Interagency Ecological Program for the San Francisco Estuary

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Of Interest to Managers

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This combined summer-fall issue of the IEP Newsletter is a substantial one, complete with highlights, status and trend articles, and contributed articles covering everything from sturgeon in the South Delta to recent trends in gelatinous zooplankton captured in the fall midwater trawl.

The issue opens with two highlight articles. First off, **Marty Gingras** (CDFW) describes recent progress with moving key IEP databases to secure servers in Sacramento from existing Stockton-office servers. This has been a non-trivial, but important effort to maintain the security of IEP data. In a fisheries highlight, **Zachary Jackson** (USFWS) brings our attention to the presence and spawning activity of sturgeon (both green and white species) in the San Joaquin River. Acoustic telemetry work and egg surveys will continue to be conducted in future years to better understand how sturgeon use this region of the Delta.

In a contributed article on the largemouth bass tournament activity in the Delta, **Jared Frantzich** (DWR) examines trends in angler participation and size of trophy largemouth bass. When tournament data were presented by Dennis Lee (CDFW) in an issue of the IEP Newsletter in 2000, they showed the size of largemouth bass on the rise. Ten years on, this trend has continued and the tournament industry has responded, with a continued increase in tournament frequency and angler participation. These results suggest that even as fishing pressure has increased, it has not yet tapped the maximum individual sizes within the Delta population.

Also in the vein of recreational fishing, **Jason DuBois** and **Marty Gingras** (CDFW) report on how catch-per-unit-effort (CPUE) of striped bass on chartered partyboats relates to abundance estimated from CDFW mark-recapture data. Overall, the relationship was weak, possibly due to unexplained dramatic variations in partyboat CPUE; however, the relationship over recent years was stronger, suggesting that partyboat CPUE may provide an efficient index of adult striped bass abundance as more data are collected in future years.

Katherine Osborn and **Michael Civiello** (CDFW) contributed a summary of introduced gelatinous zooplankton (jellyfish) that are captured in the fall midwater trawl survey, from 2001 - 2011. Over this period of record, six taxa (4 species and 2 genera) were identified, with *Maeotias marginata* being consistently present, and unlike other jellyfish, was observed in all geographic regions except the Napa River. Interestingly, periods of elevated catch of *M. marginata* in 2006 and 2011 followed wet springs and coincided with high fall outflows.

Several authors contributed Status and Trend articles. **April Hennessey** and **Tina Enderlein** (CDFW) provided the Zooplankton Monitoring Update for 2011. Among the biota with notable trends was *Eurytemora affinis*, which had its highest abundance in the spring (as in previous years), but also had the highest summer abundance since 2006 and fall abundance that exceeded the mean calculated from 1990 – 2010. As this relatively high abundance was concentrated in Suisun Marsh and the western Delta, these may have been an important food source for fishes concentrating in the low salinity zone, such as delta smelt. Among the mysid species, however, the introduced species *Hyperacanthomysis longirostris* had its lowest summer abundance since its introduction in the early 1990s, and fall abundance was below average. The native species, *Neomysis mercedis*, remained the least abundant mysid species for the second year, despite having the highest spring abundance since 2006.

Maxfield Fish, **Jennifer Messineo**, and **Kathryn Hieb** (CDFW) provided the 2011 Bay Study update, in which they present abundance trends on nineteen species or species groups from 1980 through 2011. They also provide long-term trends on ocean climate indices and sea surface temperature, noting that the 2010-2011 period was marked by two marked cold-water regimes (La Niña events). With the exception of Pacific herring, age-0 jacksmelt, and Pacific staghorn sculpin, abundance indices were low compared to previous years. In particular, the age-0 brown rockfish index was only 1.5% of the record high 2010 index, possibly due to lower than average salinities in 2011. Cool ocean conditions may have contributed to an index of 0 for the fourth consecutive year for juvenile California halibut.

2011 also proved to be an interesting year in the Yolo Bypass. **Jared Frantzich** (DWR) and colleagues have provided an update on water quality, chlorophyll-a concentration, and fisheries monitoring that has been conducted in the Yolo Bypass since 1998. Despite catastrophic equipment losses due to high flows and heavy debris loads, the Yolo Bypass team reports record-high catches of juvenile Sacramento splittail. As splittail rely on floodplain habitat for spawning and juvenile rearing, it is no surprise that recruitment was high in 2011 when there was extensive flooding in the Yolo Bypass in March and early April.

In the final status and trends article, **Meredith Nagel** (UC Davis) and colleagues provide the 2012 update on the delta smelt captive refuge population at the Fish Conservation and Culture Laboratory. Through captive breeding, this program has preserved genetic diversity of the wild delta smelt population since 2008. In 2012, 281 pair crosses were made, with a final result of 84% of the parent family groups “recovered”, or represented in the ensuing generation. This latest spawn event produced the fifth generation of the captive population. Due to intensive genetic management, the program has not resulted in any significant genetic differentiation from the founding group.

Did you know that quarterly highlights about current IEP science can be found on the IEP webpage along with a new calendar that displays IEP Project Work Team and other IEP-related public meetings? To view these features see the links below:

http://www.water.ca.gov/iep/activities/calendar.cfm
http://www.water.ca.gov/iep/highlights/index.cfm

IEP QUARTERLY HIGHLIGHTS

DFW Improves Security of IEP Data

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In response to substantial and increasing interest in data developed by Bay Delta Region's IEP program and to comply with Information Technology-focused AB 2408 (Smyth and Huber 2010), for about 1.75 years the program has been working with DFW's Information Technology Branch to migrate mission-critical and public-facing databases to secure and energy-efficient "Tier 3 servers" in Sacramento from Stockton-office servers and desktops. It's been a substantial undertaking and is nearly concluded. The end result will be rigorous data security as well as additional and more-reliable web applications for dissemination of data and summaries. Each database will have a Microsoft Access front end for use by staff and an SQL backend. The following fourteen (14) databases (status in parens) are included the effort: 20-MM Survey (complete), Bay Study Crab (underway), Bay Study CTD (complete), Bay Study Fish (underway), Bay Study Shrimp (underway), EMP Zooplankton (complete), Fall Midwater Trawl Survey (complete), Salvage (complete), Smelt Larva Survey (complete), Spring Kodiak Trawl Survey (complete), Striped Bass Population Study (complete), Sturgeon Fishing Report Card (complete), Sturgeon Population Study (complete), and Summer Townet Survey (complete). Until agreed-upon end-users develop applications to use them, the applications will only be accessed by authorized DFW staff and used by DFW data portals. California Estuaries Portal's use of the EMP Zooplankton database is the first non-DFW effort being developed to take advantage of this new capacity. Contact Marty Gingras (marty.gingras@wildlife.ca.gov) for further information.

San Joaquin River Sturgeon Investigations - 2011/12 Season Summary

Zachary Jackson (USFWS), Zachary_Jackson@fws.gov

Introduction

Prior to 2011, information regarding the distribution of sturgeon (*Acipenser* spp.) in the San Joaquin River was limited to anecdotal reports and CDFG sturgeon report card data (Gleason et al. 2008; DuBois et al. 2009, 2010). Since implementation of the Sturgeon Fishing Report Card in 2007, anglers have reported catching 169 white sturgeon and 6 green sturgeon on the San Joaquin River upstream from Stockton (Gleason et al. 2008; DuBois et al. 2009, 2010, 2011, 2012). Of the reported fish, 108 (64%) white and 5 (83%) green sturgeon were caught between Stockton and the Highway 140 bridge (rkm 202). The remaining 61 (36%) white and 1 (17%) green sturgeon were caught upstream of the Highway 140 bridge. Reports indicated anglers concentrate in two areas known locally as Sturgeon Bend (rkm 119) and Laird Park (rkm 143; H. Rutherford, CDFG warden, personal communication). Every March and April, sturgeon are observed in shallow water near Laird Park in Stanislaus County. Those that are fished in this location often freely express eggs and milt when handled (H. Rutherford, CDFG warden, personal communication). In an effort to learn more about how sturgeon are using the San Joaquin River and to inform future habitat restoration actions, the Anadromous Fish Restoration Program of the US Fish and Wildlife Service began a study in April of 2011 to determine if and where sturgeon are spawning in the San Joaquin River by collecting fertilized eggs on artificial substrate samplers. In order to identify additional spawning locations and learn more about the spatial and temporal distribution of sturgeon, trammel nets were deployed to capture adult sturgeon to be implanted with acoustic transmitters (2012 only).

Artificial substrate samplers (i.e., egg mats) were deployed in close proximity to presumed spawning areas at four locations in a 24-km reach of the San Joaquin River from Sturgeon Bend (rkm 119) to Grayson Road Bridge (rkm 143) in Stanislaus County, CA based on hydraulic conditions and anecdotal observations. Egg mats were constructed using two 89 x 65 cm rectangular sections of furnace filter material secured back to back within a welded steel frame (McCabe and Beckman 1990; Schaffter 1997; Poytress et al. 2009). Egg mats were held in position by a 2.0-kg anchor attached to the upstream end of the egg mat. Environmental data collected each time egg mats were retrieved consisted of GPS coordinates, turbidity, egg mat depth, and weather conditions. Water temperature was monitored at each site with a Stowaway® Tidbit temperature logger attached to the egg mat set to record temperature hourly. Discharge data for each site was obtained from the nearest gauging station through the California Data Exchange Center. Each year, egg mats were visually inspected twice a week throughout the sample period. Egg samples were counted and identified to species in the field using an egg key (Reyes et al. 2007; Wang 2010; Reyes 2011). Sturgeon eggs were sent to the University of California-Davis for species confirmation, photography, measurement of egg diameter, and determination of developmental stage. Spawn date was back-calculated using the egg collection date, developmental stage, and water temperature (Wang et al. 1987; Deng et al. 2002).

Adult sturgeon were sampled with large-mesh gill and trammel nets in accordance with NOAA Technical Memorandum NMFS-OPR-45 (March 2010): *A Protocol for Use of Shortnose, Atlantic, Gulf, and Green Sturgeons*. Nets were set in the presumed spawning area (rkm 119 to 143) for short duration sets (i.e., < 2 hours), depending upon water temperature. Upon capture, sturgeon were implanted with Vemco V16 coded acoustic transmitters. Movements were monitored by an array of six receivers augmented by weekly mobile tracking surveys.

2011 Egg Results

Twenty-three white sturgeon (*A. transmontanus*) eggs were collected April 25-28 at one site, likely representing a single spawning event. Several researchers have speculated that sturgeon spawn within the San Joaquin River system (Kohlhorst 1976; Schaffter 1997; Beamesderfer et al. 2004), but this had not been confirmed through any direct sampling activities. Thus, our work provided the first documentation of white sturgeon spawning in the San Joaquin River (Gruber et al. 2012).

2012 Egg Results

Sixty-five white sturgeon eggs were collected between March 22 and May 14, representing at least six distinct spawning events (Jackson and Van Eenennaam 2013). In addition, three new spawning sites were identified. The results of these surveys confirm that white sturgeon do spawn in the San Joaquin River in both a wet year (2011) and a dry year (2012) and may be an important source of production for the white sturgeon population in the Sacramento-San Joaquin river system.

2012 Adult Sturgeon Telemetry

Ten white sturgeon were captured in March and April and implanted with acoustic transmitters (Jackson 2013). Preliminary review of tag detections showed that there were three general movement patterns. One individual passed the downstream-most receiver approximately 23 hours after tagging, a distance of 23 km from the release site. Two individuals moved slowly downstream after tagging and passed the furthest downstream receiver after 16 and 42 days. The other seven sturgeon exhibited a sporadic movement pattern and spent between 23 and 61 days moving back and forth within the study reach before exiting the array. One of these seven fish spent 30 days within the receiver array, made a quick movement up to the Merced River confluence, and then slowly migrated downstream. The acoustic receiver array will be maintained year-round for the foreseeable future.

