to be a successful marking technique for sub-adult delta smelt, resulting in labor and space efficiencies as the F<sub>2</sub> generation was consolidated to a single facility in 16 of 20 broodfish tanks (combining 2 MFGs/tank, or 16 full-sibling families/tank; 4 tanks remained for tagged or mature fish). Wild fish are housed separately. Tag retention (excludes dead fish that retained tag) and recovery of families (representing the F<sub>1</sub> generation) for the F<sub>2</sub> broodfish tagged in January is best for the larger/older broodfish spawned during the first 3 months of spawning period in the previous year. Multi-family groups 1-20 had 92% tag retention compared to the 72% tag retention for the younger/smaller broodfish spawned late in previous year (Figure 1). Tag retention in the youngest fish improves later in the season as they reach 63-65mm. Each time a fish loses its tag, it requires a repeat of the labor-intensive processes of re-tagging, fin clipping, DNA processing, and parentage analysis. Wild fish had high tag loss in 2010 when tagged in January (59%), however, survival of these fish was high (89.5%).

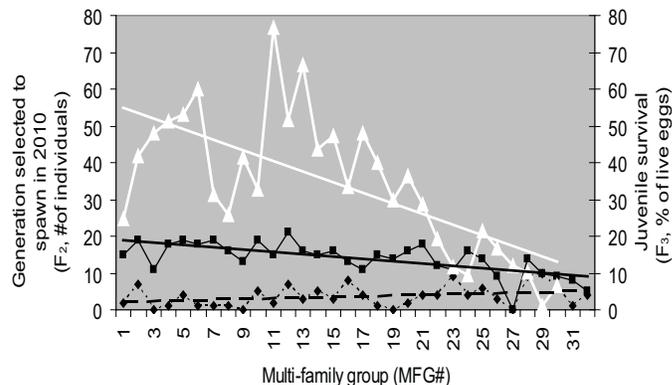
Spawning of the F<sub>2</sub> generation delta smelt began in February 2010, with most spawns occurring in March and April. Select pair crosses (258) were made from February to June (with 24, 103, 62, 44, and 25 pair crosses made each month, respectively) for a total of 516 fish crossed, exceeding the target effective population size of 500 individuals, however, not all of these crosses were successful (see below, Pedigree Reconstruction).



**Figure 1** Growth and tag retention of the  $F_2$  generation delta smelt reared in multi-family groups (MFG) and recruitment to the  $F_3$  generation. Size of  $F_2$  fish is represented by average fork length (20 fish/MFG) measured twice during the 2010 spawning season: January 5-27 (white bars) and April 7-9 (black bars). Tag retention of live fish was recorded for the fish tagged in January (% tag retention of 20 fish/MFG; white line, secondary axis). Recovery of  $F_1$  generation is expressed here as the number of  $F_2$  full-sibling families recovered from each MFG per total number of families in each MFG (percent recovered: black line, secondary axis). Straight lines represent best linear fit to data.

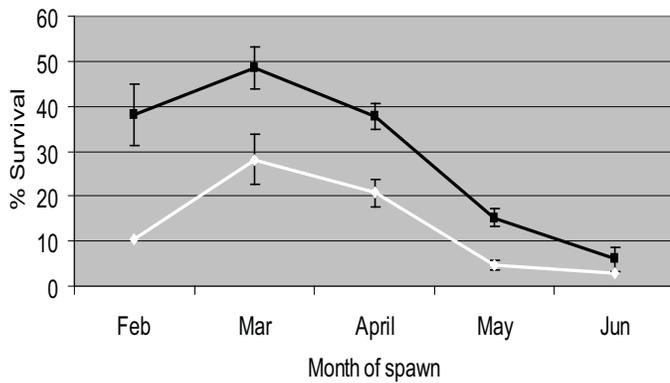
By the end of April, 188 of the 250 pair crosses (75%) were made. Recovering the last 62 pairs of fish took considerable effort over the remaining 2 months of the spawning season. These more elusive families were primarily those from the youngest/smallest  $F_2$  broodfish spawned late in the previous year (Figure 2) and the wild fish. The youngest/smallest cultured broodfish are hard to recruit to the next generation as they do not mature until late in the spawning season, and their late-spawned offspring do not survive as well (Figure 2). In addition, the younger/smaller broodfish generally have lower fecundity and fewer egg clutches, further exacerbating recovery of offspring.

Survival of juvenile delta smelt to 80 DPH was generally higher in 2010 than in 2009, and varied with spawn date (Figure 3). The improved survival is likely attributable to the many methodological factors changed in 2010, but may be due to other unknown factors as well. The younger juvenile stage fish (40-80 DPH) appeared to benefit from the 2010 rearing system changes, as they were more active and swam higher in the water column. The light levels were ~25% of the 2009 levels (1-1.5  $\mu\text{moles}/\text{m}^2/\text{sec}$ ) for the juvenile fish, while larval light levels remained higher, matching the more well-established juvenile lab of the aquaculture facility.



**Figure 2** Recruitment and survival of the  $F_3$  generation delta smelt from the  $F_2$  generation as a function of parental spawn date (or multi-family rearing group; MFG#). The total number of  $F_2$  parents selected per MFG for spawning in 2010 (solid black line) declines with spawn date (i.e. as MFG # increases throughout the spawning season). The  $F_2$  parents spawned late in the previous year (those with high MFG#s) tended to spawn late in 2010 season, e.g. not until after May 4 (dashed black line). Survival of the  $F_3$  juveniles (at 80 DPH; white line, secondary axis) reflects this pattern, as fish generated later in the spawning season (from MFGs > 22) had poor survival. Lower survival of juvenile fish from MFGs 7-10 is attributed to temporary disease problem in these groups. Lines are included representing the best linear fit of the data.

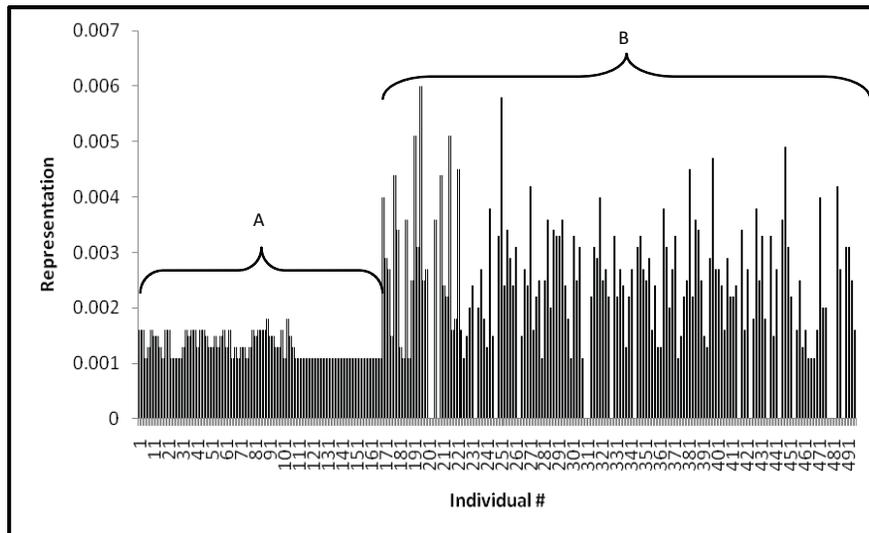
In addition, several feeding and rearing changes (see methods for more detail) may have improved survival through enhanced prey density and/or nutritional value, or by allowing more time for the digestive tracts to mature to assimilate a prepared diet (unpublished data with another prepared diet). In addition, in 2010 the older juvenile stage fish were reared for an “interim-period” (ca. 80-120 DPH) in large indoor adult tanks (aquaculture facility) before moving them to the outdoor adult tanks of the refuge facility. Rearing the late-stage juveniles in a darker environment for a longer period of time than in 2009, appeared to reduce transfer stress and mortality. Highest mortality for a single tank of fish transferred to the outdoor tanks was 219 for fish over 120 DPH in 2010 vs. 970 for fish less than 100 DPH in 2009. Steps taken to reduce incident lighting to the outdoor adult tanks at the refuge facility (as described in methods section) seems to have reduced stress in the older-juvenile life-stage (>120 DPH), as the fish are more active and swim higher in the water column.