Future Plans

Additional egg sampling, in conjunction with acoustic tracking, will be continued throughout a variety of water year types to better understand the spatial and temporal distribution and habitat preferences of white sturgeon in the San Joaquin River. A larval sampling survey will be initiated in 2013 to evaluate hatching success and initial juvenile recruitment. Continued study of the response of white sturgeon to changes in environmental conditions may be important for informing fishery and water management decisions. Understanding the effects of water management in a controlled river like the San Joaquin

River may result in increased spawning activity, spawning success, and recruitment of white sturgeon.

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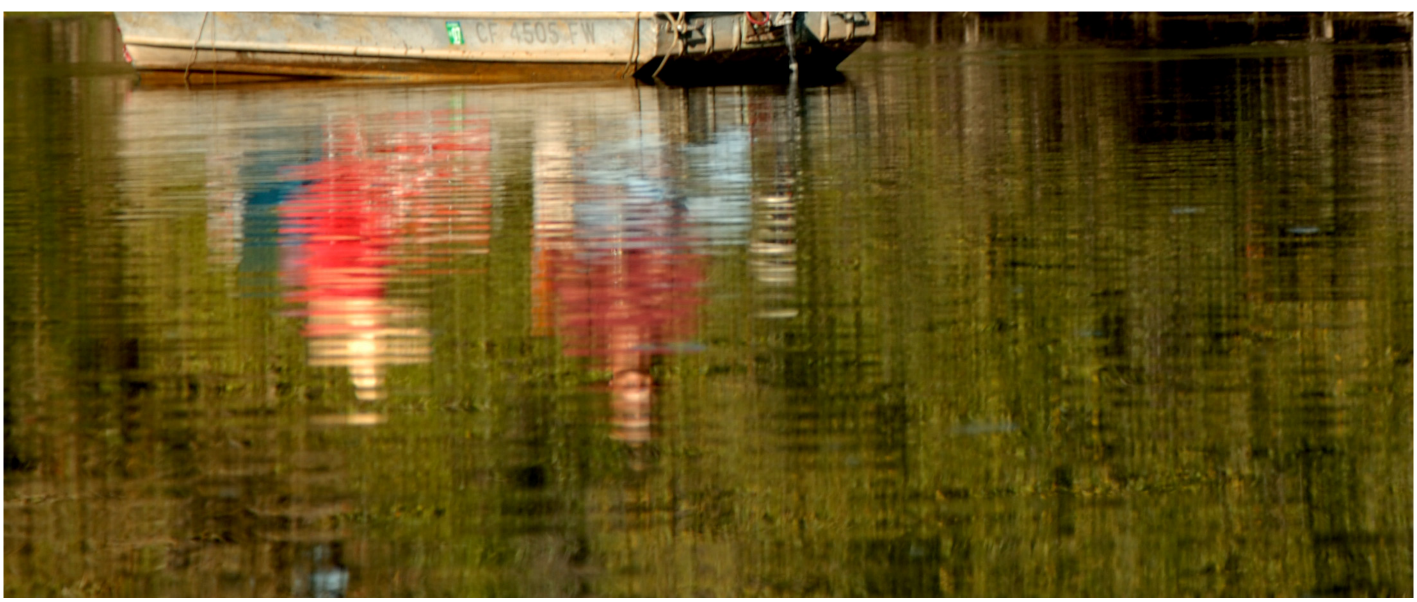

Contributed Papers

Sacramento-San Joaquin Delta: The Rise of a Trophy Size Largemouth Bass Fishery

Jared Frantzich (DWR), Jared.Frantzich@water.ca.gov.

Introduction

The Sacramento-San Joaquin Delta (Delta) has become a largemouth bass (*Micropterus salmoides*) angler's dream fishery over the last several decades. The Delta's reputation of producing largemouth bass in excess of 10 lbs has gained national attention (Hall, 2012), as it hosts an increasing number of tournament events held throughout the tangled 1,000 river miles.

The California Department of Fish and Game, now the Department of Fish and Wildlife (CDFW), has maintained a comprehensive, statewide, database of largemouth bass tournaments based on required reports after the completion of permitted fishing tournaments. These reports include data on largemouth bass size and angler fishing effort, which in turn provide important insight into the changing largemouth bass fishery in the Sacramento-San Joaquin Delta; however, it has been over a decade since these data have been examined (Lee, 2000). Analysis of recent trends in the tournament fishery may provide insight into the population dynamics of largemouth bass, including changes in the average weight, population density and structure. Such insights are valuable because largemouth bass are a keystone predator (Moyle, 2002) and, along with other centrarchids, have come to dominate the littoral zone in the Delta over recent decades (Brown and Michniuk, 2007). Using the CDFW tournament database, we address the following questions: (1) Has the largemouth bass tournament fishery grown since its inception and is there increased angler participation; and (2) Are largemouth bass in recreational tournaments in the Delta increasing in size?

Delta Tournament Fishery

The largemouth bass fishing tournament activity in the Delta has increased in popularity over the last several decades and much of this can likely be attributed to the growth of the sport nationally. Tournament circuits such as Forest L. Wood (FLW) and Bass Anglers Sportsman's Society (BASS) bring national attention to the Delta, where 100 professional anglers fish for $100,000 in prize money in three to four days of fishing. These televised circuits expose Delta bass fishing and elevate interest and tournament bass fishing participation. With publicity comes sponsorship and business investment in advertising, which in turn drive an increase in local tournament organizations. Western Outdoor News (WON) Bass, Anglers Choice, and Future Pro Tour are just a few of the popular circuits available to California bass anglers today. These circuits provide anglers several tournament formats, including Pro Team, Semi Pro Team, and Pro-Am multi-day draw events.

The structure of bass tournament competition is based on the total weight caught by anglers in a given competition day (the total weight for most tournaments per day is based on a five-fish limit). Team events involve two-angler teams fishing from the same boat for a combined total weight against other teams. The Pro-Am multi-day draw events pair amateur anglers with a different professional angler each day; the two can either fish toward a shared total weight each day or individual total weights each day. The shared weight Pro-Am event is standard for most local draw events with some tournament organizations offering an individual weight format. Notably, in addition to the larger professional tournaments, many bass fishing clubs from throughout California sanction tournaments in the Delta every year. In 2010, the Sacramento-San Joaquin Delta made up 18% of the total Event and Annual type contests that were hosted at 67 water bodies all over the state (Murphy, 2011).

Methods

CDFW Tournament Database

The CDFW began maintaining a database of permitted black bass (largemouth, smallmouth, and spotted bass) fishing tournaments throughout the state of California in 1985. The data is gathered on each tournament through the submission of a report form that includes information on tournament type, date of tournament, location, number of participants, tournament duration, and total largemouth bass caught, total weight of largemouth bass, and heaviest largemouth bass caught. Over the past 30 years, the CDFW has implemented several important changes to the permitting and reporting process in an effort to improve the reporting rate and develop a complete tournament database. In 1986, CDFW eliminated a previously established $200 limit on prize money for team tournaments and as a result encouraged more tournament sponsors to apply for permits, which in turn increased the number of submitted reports. The reporting process was further advanced in 1990 when CDFW required anyone awarding prizes during game fishing to obtain a permit and submit a report form (Lee, 2000). Given that team bass tournaments make up the majority of permitted events that take place each year, this is a significant addition to the data gathered and reported on angler effort and the catch of black bass from California waters each year. In 2007, CDFW worked to improve the reporting rate by sending a Letter of Notice to tournament organizers who failed to submit a tournament report. Currently, failure to return a required report can result in the cancellation of any existing approved permits and/or the denial of any future tournament permits, which encourages compliance and ensures that new data is entered into the tournament dataset each year (CDFG, 2008). In 2008, CDFW also began providing a writeable PDF form and e-mail submittal procedures to improve the ease of reporting (CDFG, 2008). The recent changes to the reporting process have increased report compliance significantly. The report compliance over the last several decades has varied, but has averaged 60% 1985 – 2008. Since 2009, the reporting rate has averaged 86%, with only 1 incomplete report for all fishing contests permitted by CDFW.

Tournament sponsors can apply for two different kinds of permit types: Event or Annual. Event permits require that there are more than 50 participants and prizes exceed $1,000, while Annual permits are issued when there are fewer than 50 participants and less than $1,000 in prizes. The Delta is the only individual body of water in California where a total of three Event-type tournaments may be scheduled on the same day (CDFG, 2008). This allows for a tremendous increase in angler effort and also speaks to the success of the fishery for anglers.

There are a variety of tournament rules for each sponsored event, but all permitted tournaments analyzed were “weigh-in” contests. In such tournaments, anglers are responsible for bringing their catch to a central weigh-in site by a specific time. The Delta has a 12-inch minimum length requirement (though some tournaments organizations administer a 13-inch minimum) and a five fish per angler bag limit (CDFG, 2011). Tournament anglers are required to keep their fish alive in an aerated livewell on their vessel. Once anglers have caught their tournament limits, it is their responsibility to cull fish out of the livewell if they catch larger fish. To promote black bass catch-and-release during tournaments, CDFW implemented several special rules beginning in 1988. Changes included the requirement for anglers to transport fish in water-filled containers to the weigh-in and to not exceed the five fish limit per container. The most notable change was the maximum allowable fishing time of six hours between weigh-ins for tournaments that take place in the warm summer months between June 15 and September 15 (CDFG, 2008).

Data Analyses

This analysis includes all report results for permitted Event and Annual tournaments that were held on the Delta for the 1985 – 2010 calendar years. Any tournaments that were cancelled, not reported, or for which sponsors submitted incomplete reports were not included in this analysis. To address the first question, as to whether the Delta largemouth bass tournaments have grown in recent decades, I examined annual trends in angler participation, the total number of reported Event and Annual contests, and total angler hours, then compared the Delta with several other top California water bodies, including Clear Lake and Lake Shasta. To understand interannual trends in largemouth bass size, I calculated the average weight of tournament-caught fish for each year. In addition, I calculated the weight per unit effort (WPUE, annual total weight of largemouth bass caught divided by total angler effort in hours) for each tournament, and examined the time series of the average annual WPUE. The use of WPUE was adopted from the Pacific Halibut Commission for the annual stock assessment of Pacific halibut (Hare, 2010). Finally, I used tournament catch per hour (CPH, total number of fish caught/total angler hours) to compare and show trends in angler fishing effort. I performed a linear regression to examine the relationship between CPH and mean weight of largemouth bass (Lee, 2000).

Results and Discussion

Angler Participation

There has been a continued increase in the number of largemouth bass tournaments in the Delta since the institution of CDFW required permits in 1985. The CDFW issued a total of 4,594 permits from 1985-2010 with tournament sponsors returning a total of 3,266 (71%) of the contest reports, with 2% being incomplete. Since 1998, the number of issued permits for Delta tournaments has exceeded 200 individual contests annually; by comparison, no other California water body has surpassed 150 (Clear Lake held 148 tournaments in 2010). Tournament sponsors have continued to increase the number of tournaments annually, with a record of 269 tournaments in 2010. The number of angler hours has also increased substantially in the Delta and maintained more than 100,000 angler hours from 2007-2010. A significant amount of this increase can be attributed to the regulation changes in 1990 and the ability of the Delta to host up to three different Event type tournaments daily. This also indicates a relationship between a healthier largemouth bass fishery and increased angler effort (Figure 1).