**Figure 3** Survival of cultured juvenile delta smelt spawned in 2009 and 2010. Data represent average survival for all multi-family groups of juveniles spawned in month indicated at transfer to final adult tanks (ca. 100-120 days post hatch; 2010 data: black line; 2009 data: white line; standard error of the average included).

### Pedigree Reconstruction & Mate Selection

A total of 1858 individual fish ( $F_2$  generation) were uniquely tagged, fin clipped, genetically analyzed and assigned parentage ( $F_1$  generation) during the 2010 spawning season. Of these, 1826 (98.3%) fish had a parent pair assigned to them with 95% confidence. During the 2009 spawning season, the  $F_1$  broodfish population generated 246 full-sibling families (as the eggs of the  $F_2$  generation), which were combined into 31 multi-family rearing groups (MFG 27 was lost). After rearing for a year in these multi-family groups, adult individuals were identified from 219 families (89%) of the 246 original  $F_2$  families made in 2009 (from the sampled individuals).  $F_2$  adults from 206 of the 219 families (94%) were successfully spawned. In total, 233 successful single-pair crosses were made totaling 466 individuals. Recovery of the youngest/smallest fish (spawned late in the previous year) proved difficult as discussed above. Thirty-four wild fish were incorporated into the captive population in the  $F_2$  generation (7.3% of refugial population; 9 females and 25 males, including 7 wild x wild crosses). Founder representation, the proportion of offspring that a founder contributes in a given generation relative to all other founders, is variable among the original 290 founders and is increasing among the supplemented wild fish in each generation (Figure 4).



**Figure 4** Founder representation in the  $F_2$  generation of delta smelt. Individual founders (bars) are represented as the proportion of offspring that a founder contributes, in the given generation, relative to all other founders, including the original founding population (B) and the additional wild fish incorporated each generation (A).

## Genetic Monitoring

A total of 287 alleles were identified for the 12 microsatellite loci in the samples (Table 1). Allelic richness ( $A_R$ ) ranged from 3.0 to 17.9 alleles at each locus. The allelic richness of all of the generations in captivity was  $A_R=10.9$ . These values were not significantly lower than the founding generation  $F_0$ . When compared across all loci, the difference between captive and wild populations was not significant ( $P<0.05$ ).

High levels of heterozygosity were observed in both the wild and captive populations. The mean expected heterozygosity ( $H_E$ ) was 0.86 (ranging from 0.53 to 0.96), 0.86 (ranging from 0.52 to 0.96), and 0.85 (ranging from 0.52 to 0.96) in the 3 generations of the captive population,  $F_0$ ,  $F_1$ ,  $F_2$ , respectively. The mean expected heterozygosity of the wild populations was 0.84 (ranging from 0.52 to 0.96) and 0.84 (ranging from 0.49 to 0.96) for the wild fish in  $F_1$  and wild fish in  $F_2$ , respectively (Table 1).

The  $F_{ST}$  values for the captive generations and the wild populations are presented in Table 2. The  $F_{ST}$  values between the wild populations and the three captive generations indicate little to no differentiation, and the  $F_{ST}$  values between generations were also negligible. None of the  $F_{ST}$  values were statistically significant.

## Conclusions

The captive delta smelt refugial population is currently in the  $F_3$  generation at the FCCL and has been successful at rearing, increasing survivorship and maintaining the genetic diversity of the captive population, suggesting the current breeding plan is proving successful. However, development of the refugial population is still in its early years, requiring active review of data and refinement of methodologies. In 2010, we incorporated several genetic management techniques and fish culture practices, providing culture efficiencies and improving the refugial population robustness.

Adipose fin clipping proved to be a successful marking technique in delta smelt, and allowed 2 distinct groups of fish to be housed together, improving space and fish handling efficiencies. A large and representative group of fish was tagged and fin clipped for DNA and parentage analysis in January prior to the spawning season. Process-

ing the fish early in the year proved to be an efficient management strategy for all but the youngest/smallest adult fish, which experienced higher tag loss and mortality until they reached about 65mm later in the season. Fish tagging and fin clip processing continued throughout the spawning season in order to recover as much genetic diversity as possible.

Survival of the  $F_3$  generation of juvenile delta smelt in 2010 was higher than that of the  $F_2$  juveniles in 2009, and is higher than what is typically observed at the FCCL facility (ca. 10-20% survival), except for juveniles from parents spawned late in the previous season (see below). The improved survival may be attributed to physical changes in larval and juvenile rearing systems, which included differential lighting conditions more appropriate to younger or older juvenile stages, improved feed quality and quantity, and delayed feeding of a dry diet to juvenile fish.

The wild population of delta smelt is thought to spawn primarily in March and April but spawning extends from February to July in some years (Wang 1986), and therefore an effort was made to capture the full spawning season in the refugial population. However, late-spawning delta smelt families appear to have limited utility to the captive refugial population overall. Offspring of late-spawning parents tend to spawn late themselves, offspring do not survive as well, and they do not mature until late the following season. The cycle appears to perpetuate itself and be magnified in successive generations. An entire late-spawning multi-family group (8 full-sibling families) was lost in 2009, and 2 multi-family groups are currently at risk in 2010. Although it is still early in the development of the delta smelt refugial population, we tentatively suggest that spawning be confined to February through May.

The captive delta smelt population at the FCCL has retained genetic diversity through the  $F_2$  generation based on careful genetic management, fish husbandry and incorporation of wild delta smelt into each captive generation. A software program developed to recommend pair crosses to minimize mean kinship in the captive population improved genetic management efficiency. Future generations will be managed using similar techniques to retain and equalize family representation, maintain gene diversity and preserve the evolutionary potential of the species.

**Table 1 Allelic diversity and heterozygosity of delta smelt at 12 microsatellite loci, including locus name, number of individuals genotyped at each locus (N), number of alleles in each population (A), allelic richness† ( $A_R$ ), observed heterozygosity ( $H_O$ ), expected heterozygosity ( $H_E$ ) and p-value from tests of deviations from Hardy-Weinberg Equilibrium.**