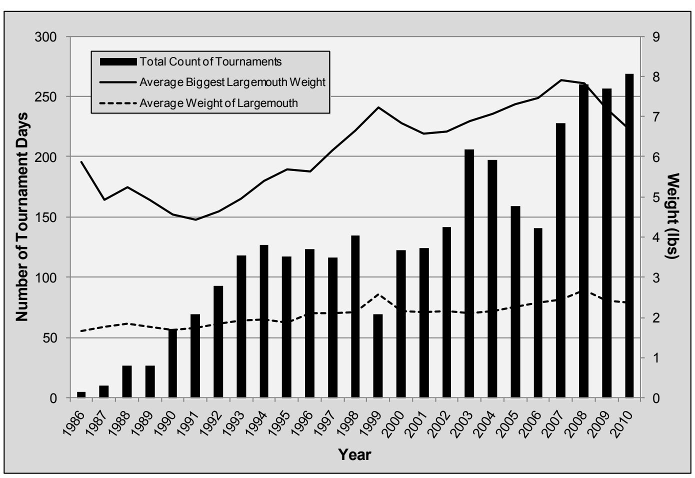

Figure 1 Total count of tournaments, average biggest largemouth bass weight, and average weight of largemouth bass reported caught in tournaments in the Sacramento San Joaquin Delta 1986 - 2010

There has been growth in all tournament types, but one-day events have shown the greatest increase as they represent 86% of the total number of reported tournaments from 1985-2010. The number of reported one-day tournaments per year in 2010 was 225, which is five times as many as in 1990 (44 reported). The increase in one-day events is most likely due to the increased ability of tournament sponsors to obtain enough angler participation to host up to three events on the Delta each day. However, this increase in one-day events has also resulted in a decline in the average number of anglers per tournament, as it has dropped from a high of 180 in 1986 to a low of 40 in 2010.

Trends in Tournament Fish Weight

As the total number of tournaments has increased, the average weight of tournament fish has also increased, indicating a largemouth bass population structure that is increasingly getting larger. There were a total of 437,106 largemouth bass weighed in from 1985-2010, and the average weight for each largemouth bass was 2.13 lbs. The average weight of each largemouth bass weighed in at each tournament has gradually increased from 1.67 lbs in 1986 to a high of 2.68 lbs in 2008. The relationship between WPUE showed a positive correlation with time (R^2= 0.67), increasing from an average of 0.52 lbs/hr in the 1980s and 1990s to the 2000s 0.71 lbs/hr on average in the 2000s (Figure 2). This trend of increased WPUE suggests that the Delta's abundant nearshore habitat is allowing for improved growth and/or survival of largemouth bass. Alternatively, the Delta largemouth bass age structure could be shifting to a larger population of older and subsequently larger fish.

In addition to average WPUE, average size of the largest fish per tournament has also increased. The average weight of the heaviest largemouth bass weighed in at each tournament was only 5.45 lbs in the 1980s and 1990s but increased to 7.13 lbs in the 2000s. In 2007, the average largest fish weight was 7.92 lbs, a 56% increase in size when compared to the average largest fish weight in 1991 of 4.43 lbs. This trend could be explained by the catch-and-release practices by tournament anglers and sponsors, which reduces fishing-related mortalities (Barnhart, 1989), thus enabling them to return to the population to reach a larger size. A look at mortality rates for Delta largemouth bass by CDFW tagging studies in 1980s suggests that many anglers were practicing catch and release, and subsequent tagging indicated that approximately 90% of largemouth bass caught in the Delta are released (Schaffter, 2000).

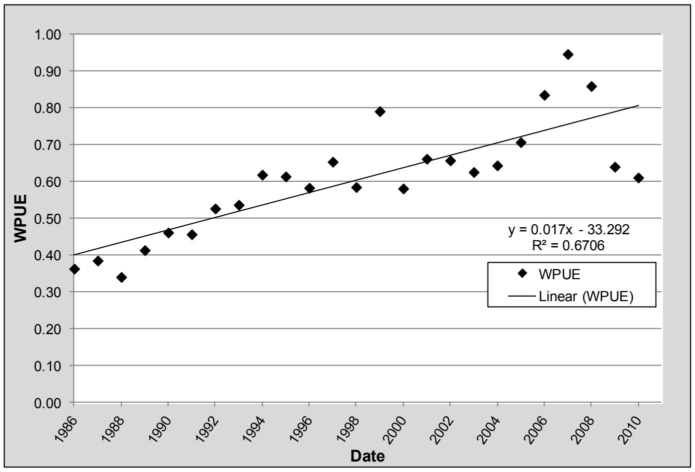

Figure 2 Weight per unit effort (WPUE) of tournament caught largemouth bass in the Sacramento-San Joaquin Delta 1986 - 2010

Within the largemouth bass fishing community, a true "trophy" largemouth bass is often equated with a fish ≥ 10 lbs. There were a total of 277 largemouth bass ≥ 10 lbs that were the largest of all fish weighed in for tournaments from 1985-2010. Of those largemouth bass ≥ 10 lbs, 236 were weighed in tournaments in the 2000s, which is 86% of all tournaments reporting largest fish ≥ 10 lbs. (Figure 3). Since 1986, the CDFW has kept record of the heaviest largemouth bass caught in all recorded tournaments in California, and since 2000, the Delta has recorded the heaviest largemouth bass caught annually five times, with the heaviest fish weighing 17.57 lbs in 2000 (Table 1) (Murphy, 2011).

One important factor that could be influencing the increasing presence of "trophy" size largemouth bass in the Delta is the introduction of Florida-strain fish into Northern California water bodies in the late 1970s and 1980s. The Florida-strain largemouth bass (*Micropterus s. floridanus*) is a genetically distinct subspecies of the northern-strain of largemouth bass (*Micropterus s. salmoides*) and was imported into California waters due to its ability to grow faster and larger than its northern-strain counterpart (Dill and Cordone, 1997). If the Delta largemouth population shows an increase in the dominance of Florida-strain alleles, it may explain an accelerated growth rate in subsequent largemouth bass offspring. Many preliminary studies of Florida-strain introductions into California reservoirs that maintained northern-strain populations resulted in improved mean size and the ability for these water bodies to produce trophy-sized bass (Dill and Cordone, 1997). The overall genetic make-up and extent of hybridization between northern- and Florida-strain largemouth bass in the Delta is unknown, but a further analysis of genotypes may help explain an increase in size of Delta largemouth bass. Genetic results from 1993 sampling of largemouth bass in the east Delta indicated 21% of the 1992 year class and 30% of the 1993 year class contained Florida-strain alleles (Schaffter, 1998; Gall, 1999). These preliminary results, though taken from a small portion of the largemouth bass population in the Delta, suggest the possibility of increased prevalence of the larger and faster growing Florida-strain largemouth bass. However, without further investigation into the genetic composition of the largemouth bass population in the Delta, the influence of the Florida strain in the Delta is purely speculative.

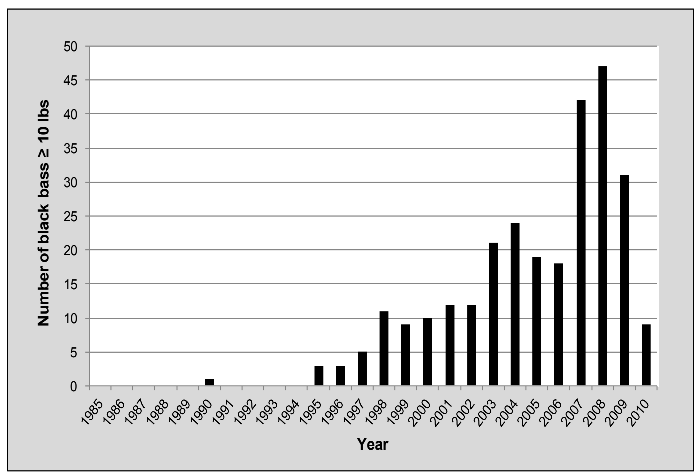

Figure 3 Total count of reported largemouth bass in the Sacramento-San Joaquin Delta ≥ 10 pounds, from 1985 - 2010

In addition to an increase in the weight of largemouth bass caught in tournaments, the Delta largemouth bass fishery has also seen a progression towards increased angler success in largemouth bass tournament catch rates. The annual angler CPH rate has increased considerably over the 25 years of tournament reports from a minimum of 0.183 fish per hour in 1988 to a maximum of 0.364 in 2007. Additionally, there is a positive correlation between CPH and the annual mean weight of the fish brought to weigh-ins (Figure 4). The Delta is one of the few water bodies in California that consistently maintains an above-statewide average annual CPH and average weight. On average, most reported tournaments throughout California experience a negative correlation between CPH and average weight per fish weighed in (Lee, 2000). The positive correlation between CPH and average weight in the Delta compared to other California tournament water bodies, suggests that even as tournament frequency and participation increases, the increased fishing pressure on largemouth bass in the Delta is not limiting to its population, in terms of its size or the weight of the largest individuals. However, after a peak in 2007 of CPH and WPUE, more recent years have seen a declining trend despite an increase in the number of reported anglers and tournaments each year in the Delta (Figures 1 and 2).

Table 1 Largest Tournament caught black bass in California 1986 - 2010

Year	*Location*	*Date Caught*	*Species*	*Weight (lbs)*
1986	Clear Lake	6/15/1986	Largemouth	12.80
1987	Lake Castaic	6/6/1987	Largemouth	17.90
1988	Lake Cachuma	3/18/1988	Largemouth	16.40
1989	Lake Castaic	6/10/1989	Largemouth	13.00
1990	Lake Casitas	3/10/1990	Largemouth	15.80
1991	Clear Lake	6/1/1991	Largemouth	15.38
1992	Lake Castaic	6/20/1992	Largemouth	17.87
1993	Lake Cachuma	4/17/1993	Largemouth	18.24
1994	Lake Casitas	4/30/1994	Largemouth	15.47
1995	Lake Castaic	6/10/1995	Largemouth	13.71
1996	Lake Perris	11/10/1996	Largemouth	15.38
1997	Lake Hodges	9/27/1997	Largemouth	16.50
1998	Lake Shasta	11/19/1998	Largemouth	16.56
1999	Lake Casitas	6/19/1999	Largemouth	14.74
2000	CA Delta	4/30/2000	Largemouth	17.57
2001	Lake Perris	11/11/2001	Largemouth	14.04
2002	Lake Casitas	6/15/2002	Largemouth	15.54
2003	CA Delta	4/12/2003	Largemouth	14.08
2004	Lake Success	5/15/2004	Largemouth	14.76
2005	Lake Shasta	10/9/2005	Largemouth	15.84
2006	CA Delta	4/15/2006	Largemouth	15.81
2007	Lake Pyramid	5/6/2007	Largemouth	16.40
2008	CA Delta	4/5/2008	Largemouth	14.25
2009	CA Delta	4/11/2009	Largemouth	15.59
2010	New Melones Reservior	3/20/2010	Largemouth	18.11

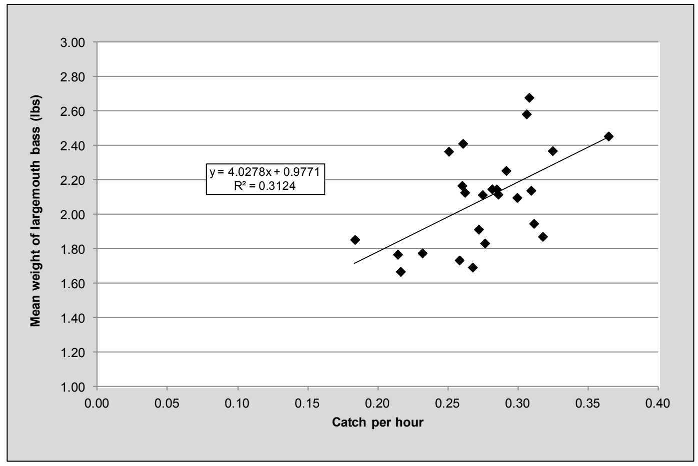

Figure 4 Relationship between catch per hour and average weight of largemouth bass weighed in during tournaments in the Sacramento-San Joaquin Delta, 1986 - 2010

Conclusions

The data collected through the submittal of CDFW tournament reports suggests that the largemouth bass in the Delta are increasing in size, even in the last decade. It is hard to pinpoint exactly what is driving this trend in the fishery, but a further investigation into current and historical growth rates and age composition on Delta largemouth bass could help address these questions. To this end, the Aquatic Ecology Section at Department of Water Resources has collected scales from tournament-caught fish in 2011 and 2012. The length-at-age data from these scales should help to address questions about the age structure of tournament-sized largemouth bass in the Delta.