Locus	Captive Population												Wild Fish Incorporated																	
	$F_0$						$F_1$						$F_2$						Wild in $F_1$						Wild in $F_2$					
	N	A	$A_R$	$H_O$	$H_E$	P	N	A	$A_R$	$H_O$	$H_E$	P	N	A	$A_R$	$H_O$	$H_E$	P	N	A	$A_R$	$H_O$	$H_E$	P	N	A	$A_R$	$H_O$	$H_E$	P
HtrG103	226	21	10.97	0.80	0.88	0.01	437	20	11.09	0.90	0.89	0.62	363	18	10.96	0.94	0.89	0.91	50	16	11.63	0.92	0.90	0.89	25	14	11.71	0.84	0.90	0.46
HtrG104	288	8	4.09	0.60	0.53	0*	384	8	3.95	0.52	0.52	0.97	363	9	4.48	0.56	0.52	0.44	36	5	4.25	0.56	0.52	1.00	25	5	4.44	0.48	0.49	0.57
HtrG109	192	19	10.28	0.86	0.89	0.84	410	20	10.52	0.89	0.89	0.80	361	18	10.10	0.91	0.89	0.38	42	13	9.96	0.83	0.89	0.12	25	12	10.69	0.84	0.90	0.14
HtrG114	285	29	15.25	0.92	0.94	0.44	393	30	15.22	0.85	0.94	0*	356	28	15.14	0.91	0.94	0.05	39	21	15.54	0.87	0.95	0.08	25	22	16.73	0.92	0.94	0.47
HtrG115	286	26	13.66	0.93	0.93	0.56	419	25	13.79	0.88	0.93	0.03	362	24	13.90	0.92	0.93	0.04	39	17	13.96	0.87	0.94	0.21	25	18	14.46	0.96	0.93	0.57
HtrG116	239	9	4.13	0.61	0.59	0.14	373	11	4.31	0.57	0.55	0.99	359	7	4.12	0.61	0.56	0.83	36	3	3.00	0.58	0.52	0.20	25	6	4.99	0.68	0.59	0.74
HtrG117	233	25	12.29	0.92	0.92	0.48	433	22	11.93	0.92	0.91	0.11	358	22	11.28	0.93	0.91	0.78	48	12	9.97	0.92	0.89	0.21	25	17	13.83	0.92	0.93	0.48
HtrG119	278	33	17.18	0.91	0.95	0*	359	34	17.29	0.87	0.95	0.01	359	32	16.68	0.91	0.95	0.26	27	21	16.14	0.93	0.94	0.44	25	23	17.94	0.96	0.96	0.82
HtrG120	276	18	8.90	0.84	0.81	0.09	425	20	9.31	0.87	0.83	0.15	362	17	9.15	0.79	0.81	0.21	48	14	8.75	0.77	0.79	0.96	25	7	6.43	0.68	0.80	0.08
HtrG126	275	33	15.52	0.87	0.94	0*	437	32	15.58	0.93	0.95	0.13	361	30	15.65	0.86	0.95	0.04	51	23	14.99	0.90	0.94	0.01	25	17	13.81	0.92	0.93	0.40
HtrG127	287	33	17.59	0.92	0.96	0.01	421	36	17.87	0.95	0.96	0.15	362	31	17.39	0.92	0.96	0.27	41	25	17.25	0.90	0.96	0.20	25	20	16.43	0.96	0.95	0.19
HtrG131	234	29	16.09	0.91	0.95	0.01	319	29	15.74	0.92	0.95	0.02	355	27	15.79	0.95	0.95	0.05	35	21	16.47	1.00	0.96	0.90	24	21	17.13	0.92	0.95	0.38
Average	---	---	10.93	0.84	0.86	0.29	---	---	10.95	0.84	0.86	0.36	---	---	10.86	0.85	0.85	0.35	---	---	10.55	0.84	0.84	0.85	---	---	11.17	0.84	0.84	0.86

†Allelic richness (AR) based on a minimum sample size of 15 diploid individuals

\*Statistically significant at  $P < 0.05$  after Bonferroni correction

**Table 2  $F_{ST}$  values for successive generations of the captive population of delta smelt and wild fish incorporated each generation (below diagonal). No pairwise comparisons were statistically significant, indicating little to no pairwise genetic differentiation between generations.**

	Captive Population			Wild Fish Incorporated	
	$F_0$	$F_1$	$F_2$	Wild in $F_1$	Wild in $F_2$
$F_0$	0		NS	NS	NS
$F_1$	-0.01	0	NS	NS	NS
$F_2$	-0.01	-0.01	0	NS	NS
$F_1$ Wild	-0.03	-0.01	-0.03	0	NS
$F_2$ Wild	-0.01	-0.01	-0.04	0.00	0

\* Significant ( $P < 0.05$ ) differentiation is indicated with \* (upper diagonal). NS = not significant.

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## 2010 Spring Kodiak Trawl Survey

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The 2010 Spring Kodiak Trawl (SKT) survey, conducted by the California Department of Fish and Game (DFG), ran from January 11 to May 6, 2010. The objective of the SKT is to determine the distribution of delta smelt (*Hypomesus transpacificus*) and provide water managers and fisheries regulators with information on areas of probable spawning. This information is of particular interest when the distribution of delta smelt favors the eastern or southern Delta, which can lead to increased entrainment loss of adults and juveniles. In addition to detecting distribution of adult delta smelt, the SKT survey also monitors the gonadal maturation of male and female delta smelt to determine the proportion of catch which is unripe, ripe, and spent. Macro-characteristics used for gonadal staging are described by R.C. Mager (personal communication, June 14, 2002) and are shown in Table 1.

**Table 1 Macro-characteristics of male and female delta smelt gonads for the purpose of identifying maturity stage; adapted from R. C. Mager.**

Stage	Male	Female
I	Left testis barely visible and right testis impossible to find.	Left ovary translucent and grainy in texture. Right ovary difficult to impossible to find.
II	Testis visible as thin strands ventrolateral to swim bladder.	Not differentiated from stage 1 for this study.
III	Left testis has developed in the central portion of the gonadal cord. Right testis visible as a thin pale white or gray cord.	Individual oocytes slightly orange, 0.25 – 0.50 mm in diameter, and visible to the naked eye.
IV	Both testis clearly visible, smooth, and pale white in color.	Abdomen is enlarged with egg mass and observable without dissection. Oocytes are bright orange and about 1 mm in diameter.
V	Testes are bright white and very smooth. Milt can be released with gentle pressure.	Oocytes are larger than 1 mm in diameter and hydrated. Clear fluid surrounds oocytes which become increasingly cloudy and degenerate.
VI	Testes and milt not as bright white as during stage V. Can be indicated by a decrease in size of testes.	Gonad is translucent and textured with a few leftover oocytes embedded in tissue. Loose abdomen is easily detected.

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The SKT has employed Delta-wide surveys (numbered 1 – 5; Figure 1) each year and has often conducted supplemental surveys (numbered 11 – 15). Supplemental surveys are designed only to monitor the reproductive maturity of delta smelt and are conducted in areas of greatest delta smelt density as indicated by catch from preceding Delta-wide surveys. Beginning in 2008 and to reduce the take of delta smelt, only monthly Delta-wide surveys have been conducted.

Delta-wide surveys consist of at least 8 boat days and 160 man hours; 4 field staff use 2 boats to sample (trawl) once at 41 stations over ~ 4 days. Gear and gear-deployment methods are previously described by Souza (2002). Following field sampling, laboratory staff examine all delta smelt samples collected to assure accuracy of the gonadal staging process.

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

The 2010 SKT collected relatively few delta smelt (3rd lowest for the period of record, 2002 – 2010) during its 5 Delta-wide surveys, and followed the recent annual trend (except for 2009) of collecting  $\leq 2$  delta smelt per trawl (Figure 2). Total catch per survey was higher early in the year (Figure 3), which is expected from the annual life-cycle of delta smelt.

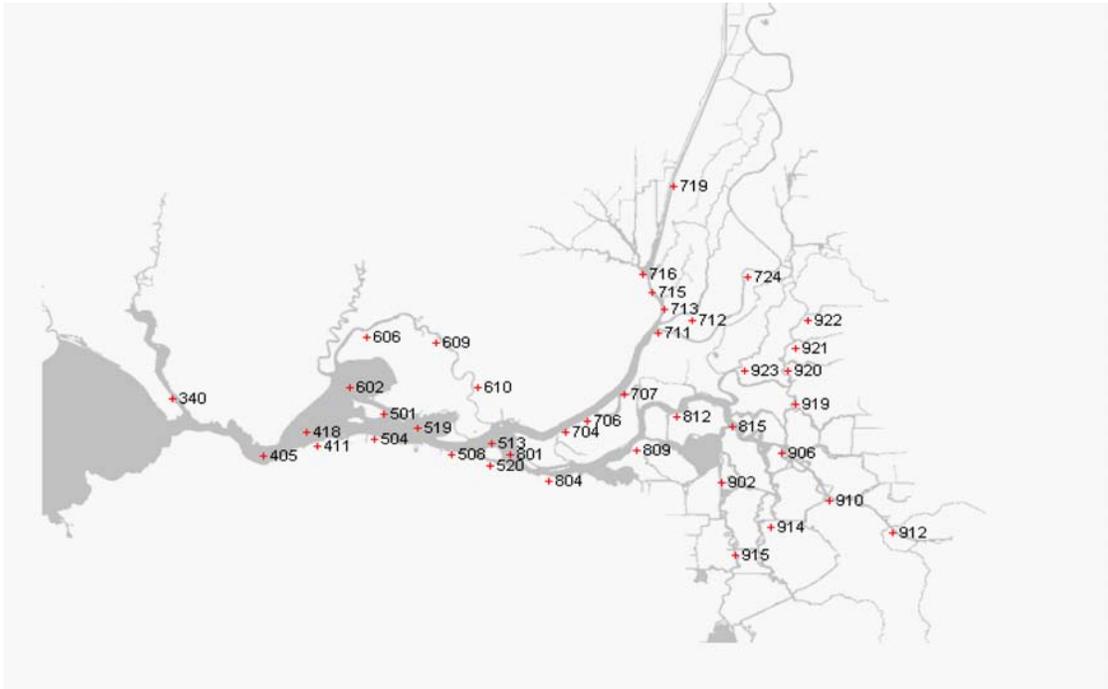
During Surveys 1 and 2, delta smelt distribution ranged broadly (Figures 4A and 4B), highest densities of delta smelt occurred in Montezuma Slough, and at least 73% of all delta smelt collected were located downstream of the confluence. During Surveys 3 and 4, at least 95% of all delta smelt were collected upstream of the confluence and peak densities occurred in Sacramento Deep Water Ship Channel (SDWC) (Figure 4C – 4D). During Survey 5, no delta smelt were collected downstream of the

confluence (Figure 4E). These distributions suggest an upstream migration for the purposes of spawning (based on female maturity results), with a majority of fish moving sometime between Survey 2 and Survey 3.

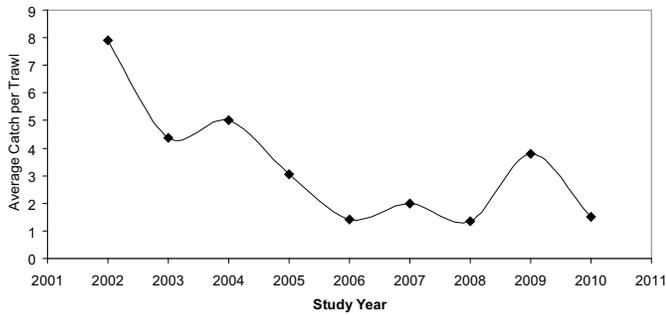
The female gonadal-stage distribution year was typical, as the fraction of ripe fish and spent fish increased (to a point) with water temperature (Figure 5). Ripe females were first detected during Survey 2, when water temperature (Figure 6) was just below the purported 12°C trigger/threshold needed to initiate spawning (Lindberg et al. 1997). Survey 3 yielded the first spent females of the year and coincided with an average water temperature of 12.1°C.

By adjusting catch to account for the frequency of temperature readings (so that more frequent readings per temperature group are not overrepresented), we found that roughly 68% of all pre-spawn females were collected at water temperatures <12°C, pre-spawn females were collected throughout the entire season's temperature range (8.7°C – 19.0°C; Figure 7), and greater than 87% of all ripe and spent females (adjusted catch) were collected at temperatures  $\geq 12^\circ\text{C}$ . We also found 98% of all delta smelt were collected at temperatures <16°C (Figure 8) and that 60% were collected at conductance values of <1000  $\mu\text{S}/\text{cm}$  (Figure 9).

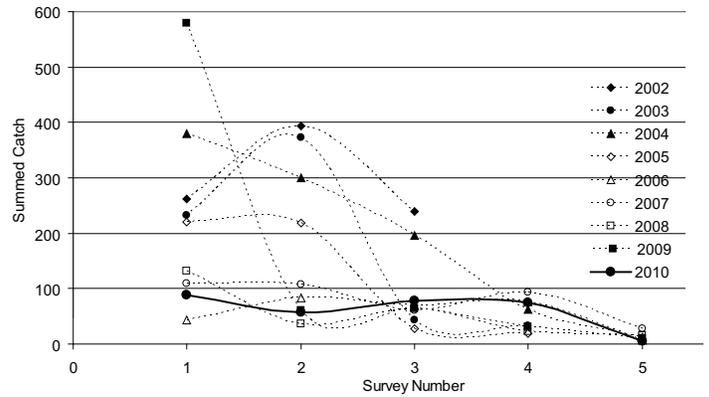
The 2011 SKT field season is scheduled to begin in January 2011 and run through May 2011 using monthly surveys. Spring Kodiak Trawl data and the geographic distribution of delta smelt are available for viewing on our web page at <http://www.dfg.ca.gov/delta/projects.asp?ProjectID=SKT>.



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



**Figure 2** Summed annual delta smelt catch divided by the summed annual number of trawls from the DFG Spring Kodiak Trawl for the period of record: 2002 - 2010.



**Figure 3** Summed catch of delta smelt by survey number of the DFG Spring Kodiak Trawl for the period of record: 2002 - 2010.

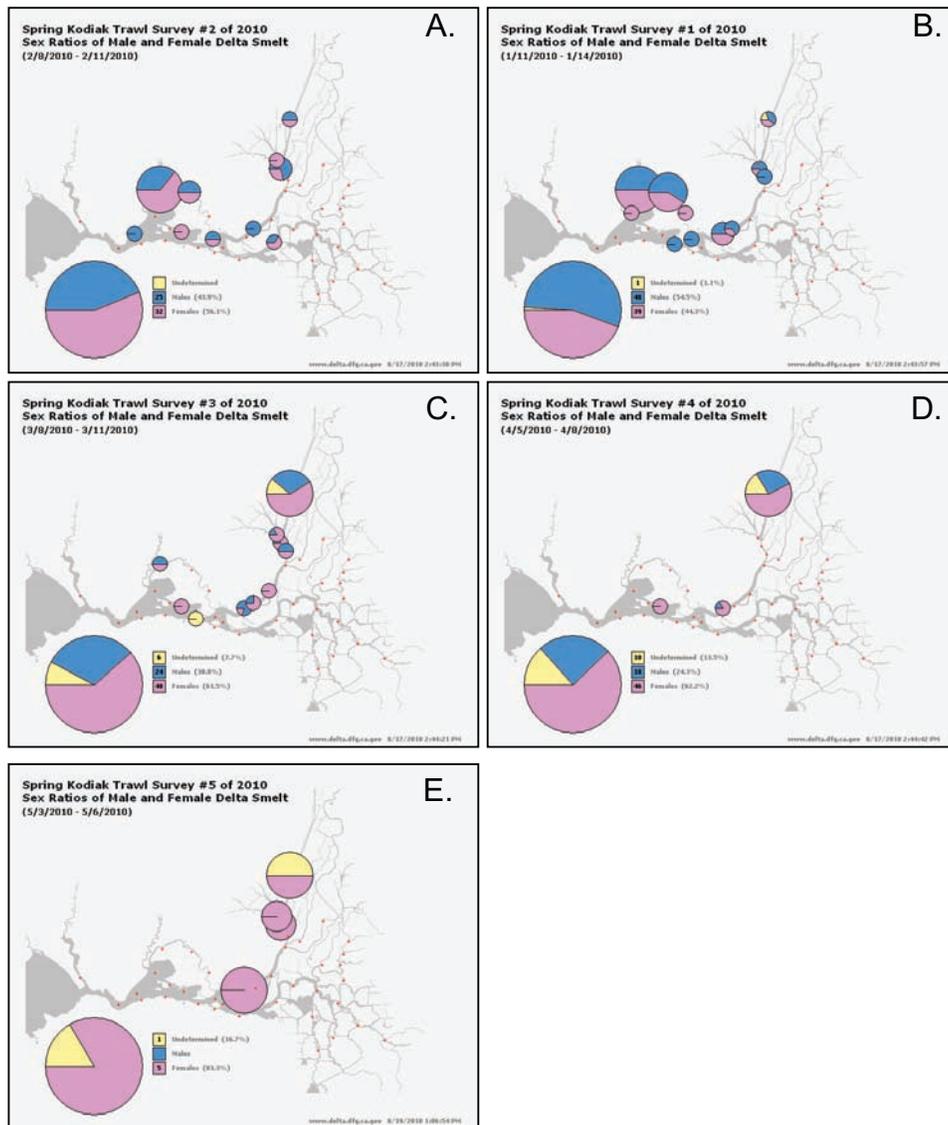
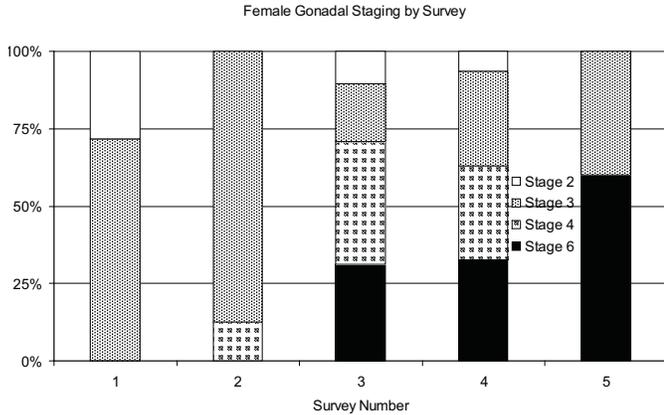
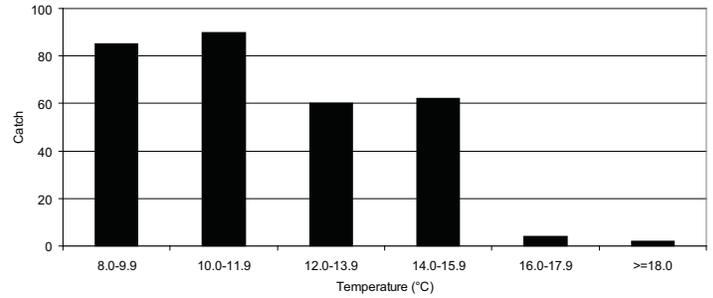