The Delta is a dynamic aquatic ecosystem, with many physical factors affecting the flow, water quality, and habitat conditions. The Delta, like most of the aquatic environments within California, has gone through many changes over the years, mostly due to anthropogenic water transport demands. These and other factors, including the introduction of Florida-strain bass, prey availability, increased submerged aquatic vegetation (chiefly after the proliferation of the Brazilian waterweed, *Egeria densa*, in early 1990s), improved water clarity, and favorable low velocity conditions in the interior Delta, have improved habitat suitability for largemouth bass (Brown and Mickniuk, 2007). Improved habitat conditions may facilitate increased recruitment rates for juvenile largemouth bass into the adult population, and/or enhance growth rates. Separately, or in addition to the effects of improved habitat conditions, the practice of catch-and-release may also contribute to the increased success and size of largemouth bass brought in for tournaments.

In summary, the high frequency and increased angler participation in largemouth bass tournaments that take place throughout the four counties that the Delta encompasses (Sacramento, Solano, San Joaquin, and Contra Costa) represents a growing recreational fishery. The contribution of these tournaments in facilitating the broader distribution of largemouth throughout the Delta, due to onsite live releases after tournament weigh-ins, is unknown. Further studies are necessary to determine how the role of the catch-and-release practice of anglers and/or improved survival and growth rates of largemouth bass due to ecosystem changes have contributed to tournament trends.

Acknowledgements

The CDFW tournament data was managed and provided by Senior Fish Biologist Kyle Murphy with the Flatwater Reservoir Research and Management Project. The CDFW tournament data is supported by funding from various grants provided by the Federal Aid Sport Fish Restoration Act Project. A special thanks to Dr. Graham Gall for providing insight into his genetic analysis of Delta largemouth bass. Additional thanks to Louise Conrad who provided various help and advice.

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Relating CPUE of Striped Bass from Partyboats and Mark-recapture Estimates of Striped Bass Abundance

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Introduction

The California Department of Fish and Wildlife (CDFW) has been conducting a mark-recapture study of anadromous striped bass age-3 and older since 1969 (Stevens et al. 1985), and striped bass abundance is one of many metrics estimated from the data. Because these abundance estimates are time-consuming, expensive, and sometimes infeasible to produce, development of an abundance index that is easier to calculate (e.g., catch per unit effort (CPUE)) would be helpful.

Commercial passenger fishing vessels (partyboats; CPFVs) are chartered by anglers for the express purpose of targeting and catching a fish species of interest (e.g., striped bass). Partyboat operators are required to complete a log for each trip (Hill and Schneider 1999). Logs contain information on catch by species, number of anglers, time fished, location (called 'blocks') fished, and the date fished. From this information, it is possible to calculate CPUE.

The CDFW has been collecting and summarizing partyboat data since 1936 (Calhoun 1949, McKechnie and Miller 1971), and CPUE calculated from partyboat data is often assumed to be an index of abundance. We have recently explored a range of ways to calculate CPUE of striped bass from partyboat data (DuBois 2011), and here we present a brief summary of the relation between striped bass CPUE from partyboat data and mark-recapture estimates of striped bass abundance.

Investigation

The relation between CPUE and abundance can be defined by Equation 1 (Ricker 1975), where q = catchability, and N_t = mean abundance at time t. For the present purposes, we assume a constant q.

$$CPUE_t = q \times N_t$$

Equation 1

We estimated annual striped bass abundance (N) by age and sex from mark-recapture data using Equation 2 (Ricker 1975). As of this writing, abundance estimates for 2007, 2008, and 2009 are preliminary.

$$N = \frac{M \times (C+1)}{(R+1)}$$

Equation 2

Where M = number of fish marked (tagged)
C = number of fish caught
R = number of recaptured tags

We calculated CPUE using data from 1980 – 2009 only, because partyboat log data prior to 1980 is only available as monthly summaries (Hill and Schneider 1999) and (thus) it is impossible to calculate species-specific effort from that portion of the dataset.

We felt it proper to calculate CPUE using many criteria, due to the migratory nature of striped bass, the improvements in technology used to track fish, and possible variations in the catch-and-release fishery component. To explore likely spatial and temporal variations in CPUE as they might pertain to the development of a robust index of abundance, we calculated annual CPUE (per Equation 3, where t = year) by using criteria based on catch (e.g., all trips; successful), 'blocks' (i.e., fishing areas), and season (Table 1, DuBois 2011). We also looked at how CPUE varied based on whether or not partyboats targeted striped bass and by considering striped bass fate (i.e., harvested or released).

Table 1 Definition of CPUE abbreviations

Abbreviation	*Definition*
success	successful trips; kept only; no target
All	kept only; no target
all.mon.6.11	"all trips; kept only; no target; only months June through November"
suc.targ	successful trips; kept only; target striped bass
all.targ	all trips; kept only; target striped bass
all.kept.rel	all trips; kept and released; no target
CPUE.303.304	combined blocks 303 and 304; successful trips; no target
CPUE.sfe.less.303.304	SFE less blocks 303 and 304; successful trips; no target
CPUE.303.304.305	"combined blocks 303, 304, and 305; successful trips; no target"
CPUE.sfe. less.303.304.305	"SFE less blocks 303, 304, and 305; successful trips; no target"
CPUE.less.5	excluding five vessels identified as specifically targeting striped bass; successful trips; kept only
CPUE.only.5	including only the five vessels identified as specifically targeting striped bass; successful trips; kept only
successful trips means trips where at least one angler kept at least one fish	
kept only means only using number of fish that were kept	
no target means vessel did not target a particular species	
block 303 represents the Sacramento River from the confluence to about Rio Vista	
block 303 also includes some of the San Joaquin River just east of the confluence	
block 304 represents the Sacramento River from about Rio Vista to the City of Sacramento	
block 305 represents the Sacramento River from the City of Sacramento northward	

We examined the relation between each permutation of CPUE and the others by way of scatter plots (see Figure 1 for an example), and found that the relations vary substantially, especially when filtered by geographic criteria (DuBois 2011). We then compared 12 CPUE permutations to estimated annual striped bass abundance. Correlation coefficients (R^2) for five of the 12 exceeded 0.4 (Figure 2). Two of those five contained the complete CPUE time series (1980-2009; N=25) while, as some information was not required of partyboats prior to 1995, the remainder used data from 1995-2009.

Figure 3 is a typical time series of partyboat CPUE for striped bass, showing the substantial increase in abundance (relative and absolute) from 1995-2000 and several short-duration extreme variations in CPUE.

$$CPUE_t = \frac{\sum catch}{\sum anglerhours}$$

Equation 3

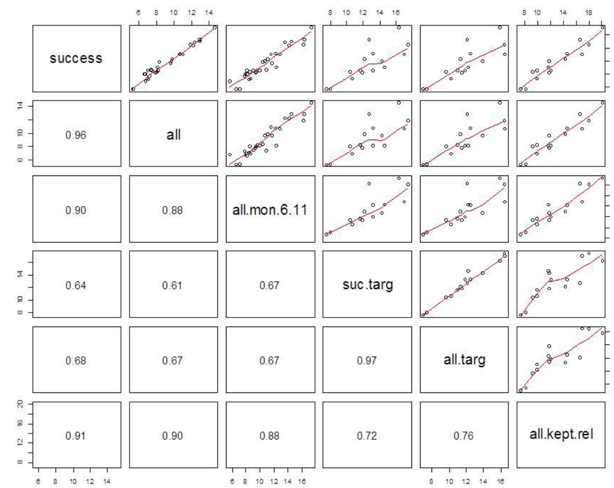

Figure 1 Scatter plot matrix comparing annual partyboat CPUE (effort as 100 angler-hours) for striped bass from trips inside the San Francisco Estuary and various other criteria; upper panels with loess line, lower panels values = R2; data 1980-2009

Discussion

Partyboat CPUE for striped bass does not vary monotonically with estimated striped bass abundance, but several CPUE permutations appear to be helpful indices of abundance. Some extreme variations in CPUE as yet defy explanation (e.g., steep declines in 1986 and 1996) and weaken relations between CPUE and abundance. The best relations we observed come from data (i.e., species targeted; released fish) that has been required of partyboats only since 1995, such that we expect stronger relations between CPUE and abundance in the future.

Variations in q likely bias the time-trend in CPUE. We have explored ways to estimate q but have not come to any resolution. From Equation 1, q can be estimated by dividing CPUE by estimated abundance (N_t). However, doing so would create "circular logic" in our effort to relate CPUE and estimated abundance. Ricker (1973) offers $F = q \times f$ for estimating the instantaneous rate of fishing (F) given fishing effort (f). Thus, q could be estimated by dividing F by f. Estimating F could be possible by rearranging the Ricker (1975) equation, $\mu = \frac{F \times A}{Z}$ where μ = rate of exploitation, A = total mortality rate, and Z = instantaneous total mortality rate. We may consider further investigations (e.g., calculating F) to better understand the potential effects of q (and variations thereto) in this process.

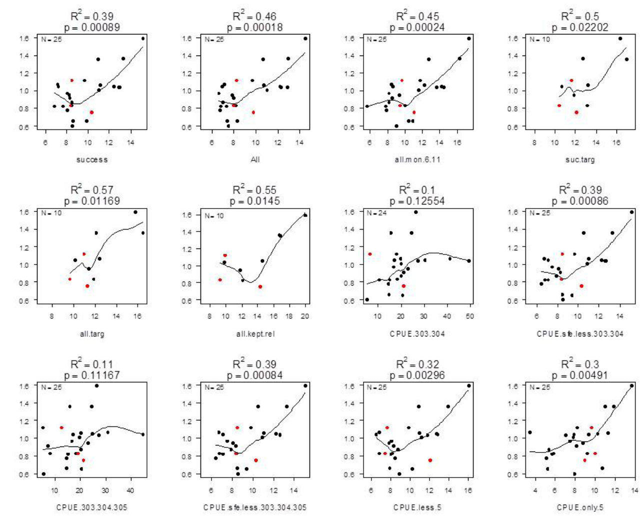

Figure 2 Scatter plot matrix comparing annual partyboat CPUE (x-axis, effort as 100 angler-hours) for striped bass from trips inside the San Francisco Estuary and various other criteria on estimated annual striped bass abundance (y-axis in millions); red dots indicate preliminary abundance estimates for 2007-2009; data 1980-2009

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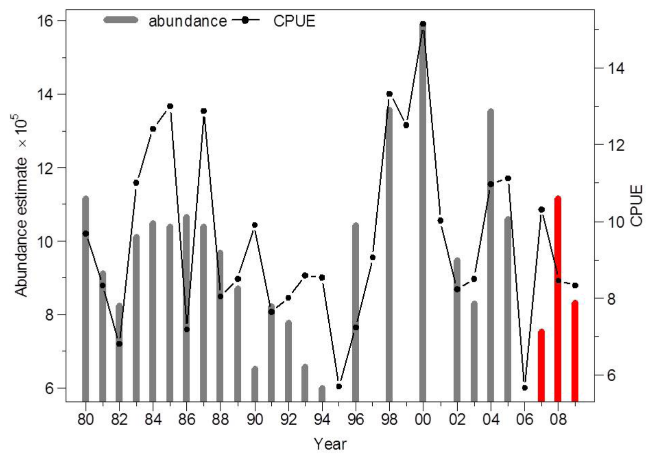

Figure 3 Estimated annual striped bass abundance and partyboat CPUE (success (Table 1); effort as 100 angler-hours); no abundance estimates were made for 1995, 1997, 1999, 2001, and 2006; effort was substantial every year (min: 13,174 hours; max: 117,715 hours; avg: 51,470 hours); red bars indicate preliminary abundance estimates

Fall Midwater Trawl 2001-2011 Gelatinous Zooplankton (jellyfish) Summary

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Introduction

The California Department of Fish and Wildlife (CDFW) initiated the Fall Midwater Trawl (FMWT) Survey in 1967, and have since conducted annual surveys in all years, except 1974 and 1979. CDFW created the FMWT survey to determine the relative abundance and distribution of age-0 striped bass (*Morone saxatilis*) in the San Francisco Estuary, but also developed the same information for American shad (*Alosa sapidissima*), threadfin shad (*Dorosoma petenense*), delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), and splittail (*Pogonichthys macrolepidotus*). The FMWT survey began formally recording pelagic gelatinous zooplankton (jellyfish) catch in 2001, due to increased frequency of jellyfish observations in the field (D. Contreras, CDFG, personal communication). Prior to 2001, records were sporadic as there was no formal method for noting jellyfish presence.

Despite many years of observation, relatively little information is available regarding jellyfish in the upper San Francisco Estuary. Abundance for most gelatinous zooplankton species varies seasonally; jellyfish typically spend winter as polyps and mature into medusa in spring or early summer. Abundance peaks in summer, although the adult medusa often persist in the system and continue to grow in size through fall, before dying off in winter (Mills 2001). Therefore, jellyfish catch data from the FMWT survey may be appropriately timed to help ascertain the status of these invertebrates in the estuary. We summarize the catch of 6 jellyfish taxa collected by the FMWT from 2001 to 2011. Jellyfish include four hydromedusae: *Aequorea* spp., *Maeotias marginata*, *Polyorchis penicillatus*, and *Scrippsia pacifica*; one scyphomedusae complex, *Aurelia* spp., and one cydippid ctenophore, *Pleurobrachia bachei*.

Methods

The FMWT survey sampled 116 stations monthly, from September to December from 2001-2008. Sampled area ranged from San Pablo Bay to Hood on the Sacramento River, and to Stockton on the San Joaquin River (Figure 1). Five additional stations were added in the Sacramento Deep Water Ship Channel in 2009 and one additional station was added in Cache Slough in 2010. One tow was performed at each station, with an average tow volume of 6,050 m^3 per station.

The midwater trawl net mouth is 3.7 m (12 feet) x 3.7 m when taut, but these dimensions shrink under tension during a tow. Net mesh sizes graduate in nine sections from 200 mm (8 inch) stretch mesh at the mouth, to 12.7 mm (0.5 inch) stretch mesh at the cod-end. All four net mouth corners connect to planing doors, which work to counteract drag on the net material, and hold the net mouth open during tows. A 12-minute tow was conducted at each station, during which the net was retrieved obliquely through the water column, from bottom to surface. Field crews identified and enumerated all fish and invertebrates when the catch was small, and sub-sampled when the lead sampler determined that catch was sufficiently high. When fish catch was exceptionally high, field crews visually estimated catch for each jellyfish species rather than counting each jellyfish, by sub-sampling all jellyfish in a container and scaling up to total catch.

Species catch is summed across all stations and summarized for *Aequorea* spp., *Maeotias marginata*, *Polyorchis penicillatus*, *Scrippsia pacifica*, *Aurelia* spp., and *Pleurobrachia bachei*. In this paper, we define "bloom" as a drastic increase in fall catch, many times that of average annual catch. Catch was evaluated by year, region, salinity, temperature, and month. For regional catch, FMWT stations were grouped into 16 geographic areas (Figure 1). Catch was also evaluated based on salinity intervals of 5‰; from 0 to less than 5‰, from 5 to less than 10‰, and so on. Similarly, catch was grouped into temperature intervals of 5 °C. Catch was summed by month over all years to evaluate how catch changes throughout fall. Finally, we examined how catch was related to delta outflow. Outflow data was obtained from DWR's Dayflow at: http://www.water.ca.gov/dayflow/output/Output.cfm.

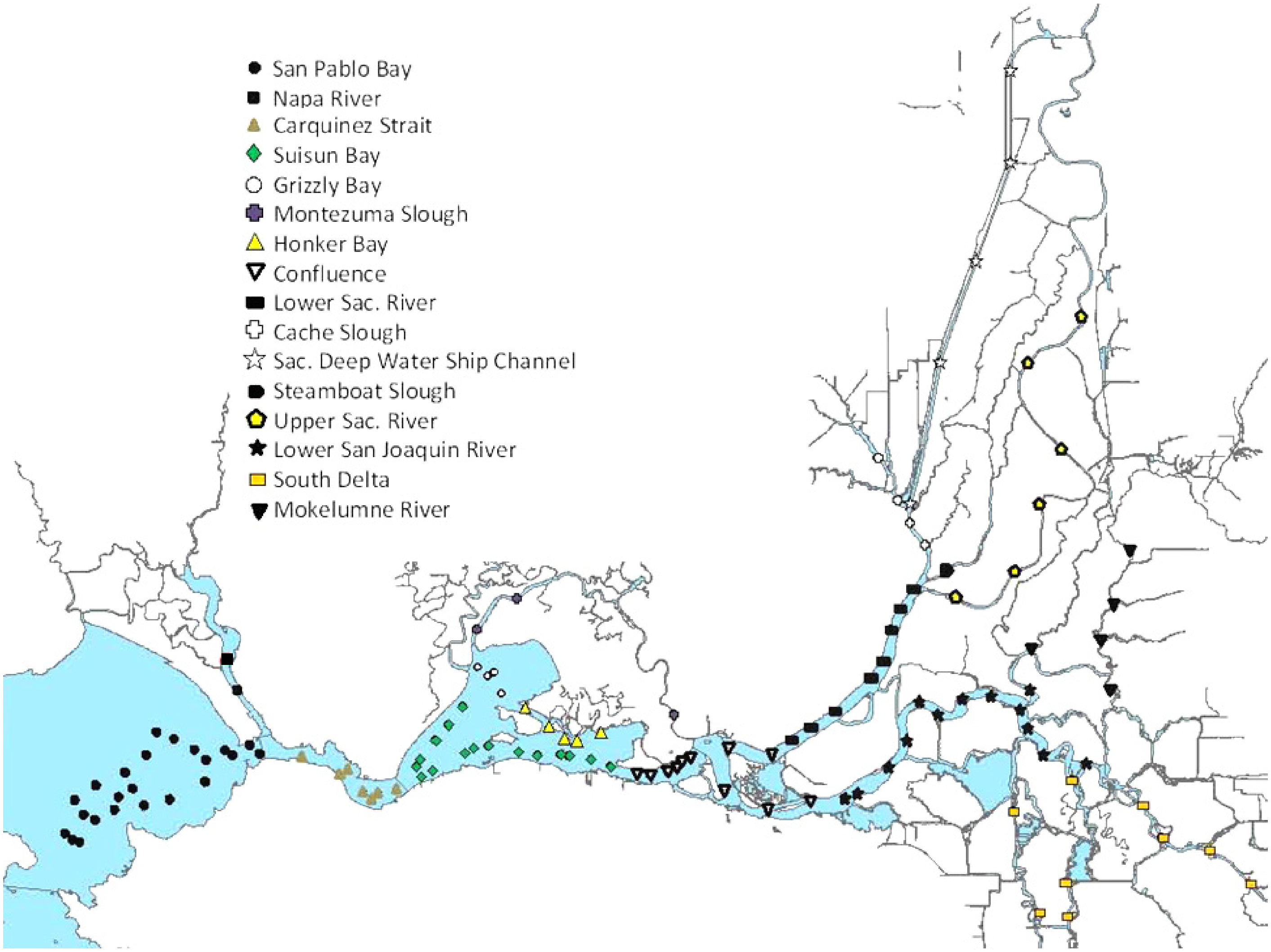

Figure 1 Fall Midwater Trawl stations grouped into regions

Results

Aequorea spp.

Aequorea spp. are nonindigenous, transparent, hydromedusae, with bioluminescent bells that grow up to 25 cm in diameter (Rees and Kitting 2002). The *Aequorea* spp. catch totaled 33, the rarest species observed. As these species are small, clear, and flat, the field crew may have overlooked them within the sample. Nearly all *Aequorea* spp. (n=32) were collected in 2011 (Table 1), with the exception of one individual caught in 2010. All *Aequorea* spp. were collected in San Pablo Bay (Figure 2). They were mostly found in salinities of 23-24‰ (n=29), (Figure 3). *Aequorea* spp. were all found in temperatures from 10.5 °C to 11.4 °C (n=32), except for one found at 15.8 °C (Figure 4). One individual was caught in November, the rest in December (Figure 5).

Maeotias marginata

An invasive jellyfish presumed to originate from the Black Sea, *Maeotias marginata* may have arrived in the San Francisco estuary as early as 1959, based on CDFW field notes (see Rees and Gershwin 2000). The adults have a milky coloring, which combined with a distinct reddish edge around the bell places them among the easier jellyfish to spot in FMWT catch. The adult medusa range from 2-5 cm in bell diameter, are present in summer and fall in the estuary, and feed on benthic and pelagic organisms (Rees and Gershwin 2000). Presence of this brackish-water species has been confirmed throughout the

Table 1 Total annual jellyfish catch by species or genera and total volume sampled in m^3 for the years 2001 through 2011 in the Fall Midwater Trawl

Year	*Polyorchis penicillatus*	*Aurelia spp.*	*Maeotias marginata*	*Scrippsia pacifica*	*Pleurobrachia bachei*	*Aequorea spp.*	*Total Volume Sampled (m^3)*
2001	34	1	904	0	0	0	2332873
2002	16	89	2686	27	0	0	2018912
2003	0	7	2355	0	0	0	2561915
2004	674	0	2011	0	172	0	2462010
2005	0	0	1844	0	0	0	2450543
2006	2	0	6053	0	0	0	2360423
2007	489	209	1978	0	87	0	2455030
2008	412	129	722	1	14	0	2519816
2009	1154	105	536	4	6724	0	2489484
2010	163	27	186	0	1282	1	2644787
2011	725	64	2825	2	615	32	2644415

estuary, from the Napa River up to the Sacramento and San Joaquin Rivers, in salinities as low as 1‰ (Rees and Kitting 2002).

During the study period, *M. marginata* was the most common jellyfish, with a total count of 22,100. This may be partly due to the fact that at 2-5 cm, the adults fall within the target size for the gear at all sizes. Prior to 2006, *M. marginata* annual counts ranged around 2,000, save for excluding a low catch of 904 in 2001. In 2006 there was a bloom of 6,053 *M. marginata* concentrated in Suisun Bay, which represented 27% of total catch over 10 years. The only other species caught that year was *Polyorchis penicillatus* (n=2). In 2007 the *M. marginata* count returned to pre-bloom levels (n=1978) followed by a steady decline to a 10-year low in 2010 (n=186). In 2011, the count rebounded to 2,825 (Table 1). *M. marginata* were mostly caught in the Sacramento-San Joaquin confluence (hereafter confluence) and Suisun Bay regions. *M. marginata* were also common in Grizzly Bay, Montezuma Slough, Honker Bay, and the Lower Sacramento River (Figure 2).

M. marginata seemed to show a preference for salinities ranging from 0-12‰, and they were most abundant at salinities around 5‰, but occurred in salinities up to 25.1‰ (Figure 3). *M. marginata* were also caught over a broad range of temperatures, from 10.2 °C to 29.0 °C, but were most common between 19 °C and 20 °C (Figure 4). Overall, *M. marginata* counts were greatest in September and gradually declined to near absence by December (Figure 5). In some years, *M. marginata* counts peaked in October rather than September, but still declined by December. This may be due to an apparent preference for warmer waters, above 15 °C (Rees and Gershwin 2000).

The distribution of the 2006 *M. marginata* bloom and the elevated 2011 catch followed wet springs and coincided with high fall outflows (Figure 6). These were the only years when counts were higher in Suisun Bay than in the confluence. This may be because average fall salinities in both regions dropped due to high outflows in the wet years of 2006 and 2011, especially in the confluence. Schroeter (2008) posited that salinity was the primary predictor of *M. marginata* abundance, followed by temperature. Average September salinity for 2001-2011 in the confluence was 8.8‰, or 9.7‰ excluding the wet years of 2006 and 2011. These values dropped in the confluence to 1.1‰ in 2006 and 0.2‰ in 2011. Low salinities in the confluence in 2006 and 2011 may have driven them downriver, or Suisun Bay may offer preferable habitat that is less accessible at higher salinities. In Suisun Bay, average September salinity was 2.3‰ for 2001-2011, or 2.7, excluding 2006 and 2011. Suisun Bay salinity dropped to 6.1‰ in 2006 and 3.7 in 2011. Despite lower salinities in 2011, *M. marginata* failed to bloom as it had in 2006. In 2010, the FMWT survey experienced its lowest annual catch of *M. marginata* (n=186) on record. Based on this data, populations of *M. marginata* may have been insufficient in 2010 to support the greater population growth required for a bloom in 2011.