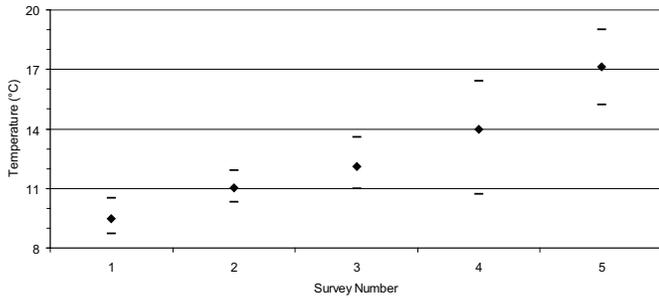
Figure 4 Geographical distribution of delta smelt by catch and by sex ratio for each 2010 Delta-wide survey, from the DFG Spring Kodiak Trawl web-page (<http://www.delta.dfg.ca.gov/data/projects/?ProjectID=SKT>).



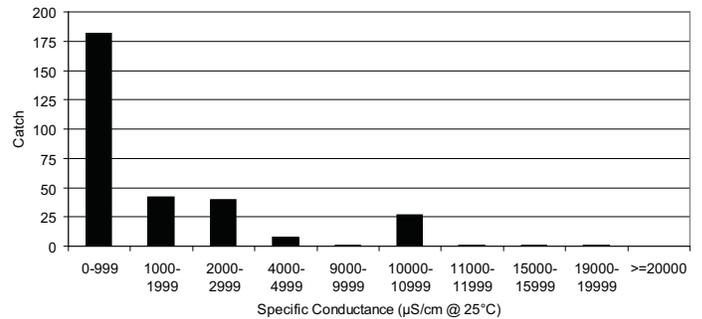
**Figure 5** Gonadal-stage percent distribution of female delta smelt during each 2010 Delta-wide survey of the DFG Spring Kodiak Trawl. Stages 2 & 3 are pre-spawn, Stage 4 is ripe, and Stage 6 is spent.



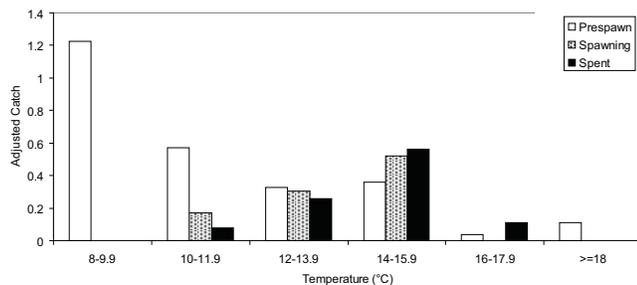
**Figure 8** Temperature ranges in which delta smelt were collected during the DFG Spring Kodiak Trawl 2010 field season.



**Figure 6** High, low, and average temperatures for each 2010 Delta-wide survey of the DFG's Spring Kodiak Trawl.



**Figure 9** Specific conductance ranges in which delta smelt were collected during the DFG Spring Kodiak Trawl 2010 field season.



**Figure 7** Temperature ranges in which female delta smelt were collected during the DFG Spring Kodiak Trawl 2010 field season. Female gonadal stages are broken down into pre-spawn, ripe, and spent groups.

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# Review of Juvenile Sturgeon Setline Survey

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## Introduction

Here we briefly summarize catch and effort information from a multi-year, long-concluded (2002) survey that was conducted to assess the year-class strength of white sturgeon (*Acipenser transmontanus*) in the San Francisco Estuary. The survey is one of very few sources of distribution and brood-year information on white sturgeon 2-8 years of age in California and provides some insight into green sturgeon status, trends, and research methodology. R. Schaffter provided several progress reports (Schaffter 1999a, 1999b, 2000) while the survey was underway but the results of surveys after 1999 have not been previously reported.

## Materials and Methods

Baited setlines were used to target white sturgeon 40-116 centimeters total length (cm TL; Schaffter 1999a). Lines were set and collections were made by boat on 118 days from Carquinez Strait to the Sacramento-San Joaquin river confluence (Tables 1 and 2; Figure 1).

Up to 4 setlines baited with some combination of lamprey, squid, and shrimp were deployed by one boat each field day. Lines were set 343 times (Table 2). Typical lines were about 550 m (1,800-ft) long and fitted with about 80 gangions (Honey et al. 2004). Each gangion was fitted with one 2/0-, 4/0-, or 6/0-sized hook affixed by a 1-m (3-ft) leader (Honey et al. 2004). Lines were deployed and fished at 1-11 m depths, averaging about 4 m.

White sturgeon and green sturgeon were usually measured to the nearest cm TL, and sturgeon greater than approximately 125 cm TL were sometimes counted and released without being measured. Sturgeon were speciated and counted if lost at the boat before a measurement was made. By-catch was counted and in some cases measured (cm fork length). Condition and mortalities were not noted.

Sampling occurred primarily in June, July, and August (Table 3). Deployment dates were always recorded but deployment times, retrieval dates, and retrieval times were not recorded in 1991 and were sometimes not recorded thereafter. Count of hooks per set was recorded, but the number of hooks by size per line was not. Temperature (°C or °F), electrical conductivity (µmhos or mmhos), and water clarity (Secchi, cm) were recorded at most once for each set. GPS coordinates were recorded for most sets.