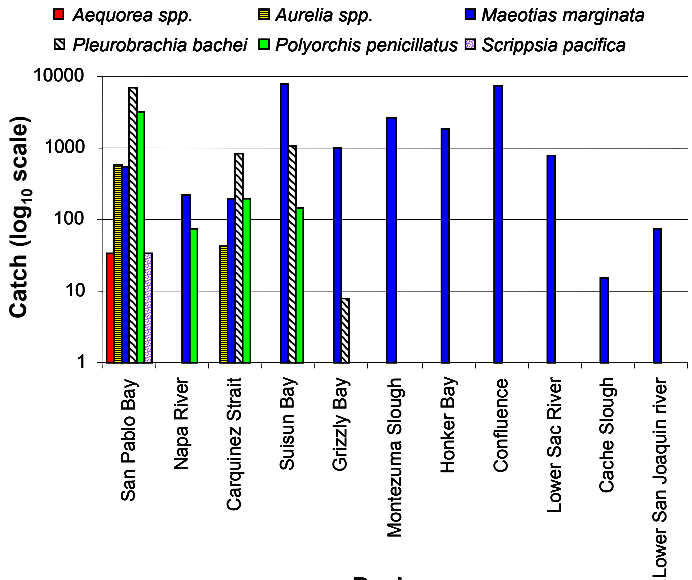

Figure 2 Total jellyfish catch by region for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale). See Figure 1 for region map.

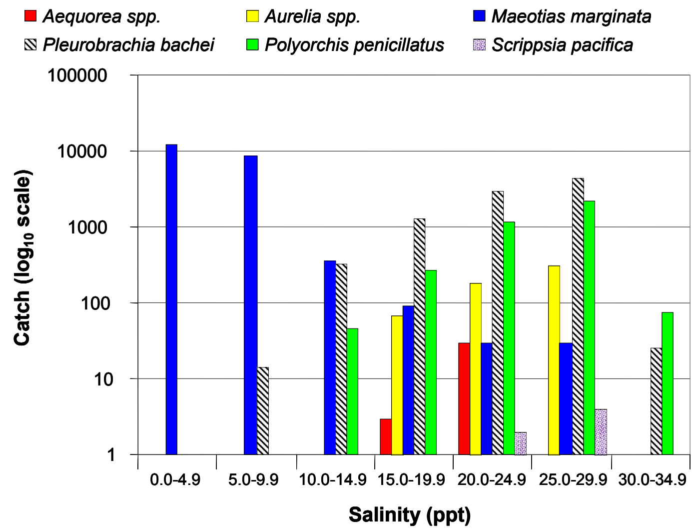

Figure 3 Total jellyfish catch by 5 °C temperature intervals for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale)

During the study period, temperature variability did not seem to be a driving factor in the geographic regional shifts in 2006 and 2011. This may be because average September temperature in 2006 and 2011 in the confluence and Suisun Bay varied by less than one degree from ten-year averages. September temperature in the confluence dropped from an average of 20.3 °C for 2001-2011, to 20.2 °C in 2006 and then rose to 20.9 °C in 2011. In Suisun Bay, average September temperature was 19.4 °C in 2006 and 19.9 °C in 2011, just below an overall average of 20.1 °C for 2001-2011.

Polyorchis penicillatus

The native jellyfish, *Polyorchis penicillatus*, spends most of its time perched on its tentacles, feeding on benthic organisms, although it sometimes swims and feeds in the water column (Mills 2001). It is distinguished by a tall and narrow bell that grows up to 5 cm in height, and the reddish tinge at the base of the tentacles (Rees and Kitting 2002). *P. penicillatus* had a total count of 3,669 for the study period. The highest catch was recorded in 2009, with moderate counts occurring in 2004 and again in 2007, 2008, and 2011. No *P. penicillatus* were observed in 2003 or 2005. In 2006, year of the *M. marginata* bloom, *P. penicillatus* was the only species recorded other than *M. marginata* (Table 1).

P. penicillatus were primarily seen in San Pablo Bay (n=3,256), and to a lesser extent in the Napa River, Carquinez Strait, and Suisun Bay (Figure 2). These regions tend to be more saline and cooler during fall than upstream areas. *P. penicillatus* were most highly concentrated at 29‰, and 89% were collected between 20‰ and 31‰, but they ranged as low as 10.7‰ (Figure 3). Ninety-eight percent of *P. penicillatus* were caught in cooler water ranging from 11 °C to 14 °C (Figure 4). Ninety-seven percent of *P. penicillatus* were caught in December. They were absent in September in all years, excluding 2008 (n=1) and 2010 (n=3). So, *P. penicillatus* were absent in September 2006 during the *M. marginata* boom (Figure 5), although they were captured later that year.

Scrippsia pacifica

Scrippsia pacifica is a native jellyfish, with feeding patterns similar to those of *Polyorchis* (Mills 2001). Like *P. penicillatus*, its tall bell and the red tinge at the base of its tentacles are distinguishing characteristics. *S. pacifica* grow up to 10 cm in bell height and their tentacles can originate above the bell margin. They are rarely observed in the estuary (Rees and Kitting 2002). Indeed, *S. pacifica* was one of the most infrequently captured jellyfish in FMWT records, having a 10-year count of just 34 individuals. The most *S. pacifica* were recorded in 2002 (n=27), and since then annual catch since has been sporadic and low (Table 1). All were caught in San Pablo Bay, save for one in Suisun Bay (Figure 2). Salinity and temperature data were missing for the 2002 samples. However, the remainder S. pacifica were found in salinities of 16-29.5‰ (Figure 3), and temperatures of 10-14 °C (Figure 4). All 34 individuals were captured in December (Figure 5).

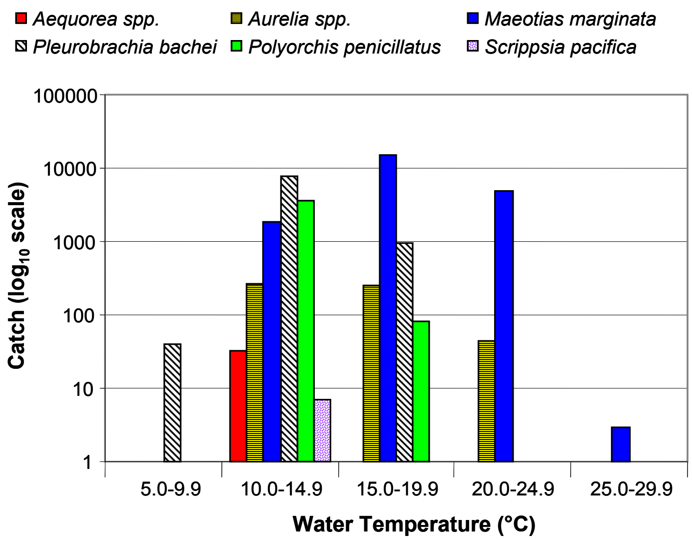

Figure 4 Total jellyfish catch by 5 ppt salinity intervals for the years 2001 through 2011 in the Fall Midwater Trawl ($\log_{10}$ scale)

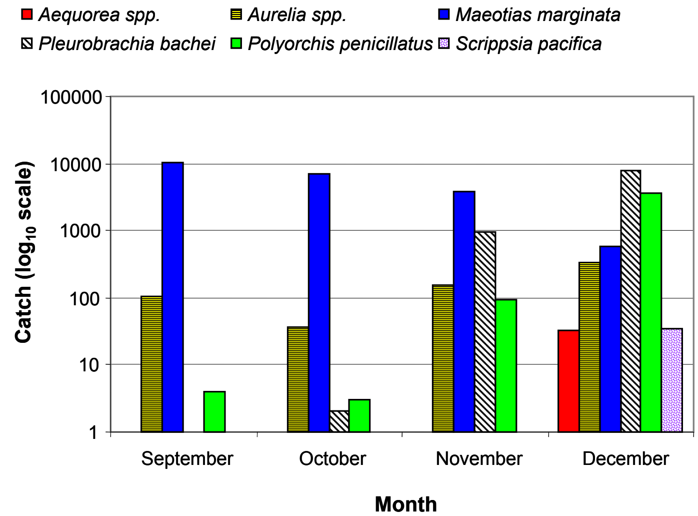

Figure 5 Total jellyfish catch by species or genera and month for the years 2001 through 2011 in the Fall Midwater Trawl ($\log_{10}$ scale)

Aurelia spp.

Aurelia spp. are commonly called "moon jellies" in reference to their four lunate-shaped gonads. *Aurelia labiata* is native to the Pacific coast, while its cosmopolitan cousin, *Aurelia aurita*, is thought to be endemic to the North Atlantic and may be increasing in abundance worldwide (Mills 2001). Both *A. labiata* and *A. aurita* have been confirmed in San Francisco Bay (Rees and Kitting 2002), although FMWT staff did not identify these scyphozoans to the species level. Both species can grow to a few meters in bell diameter in marine environments, and up to 50 cm in bell diameter in the estuary (Rees and Kitting 2002), although they were captured at smaller sizes in the FMWT.

Aurelia spp. catch totaled 631 for the study period. None were caught from 2004-2006, but this was followed by the highest annual catch on record in 2007 (n=209), and numbers have steadily declined since (Table 1). *Aurelia* spp. have been distributed primarily in San Pablo Bay, but were also caught in Carquinez Strait in 2001 and 2007 (Figure 2). One individual was found in the Napa River in 2008. Seventy-five percent of *Aurelia* spp. were in salinities above 22‰, with the notable exception of a single catch in 2011 at 16.7‰ (Figure 3). *Aurelia* spp. were primarily collected at temperatures between 12 °C and 15 °C, but also occurred at temperatures as low as 10.5 °C and as high as 21.2 °C (Figure 4). *Aurelia* spp. were captured throughout the fall, but with greater frequency in December (Figure 5).

Pleurobrachia bachei

Pleurobrachia bachei is a native cydippid ctenophore common near Alameda in late summer and fall. They have the smallest maximum size of the jellyfish here described, having "the size and shape of a clear marble" (Rees and Kitting 2002). They are commonly referred to as "cat's eyes" or "sea gooseberries." The *P. bachei* total catch was 8,894 for the survey period. The first recorded catch was in 2004, none were observed in 2005 or 2006, and 2007 and 2008 had low catches (Table 1). In 2009, 6,724 P. bachei were collected, which represents 76% of total catch from the last 10 years. Numbers remained relatively high in 2010 and 2011 (Table 1). *P. bachei* were most numerous in San Pablo Bay, but were also present in Suisun Bay, Carquinez Strait, and the Napa River, with small catches in Grizzly Bay (n=8) and Montezuma Slough (n=1) (Figure 2). *P. bachei* inhabited a wide range of salinities, from 8.1‰ to 31.2‰, with the greatest catches in 29-30‰ (n=2,079) (Figure 3). It primarily inhabited temperatures between 11 °C and 13 °C (n=7,125) (Figure 4). *P. bachei* catches typically increased from November (rarely October) through December (Figure 5).

The cause of the 2009 *P. bachei* bloom is unknown. Salinity, water temperature, and water outflow in 2009 were consistent with 2001-2011 annual averages. Polyorchis penicillatus counts rose in 2009 as well, but the increase in *P. bachei* populations was tenfold that of the increases observed in other jellyfish species.

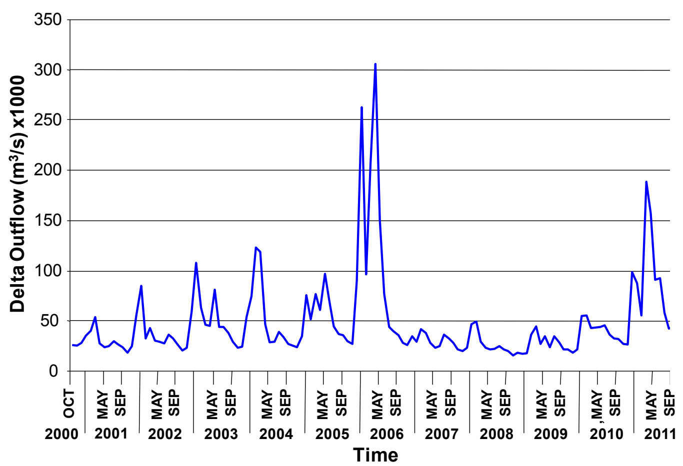

Figure 6 Mean monthly Delta outflow for the years 2000 through 2011

Discussion

Whether from natural or anthropogenic causes, there is evidence that gelatinous zooplankton populations may be on the rise in certain ecosystems (Brodeur et al. 1999, Condon et al. 2012). This is of special concern in the San Francisco Estuary, already referred to as the most invaded estuary in the world (Cohen and Carlton 1998). Many jellyfish can compete with fish for food resources, or directly consume ichthyoplankton (Shiganova 1998, Schroeter 2008). In at least one case, an invasive jellyfish has been linked to the decline of anchovy and other pelagic fishes in the Black Sea (Kideys 1993). The populations of at least three invasive species of jellyfish seem to be on the rise in the San Francisco Estuary (Mills and Rees 2000). Hence, the need for further monitoring and research of gelatinous zooplankton.

The FMWT survey has been able to recognize and enumerate 4 jellyfish species and 2 genera since it began recording jellyfish catch in 2001. Although there was no clear trend in the catch data for any of these 6 taxa, 4 of them were collected for the first time or were collected more consistently after 2006 (Table 1). Currently, many but not all IEP fish trawl surveys identify and enumerate jellyfish as part of their routine data collection. Specifically, Spring Kodiak Trawl, Summer Townet Survey (STN), FMWT, and Bay Study Midwater Trawl record jellyfish catch. However, trawl gear targeting juvenile fishes may not be well suited to collection of jellyfish. Careful collection by divers is the preferred method for catching intact gelatinous zooplankton (Kingsford and Battershill 2000), although trawl nets (Kingsford and Battershill 2000, Brodeur et al. 1999) and otter trawls (Schroeter 2008) have collected larger quantities of jellyfish.

The FMWT may not be appropriate for jellyfish sampling for two reasons. First, the cod end mesh size (12.7 mm stretch mesh) allows many small jellyfish to pass through (e.g. *Moerisia* spp. with a 10 mm bell and *Blackfordia virginica* with a 4-5mm bell). Second, the netting potentially cuts through jellyfish, causing the net to extrude them in pieces. Both *Moerisia* spp. and *Blackfordia virginica* adult medusa have been detected in Suisun Bay as early as June and as late as November (Schroeter 2008), thus overlapping FMWT sampling, but neither has been identified from the FMWT survey.

The 2009 addition of a mysid net tow to a subset (n= 32) of FMWT stations provides an opportunity to gather jellyfish catch data on species and individuals small enough to be extruded by the FMWT. The mysid net has a 29 cm mouth and possesses 505 micron mesh, which would retain all sizes of jellyfish well. Jellyfish identification would occur post-preservation in the laboratory. Earlier in the year, when jellyfish are smaller, data from the STN survey may provide useful catch data for jellyfish due to its smaller mesh size, relative to the FMWT. STN runs from June through August and has identified and enumerated jellyfish catch since 2007.

For increased data confidence, sampling methods for species detection need to be more thorough, and a sound sampling procedure needs to be established to determine when and how to sub-sample the larger catches. To increase fish survivability and ease of processing, samples are often poured from the trawl net into a bucket of water. Small, clear jellyfish, such as *Aequorea* spp., are easy to miss in such a container. To increase detection, samples were passed through a hand fishnet and spread onto a white surface starting in 2012. For large catches, the entire catch is currently poured into a quart container until it is full. This water should then be passed through a hand net, so that jellyfish can be enumerated and identified effectively. This count would then be scaled up to give an estimated total catch. Currently, there is no record of when sub-sampling takes place, for accurate calculation of error frequency in the future, it would be necessary to record this information.

Conclusion

Since the FMWT survey began recording jellyfish catch in 2001, *M. marginata* was the most frequently encountered jellyfish, followed by *P. bachei*, P. *penicillatus*, and *Aurelia* species. *Aequorea* spp., *Aurelia* spp., and *S. pacifica* were only infrequently captured. Since 2007, *P. bachei*, *P. penicillatus*, and *Aurelia* spp. have been caught annually; before 2007 they were only encountered in some years. *Aequorea* spp. was first recorded in 2010 (Table 1). *P. bachei*, *P. penicillatus*, *Aurelia* spp., *Aequorea* spp., and *S. pacifica* are primarily marine jellies, and were mainly found in San Pablo Bay, the Napa River, Carquinez Strait, and Suisun Bay, with some *P. bachei* also caught in Grizzly Bay (Figure 2). Catches for these 5 jellyfish tended to increase with increasing salinity, peaking at salinities of 20-30‰. *P. bachei* and *P. penicillatus* were the only species captured at 30‰ or above, although catch decreased at these high salinities (Figure 3). Except for *M. marginata*, all jellies were found primarily at 10-20 °C (Figure 4) and during the months of November and December (Figure 5).

M. marginata was the most frequently captured jellyfish, and as the only brackish water species, its distribution varied noticeably from other jellyfish taxa reported in FMWT catch. *M. marginata* was the only jellyfish species found in all years (Table 1). It was also found in all regions, except for the Napa River (Figure 2).

The scarcity of information regarding the status and trends of jellyfish in the upper San Francisco Estuary, combined with their potential ecosystem impacts underlines the importance of increased monitoring efforts. The FMWT survey currently provides useful information regarding jellyfish catch and distribution, which could be improved upon with greater attention to detection and a more rigorous sub-sampling protocol. However, to gain a more comprehensive view of jellyfish status and trends in the San Francisco Estuary, it would be highly beneficial to begin identifying and enumerating jellyfish catch in the mysid net that, unlike the FMWT, has a mesh size capable of retaining smaller jellyfish species such as *Moersia* spp. and *B. virginica*.

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Status and Trends

Zooplankton Monitoring 2011

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Introduction

The Zooplankton Study has estimated the abundance of zooplankton taxa in the upper San Francisco Estuary since 1972 to assess trends in fish food resources. The study also detects and monitors zooplankton recently introduced to the estuary and determines their effects on native species. Three gear types are used: 1) a pump for sampling microzooplankton < 1.0 mm long, including rotifers, copepod nauplii, and adult copepods of the genus *Limnoithona*; 2) a modified Clarke-Bumpus (CB) net for sampling mesozooplankton 0.5-3.0 mm long, including cladocerans, copepodids (immature copepods), and adult copepods; and 3) a macrozooplankton net for sampling zooplankton 1-20 mm long, which targets mysid shrimp. Here seasonal abundance indices are presented from 1974 through 2011 for a select group of the most common copepods, cladocerans, rotifers, and mysids.

Methods

During 2011, sampling occurred monthly from January through December at 22 stations, including 12 core stations (i.e., stations sampled consistently since study inception in 1972) and 2 floating entrapment zone (EZ) stations located at bottom electrical conductivity of 2 and 6 mS/cm (approximately 1 and 3‰). The study area extends from eastern San Pablo Bay through the delta and the station map can be viewed at www.dfg.ca.gov/delta/data/zooplankton/stations.asp. Seasonal indices presented here were calculated using 16 stations: the 12 core stations, the 2 EZ stations, and 2 additional stations sampled consistently since 1974 (Suisun Slough station S42 and Disappointment Slough station MD10). Reports published prior to 2007 used data from 1972 that included only the 12 core and 2 EZ stations. Since this report utilized data from 2 additional stations, indices started in 1974 and may be slightly different from those reported prior to 2007. However, overall trends remained the same.

Data were grouped into 3 seasons: 1) spring, March through May, 2) summer, June through August, and 3) fall, September through November. January, February, and December were not always sampled historically and therefore not used for long-term trend analyses. Abundance indices were calculated as the mean number of each taxon per cubic meter of water (reported as catch-per-unit effort, CPUE) by gear, season, and year for the 16 stations. Relative calanoid copepod abundance for each season of 2011, including winter (December 2010 through February 2011), used data from all stations sampled. Similar to 2004 through 2011 Status and Trends reports, indices were separated by gear type and taxon, whereas pre-2004 reports combined CB and pump data for each taxon into a single index.

Copepods

Both congeners of the cyclopoid copepod genus *Limnoithona* inhabit the upper estuary: *L. sinensis*, first recorded in 1979, and *L. tetraspina*, first recorded in 1993. In 1993, *L. tetraspina* mostly supplanted the historically common and slightly larger *L. sinensis*, and numerically became the dominant copepod in the upper estuary. *L. tetraspina* is common in both brackish and freshwater. As an ambush predator that feeds on motile prey (Bouley and Kimmerer 2006), *L. tetraspina* may have benefited from the phytoplankton species composition change (described by Brown 2009) from non-motile diatoms to motile flagellates. Despite high densities of *L. tetraspina* in the estuary, it may not be a readily available food source for visual predators, like delta smelt, due to its small size and relatively motionless behavior in the water column (Bouley and Kimmerer 2006). Both pump and CB net indices are presented here because *L. tetraspina* is not completely retained by the CB net, especially in summer and fall when adults are smaller. Pump *L. tetraspina* abundance decreased again in 2011 in all seasons, whereas CB abundance increased in all seasons (Figure 1). In 2011, spring pump abundance was the lowest since 1994, summer pump abundance was the lowest since 1993, and fall pump abundance was the lowest since 1998 (Figures 1A, 1B, and 1C). In contrast, *L. tetraspina* 2011 spring CB abundance was the highest since 2008 and summer and fall abundance the highest since 2006 (Figures 1A, 1B, and 1C). Lower 2011 pump abundance and higher CB abundance indicated that *L. tetraspina* individuals were larger and therefore retained better by the CB net. *L. tetraspina* was most abundant during early fall 2011 in Grizzly Bay and Montezuma Slough, with peak densities in September in Montezuma Slough (74,448 m^{-3}). *L. sinensis* continued to be collected in very low numbers in 2011.