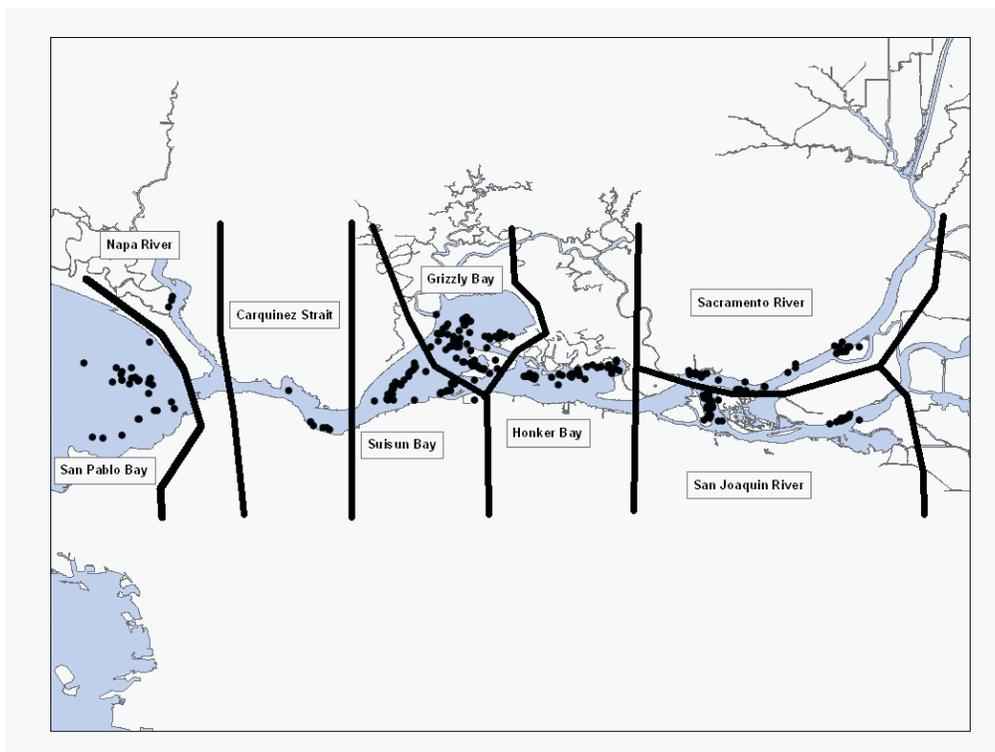
**Table 1 Regions sampled by year; X = region sampled, blank = region not sampled.**

Region	1991	1995	1996	1997	1998	1999	2000	2001	2002
Carquinez Strait	X	X			X	X	X	X	X
Grizzly Bay	X	X	X	X	X	X	X	X	X
Honker Bay	X	X	X	X	X	X	X	X	X
Napa River			X	X					
Sacramento River	X	X	X	X	X	X	X	X	X
San Joaquin River	X	X	X	X	X	X	X	X	X
San Pablo Bay	X	X	X	X	X	X	X		
Suisun Bay	X	X	X	X	X	X	X	X	X

**Table 2 Number of lines set by region and year.**

Region	Number of lines set									Total lines set
	1991	1995	1996	1997	1998	1999	2000	2001	2002	
Carquinez Strait	1	1			1	2	2	1	2	10
Grizzly Bay	1	2	5	4	4	6	6	2	4	34
Honker Bay	3	5	9	6	6	12	9	3	3	56
Napa River			2	1						3
Sacramento River	3	6	8	6	6	8	7	6	2	52
San Joaquin River	3	3	9	6	6	10	7	6	4	54
San Pablo Bay	2	3	8	3	6	6	3			31
Suisun Bay	5	8	18	11	10	18	15	6	12	103
<b>Total</b>	18	28	59	37	39	62	49	24	27	343

*blanks = region not sampled*



**Figure 1 Region demarcations and sites where lines were set.**

For collections when effort data were recorded, lines typically remained in the water for a day (N= 302, average = 22.54 h, range = 14.42-48.25 h). Annual hook-hours (Equation 1) by region were typically around 2,000 (Table 4). This data excludes 14 lines that were noted as being compromised by theft, vandalism, or bait loss.

$$\text{Hook - hours} = (\text{number of hooks on setline}) \times (\text{hours fished}) \quad (1)$$

## Results

Lengths were recorded for 2,326 white sturgeon (average = 86 cm TL; Figure 2). The 2 green sturgeon collected were both 57 cm TL. Striped bass (N=196), white catfish (N=145), and leopard shark (N=82) were the most-common by-catch (Table 5).

Because catch per unit effort might be an index of juvenile white sturgeon abundance, we calculated catch per 100 hook-hours for each site (CPUE<sub>i</sub>) using (1) all white sturgeon for which a measurement of ≤ 116 cm TL was recorded and (2) only sets where duration and number

of hooks were recorded (i.e., sets for which hook-hours could be calculated; Equation 2). Average catch per 100 hook-hours ( $\hat{R}_1$ ) (Equation 3; Table 6) differs by region and year, such that the differences might suggest trends in juvenile white sturgeon abundance.

$$\text{CPUE}_i = \left[ \frac{c_i}{e_i} \right] \times 100 \quad (2)$$

where *i* = individual site  
*c* = number of fish measured  
*e* = hook-hours

$$\hat{R}_1 = \frac{\sum_{i=1}^n \text{CPUE}_i}{n} \quad (3)$$

where *n* = number of sites for which CPUE<sub>i</sub> was estimated

**Table 3 Months sampled by sampling year; X = sampled, blank = not sampled.**

Year	Months Sampled							
	March	June	July	August	September	October	November	December
1991		X	X					
1995				X			X	X
1996				X	X	X		
1997			X				X	
1998				X			X	
1999	X	X	X		X			
2000		X	X	X				
2001		X	X					
2002		X	X					

**Table 4 Average, standard error (SE), minimum, and maximum hook-hours by region and sampling year; N = number of sites used for average and SE (all valid lines set included).**

	<b>Avg</b>	<b>SE</b>	<b>N</b>	<b>Min</b>	<b>Max</b>	<b>Avg</b>	<b>SE</b>	<b>N</b>	<b>Min</b>	<b>Max</b>
<b>Region</b>	<b>1995</b>					<b>1996</b>				
Carquinez Strait	1592.5	NA	1	1592.5	1592.5	not sampled				
Grizzly Bay	1763.3	3.3	2	1760.0	1766.7	1708.0	49.5	5	1590.0	1885.0
Honker Bay	1737.2	144.7	4	1425.0	2125.0	1801.8	72.1	8	1458.9	2107.0
Napa River	not sampled					1662.7	30.7	2	1632.0	1693.3
Sacramento River	1582.3	110.3	6	1100.7	1800.0	1725.2	84.7	8	1241.3	1987.5
San Joaquin River	1785.9	126.6	3	1532.7	1912.5	1527.8	106.6	7	924.0	1753.3
San Pablo Bay	1872.5	88.3	3	1697.5	1980.0	1766.5	91.4	8	1440.0	2237.7
Suisun Bay	1716.7	80.0	6	1487.5	1953.3	1601.4	67.4	17	1282.5	2215.7
<b>Region</b>	<b>1997</b>					<b>1998</b>				
Carquinez Strait	not sampled					1760.0	NA	1	1760.0	1760.0
Grizzly Bay	1375.1	397.3	3	582.5	1820.0	1566.9	172.4	3	1222.7	1756.3
Honker Bay	1657.6	86.0	6	1317.8	1879.2	1595.0	106.9	5	1245.4	1806.7
Napa River	1706.7	NA	1	1706.7	1706.7	not sampled				
Sacramento River	1869.9	139.9	6	1503.5	2401.0	1604.5	116.5	6	1306.7	2002.0
San Joaquin River	1681.4	97.2	5	1392.4	1920.0	1552.0	72.5	6	1230.0	1726.7
San Pablo Bay	1595.6	96.6	3	1420.0	1753.3	1869.8	71.2	5	1715.3	2096.7
Suisun Bay	1730.7	48.4	11	1481.7	1969.5	1721.5	110.8	9	1153.3	2217.1
<b>Region</b>	<b>1999</b>					<b>2000</b>				
Carquinez Strait	1692.0	250.2	2	1441.8	1942.2	1665.1	73.9	2	1591.3	1739.0
Grizzly Bay	1595.6	69.9	6	1290.0	1810.4	1813.6	175.5	5	1256.7	2340.0
Honker Bay	1763.6	22.2	12	1625.0	1886.7	1473.1	104.1	9	1037.0	1950.0
Napa River	not sampled					not sampled				
Sacramento River	2076.2	222.5	8	1668.8	3620.5	1469.6	128.2	7	931.7	1786.7
San Joaquin River	2101.9	174.1	10	1687.6	3240.0	1519.5	164.6	7	866.3	2239.8
San Pablo Bay	1577.7	53.2	6	1412.6	1786.0	1590.3	291.7	3	1120.8	2125.0
Suisun Bay	1699.8	60.2	17	1310.0	2269.3	1703.0	88.0	14	1032.0	2259.8
<b>Region</b>	<b>2001</b>					<b>2002</b>				
Carquinez Strait	1821.3	NA	1	1821.3	1821.3	1414.5	NA	1	1414.5	1414.5
Grizzly Bay	1713.3	14.8	2	1698.5	1728.0	1729.9	125.1	4	1377.0	1911.0
Honker Bay	1732.0	179.6	3	1528.1	2090.0	1547.1	NA	1	1547.1	1547.1
Napa River	not sampled					not sampled				
Sacramento River	1547.3	38.0	5	1414.4	1630.3	2908.5	951.5	2	1957.0	3860.0
San Joaquin River	1717.1	49.9	5	1560.0	1869.0	2848.3	504.2	4	1906.5	3746.7
San Pablo Bay	not sampled					not sampled				
Suisun Bay	1572.7	41.5	6	1446.3	1740.9	1808.7	39.7	10	1619.5	2000.0

**Table 5 By-catch count during setline sampling (By-catch was not recorded in 1991)**

Year	Region	Brown Smoothhound	Channel Catfish	Leopard Shark	Sacramento Pikeminnow	Spiny Dogfish	Staghorn Sculpin	Striped Bass	Sevengill Shark	White Croaker	White Catfish	Other Species <sup>a</sup>
1995	Carquinez Strait						1	2				
1995	Grizzly Bay							7				
1995	Honker Bay				2		1	5				
1995	Sacramento River				2		2	9			4	1
1995	San Joaquin River		1					5			11	1
1995	San Pablo Bay			12		1	4	1	1	1		2
1995	Suisun Bay						3	27				
	Yearly Totals	0	1	12	4	1	11	56	1	1	15	4
1996	Grizzly Bay							9				
1996	Honker Bay				8			14			4	
1996	Napa River						1			1		
1996	Sacramento River				2			6			17	
1996	San Joaquin River		2		4			10			8	
1996	San Pablo Bay	15		53		3	2		11	8	1	
1996	Suisun Bay						6	20				2
	Yearly Totals	15	2	53	14	3	9	59	11	9	30	2
1997	Honker Bay				1			7			7	
1997	Sacramento River		3		6			9			12	
1997	San Joaquin River				2			4			9	
1997	San Pablo Bay	12		3				2		3		1
1997	Suisun Bay						1	8				
	Yearly Totals	12	3	3	9	0	1	30	0	3	28	1
1998	Grizzly Bay							1				
1998	Honker Bay				1			3			4	
1998	Sacramento River		5		2			1			2	
1998	San Joaquin River		5								1	
1998	San Pablo Bay			11		4		3		5		2
1998	Suisun Bay							2				
	Yearly Totals	0	10	11	3	4	0	10	0	5	7	2
1999	Carquinez Strait							1				
1999	Grizzly Bay							1				
1999	Honker Bay				2			5			5	
1999	Sacramento River				1			2			8	
1999	San Joaquin River				3						7	2
1999	San Pablo Bay	2		1		1		1				2
1999	Suisun Bay							6			1	1
	Yearly Totals	2	0	1	6	1	0	16	0	0	21	5
2000	Grizzly Bay				1			3				
2000	Honker Bay				3			7			5	
2000	Sacramento River				7			2			9	
2000	San Joaquin River				1			6			11	
2000	San Pablo Bay	8		2		12						5
2000	Suisun Bay							3			1	1
	Yearly Totals	8	0	2	12	12	0	21	0	0	26	6
2001	Grizzly Bay							1				
2001	Honker Bay							1			6	
2001	Sacramento River				1						9	
2001	San Joaquin River							1			2	
	Yearly Totals	0	0	0	1	0	0	3	0	0	17	0
2002	Sacramento River		1									
2002	Suisun Bay							1			1	
	Yearly Totals	0	1	0	0	0	0	1	0	0	1	0
	Survey Totals	37	17	82	49	21	21	196	12	18	145	20

<sup>a</sup>Other species included bat ray (2), cottid unid (4), croaker unid (3), green sturgeon (2), Sacramento blackfish (1), Sacramento splittail (3), starry flounder (3), and thresher shark unid (2)

**Table 6 White sturgeon  $\leq$  116 cm TL average catch per 100 hook-hours with standard error (SE) and sample size (number of sets used in average, N) by region and sampling year.**

Year	Carquinez Strait			Grizzly Bay			Honker Bay			Napa River		
	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N
1995	0.06	NA	1	1.05	0.37	2	0.37	0.09	4	<i>not sampled</i>		
1996	<i>not sampled</i>			0.41	0.14	5	0.39	0.05	8	0.12	0.00	2
1997	<i>not sampled</i>			0.24	0.13	3	0.50	0.14	6	0.23	NA	1
1998	0.00	NA	1	0.13	0.07	3	0.24	0.13	5	<i>not sampled</i>		
1999	0.21	0.21	2	0.42	0.15	6	0.23	0.06	12	<i>not sampled</i>		
2000	0.06	0.06	2	0.62	0.30	5	0.60	0.18	9	<i>not sampled</i>		
2001	0.11	NA	1	0.21	0.09	2	0.64	0.30	3	<i>not sampled</i>		
2002	0.14	NA	1	0.77	0.09	4	0.58	NA	1	<i>not sampled</i>		

Year	Sacramento River			San Joaquin River			San Pablo Bay			Suisun Bay		
	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N	Avg Catch/ 100 hook-hours	SE	N
1995	0.34	0.09	5	0.48	0.17	3	0.51	0.31	3	0.67	0.11	6
1996	0.13	0.03	8	0.23	0.11	6	0.25	0.07	8	0.41	0.06	17
1997	0.39	0.08	6	0.35	0.12	4	0.10	0.06	3	0.32	0.05	11
1998	0.08	0.04	6	0.05	0.02	5	0.26	0.10	5	0.45	0.13	9
1999	0.10	0.03	7	0.13	0.04	10	0.02	0.01	6	0.45	0.07	17
2000	0.23	0.05	7	0.13	0.07	7	0.07	0.04	3	0.55	0.09	14
2001	0.48	0.25	5	0.21	0.12	5	<i>not sampled</i>			0.32	0.11	6
2002	0.53	0.19	2	0.44	0.09	4	<i>not sampled</i>			0.85	0.12	10

**Table 7 Age-length key for white sturgeon; number of fish in each length bin (from length frequency) assigned an age based on proportions in key (data for key in Kohlhorst et. al. 1980).**

Length bin (cm TL)	Age-0	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8	Age-9	Age-10	Age-11	Age-12	Age-13	Age-14	Age-15	Age-16	Age-17	Age-18	Age-19	Age-20	Age-21	≥Age-22
21-25	1.0000																						
26-30	1.0000																						
31-35	1.0000																						
36-40	0.7000	0.2000	0.1000																				
41-45		0.6667	0.3333																				
46-50		0.3542	0.5625	0.0833																			
51-55		0.1148	0.8033	0.0656	0.0164																		
56-60			0.6863	0.2157	0.0588	0.0196	0.0196																
61-65			0.2308	0.3846	0.2308	0.0769	0.0513	0.0256															
66-70			0.0625	0.2813	0.3125	0.2813	0.0313	0.0313															
71-75				0.0175	0.3333	0.4211	0.2105	0.0175															
76-80					0.1136	0.2273	0.4091	0.2500															
81-85					0.0313	0.1719	0.3125	0.2969	0.1094	0.0625	0.0156												
86-90						0.0317	0.1746	0.3968	0.2381	0.1270	0.0317												
91-95							0.0526	0.2500	0.3158	0.2763	0.0789	0.0263											
96-100							0.0541	0.2568	0.3108	0.2838	0.0811	0.0135											
101-105							0.0526	0.2281	0.1842	0.3070	0.1579	0.0702											
106-110							0.0286	0.0571	0.2143	0.3000	0.2429	0.1000	0.0286	0.0286									
111-115									0.1186	0.3051	0.4237	0.1017	0.0169	0.0339									
116-120									0.1136	0.1818	0.1818	0.1591	0.1591	0.0455	0.0909	0.0455	0.0227						
121-125										0.0833	0.1111	0.1944	0.1389	0.1389	0.1389	0.1667	0.0278						
126-130										0.0541	0.0811	0.2162	0.1351	0.0541	0.1622	0.0541	0.0811	0.0811	0.0270	0.0270	0.0270		
131-135											0.0882	0.1176	0.1471	0.1176	0.0294	0.1176	0.1471	0.1176	0.0294	0.0000	0.0882		
136-140												0.1154	0.0000	0.2308	0.1538	0.2308	0.1538	0.0385	0.0769	0.0000			
141-145												0.0286	0.0571	0.1429	0.1429	0.2286	0.1714	0.1143	0.0000	0.0857	0.0286		
146-150												0.0270	0.1081	0.1622	0.1622	0.1351	0.0541	0.1892	0.1622	0.0000	0.0000		
151-155													0.0435	0.1304	0.0870	0.0870	0.1304	0.3478	0.0000	0.0870	0.0870		
156-160														0.0769	0.0769	0.1538	0.0769	0.1538	0.0769	0.3077	0.0000	0.0769	
161-165																	0.2500	0.1667	0.1667	0.0833	0.1667	0.1667	
166-170																	0.1250	0.0000	0.1250	0.5000	0.2500	0.0000	
171-175																	0.1250	0.2500	0.2500	0.3750	0.0000	0.0000	
176-180																			0.1667	0.1667	0.3333	0.1667	0.1667
181-185																				0.3333		0.3333	0.3333
>185																					0.7500		0.2500

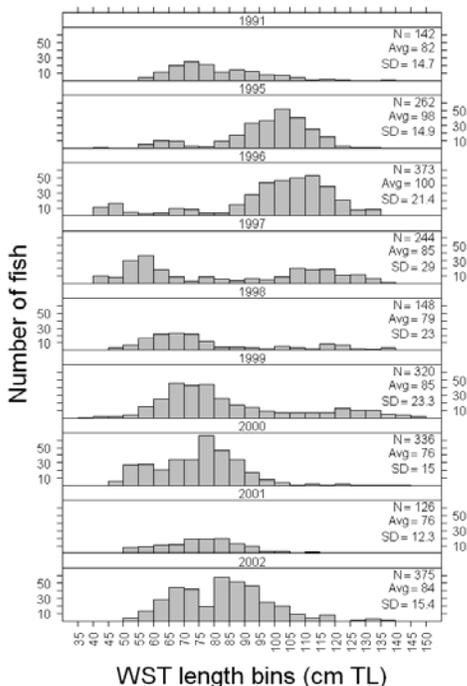


Figure 2 Annual length frequency distribution of white sturgeon.

### Discussion

Due largely to errors in estimated effort, any time-trends in white sturgeon abundance (e.g., abundance by brood year) that might be suggested by setline catch per unit effort are not likely to be reliable. Much of the error in effort was thought to be attributable to removal of bait by Chinese mitten crabs, *Eriocheir sinensis*, (Schaffter 1999a; Hieb 2009; K. Hieb pers. comm.), but non-sturgeon by catch and bait preference are likely also confounding.

The length frequency distributions of white sturgeon showed within-year structure and changes over time that demonstrate varying recruitment and growth. When using an age-length key (Table 7) to assign brood years, trends in annual year-class strength are evident (Figure 3). The trends are generally consistent with the year-class strength index reported by Fish (2010), but differences warrant further investigation because they may speak to white sturgeon ecology, the merits of various indices of white sturgeon abundance, and limits on white sturgeon age-length key utility.

Since their implementation by the California Fish and Game Commission in 2007, Sturgeon Fishing Report Cards have also provided white sturgeon length frequency

distributions that show within-year structure (e.g., DuBois et al. 2010) and changes over time that demonstrate varying recruitment and growth. We have begun to explore the degree to which these trends are consistent with the year-class strength index reported by Fish (2010), because — should they be generally consistent — Sturgeon Fishing Report Card data may be a very low cost ongoing alternative or complement to any new setline survey.

Green sturgeon were not particularly susceptible to the setlines or were not abundant (or both). Catch of green sturgeon in trammel nets from 1990-2002 does not alone help distinguish between the two possibilities, because the setlines were selected for relatively small fish and the trammel nets were not (Schaffter and Kohlhorst 1999). However, trammel-net catch of small green sturgeon in 2009 was relatively high (DuBois and Mayfield 2009) while angler catch of small green sturgeon has been consistently low for several years (DuBois et al. 2010; DuBois et al. 2009; Gleason et al. 2008), it is at least plausible and is probably likely that green sturgeon catch by setline was low largely because they were not particularly susceptible to baited hooks.

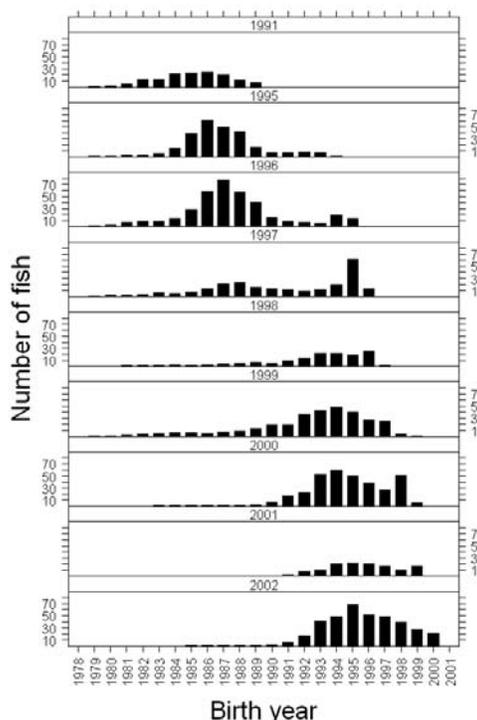


Figure 3 Annual birth-year (BY) frequency distribution of white sturgeon (BY cutoff at 1978 for simplicity - sampling-year 1991: 1 fish BY=1977; 1996: 1 fish BY=1976; 1997: 1 fish BY=1977).

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## Notes

Kathryn Hieb (California Department of Fish and Game), e-mail, 25-Aug-2010

## Production Schedule: IEP Newsletter

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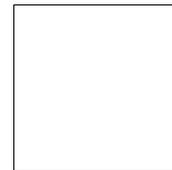
Article Deadline: Friday October 28, 2011

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