Eurytemora affinis, a calanoid copepod introduced to the estuary before monitoring began, was once a major food source for larval and juvenile fishes of many species, as well as adult planktivores such as delta smelt and threadfin shad. It is found throughout the upper estuary in every season and is most abundant in salinities less than 6‰. *E. affinis* abundance declined in all seasons since monitoring began, with the sharpest downturns during summer and fall of the late-1980s (Figure 2), subsequent to the introductions of the overbite clam, *Potamocorbula amurensis*, and the calanoid copepod *Pseudodiaptomus forbesi*. Prior to these introductions, *E. affinis* abundance was usually highest during summer; however, since 1987 abundance has been highest in spring and dropped abruptly in summer, when both *P. forbesi* abundance and *P. amurensis* grazing rates increase. Again in 2011, *E. affinis* was the fifth most abundant calanoid copepod in the study area. Abundance was highest in spring, when it accounted for 35% of the total calanoid copepod CPUE and was the most abundant calanoid copepod (Figure 3). *E. affinis* abundance increased in spring and summer 2011 from 2010, but decreased slightly in fall. Spring abundance increased sharply in 2011, from the lowest abundance on record, and was the third highest in the last decade (Figure 2A). Summer *E. affinis* abundance was the highest since 2006 (Figure 2B). Although fall abundance decreased slightly in 2011 (Figure 2C), it was still higher than the 1990 through 2010 mean. *E. affinis* was common in Suisun Marsh from January through May, and in western Suisun Bay in the entrapment zone from April through June. In the eastern delta, densities were low most of the

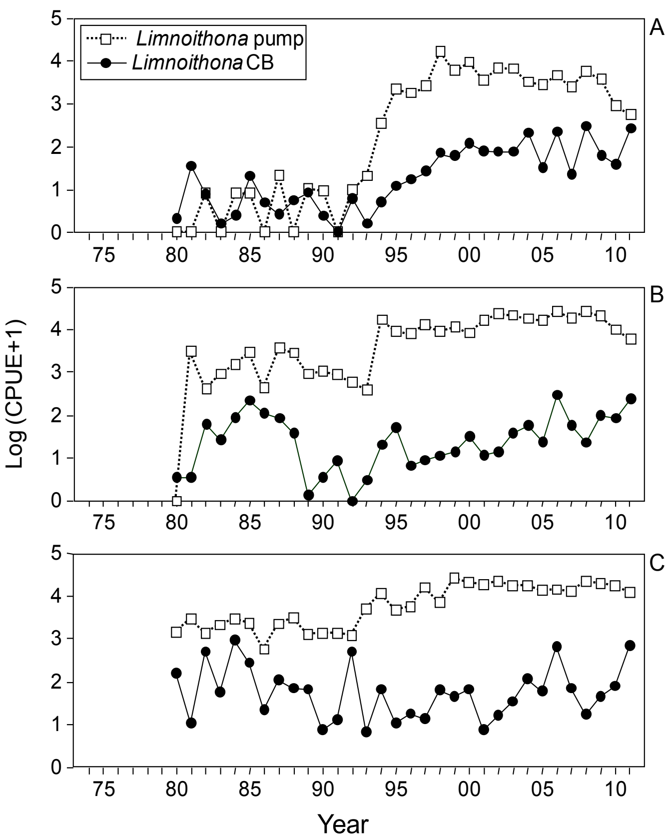

Figure 1 Abundance of *Limnoithona tetraspina* and *L. sinensis* combined (Log of mean catch*m^{-3}+1) from the pump and CB net in spring (A), summer (B), and fall (C), 1974 – 2011

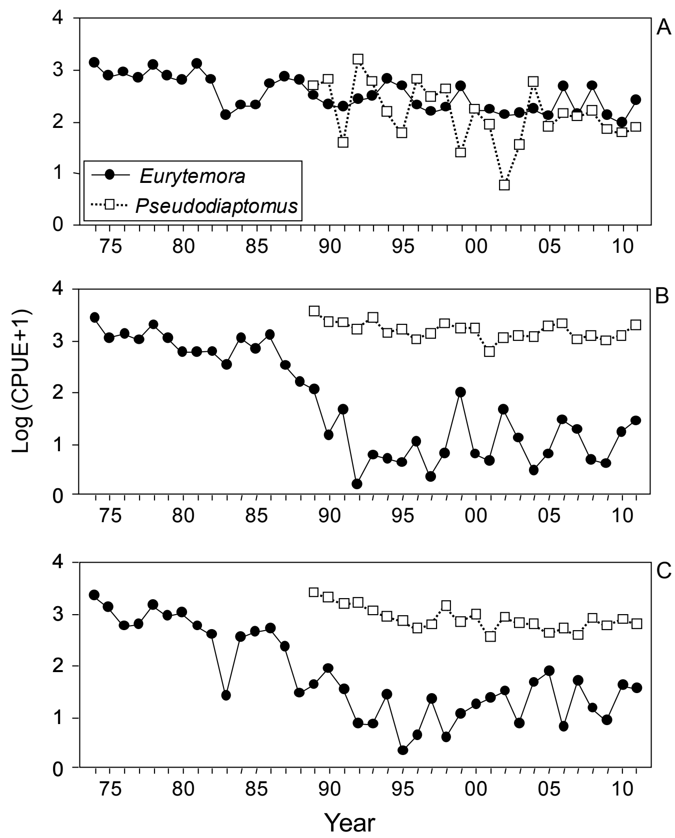

Figure 2 Abundance of *Eurytemora affinis* and *Pseudodiaptomus forbesi* (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 – 2011

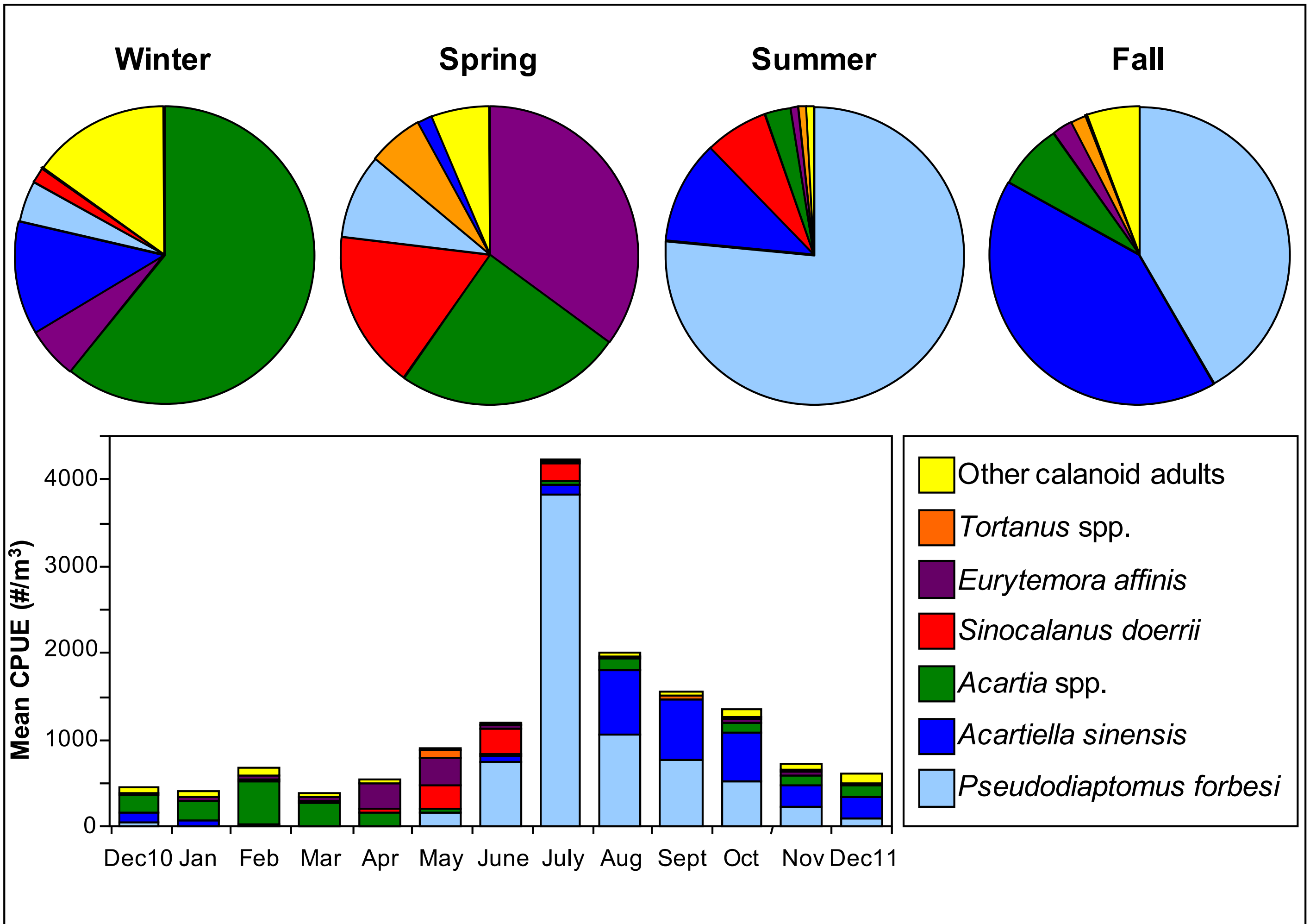

Figure 3 Relative abundance of the most common calanoid copepods (percent mean catch*m^{-3}) from the CB net from all stations by seasons and by months in 2011. Seasonal pie charts include winter (December 2010-February 2011), spring (March-May 2011), summer (June-August 2011), and fall (September-November 2011). Bar graph shows average monthly CPUE of the most common calanoid copepods.

year before increasing in late fall. In 2011, *E. affinis* abundance peaked in April in western Suisun Bay (2,521 m^{-3}) and in May in Suisun Slough (1,569 m^{-3}) and Old River in the South Delta (1,132 m^{-3}).

P. forbesi is an introduced freshwater calanoid copepod first detected in the upper estuary in 1988. By 1989, *P. forbesi* summer and fall abundance was comparable to *E. affinis* before its decline (Figure 2). Although *P. forbesi* abundance declined slightly since its introduction, it remained relatively abundant in summer and fall compared to other copepods. In both 2010 and 2011, *P. forbesi* was the most abundant calanoid copepod in the study area. In 2011, relative abundance peaked in summer, when it accounted for 76% of the total calanoid copepod CPUE (Figure 3). Spring abundance has always been highly variable and increased slightly in 2011 from 2010 (Figure 2A). Summer abundance also increased, whereas fall abundance decreased slightly from 2010 (Figures 2B and 2C). During summer and fall 2011, *P. forbesi* was common in all regions upstream of Suisun Bay, and most abundant in Suisun Marsh, the San Joaquin River, and the delta. The highest density was in July in Frank's Tract in the South Delta, where CPUE was 23,284 m^{-3}.

Several species of the native calanoid copepod genus *Acartia* are abundant in San Pablo Bay, and expand their range into Suisun Bay and the western delta as salinity increases seasonally and annually. Conversely, their affinity for higher salinities is sufficiently strong that their distribution shifts seaward of the sampling area during high-outflow events, resulting in low seasonal and annual abundance. In 2011, *Acartia* was the third most abundant calanoid copepod in the study area. Relative abundance peaked in winter, when *Acartia* accounted for 61% of the total calanoid copepod CPUE (Figure 3). *Acartia* abundance declined in spring and fall of 2011, but increased slightly in summer (Figure 4). Higher spring outflow in 2011 resulted in the lowest *Acartia* abundance since 1996 (Figure 4A). Lower summer abundances generally corresponded with the highest outflow years, so the slight increase in summer 2011 was unexpected (Figure 4B). By fall 2011 outflow decreased, which allowed abundance to increase from summer levels (Figure 4C). However, fall 2011 outflow was higher than recent years, which caused *Acartia* to be further downstream and resulted in lower fall abundance when compared to 2010 (Figure 4C). *Acartia* was common throughout the year in San Pablo Bay, where the highest densities occurred from January through March with a peak in February (3,406 m^{-3}). *Acartia* was also found in Carquinez Strait during every month of 2011 except May, with a peak in February (2,339 m^{-3}).

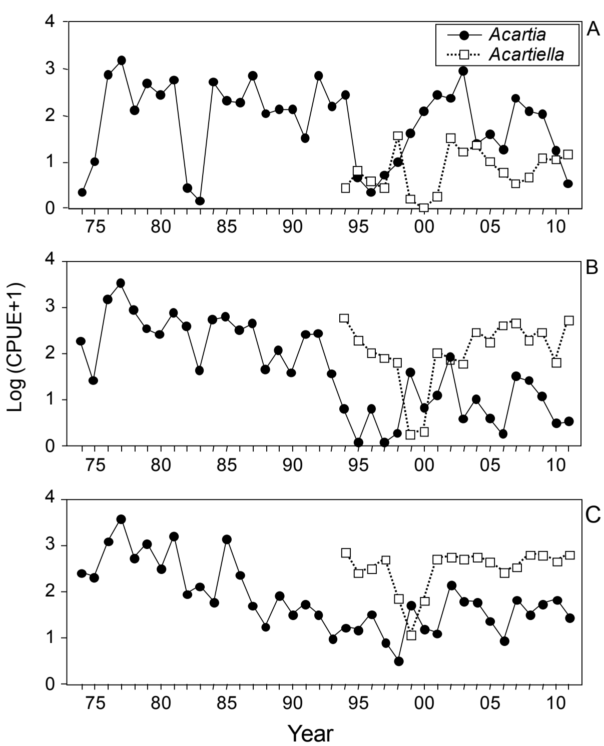

Figure 4 Abundance of *Acartia* spp. and *Acartiella sinensis* (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 – 2011

Acartiella sinensis is an introduced calanoid copepod, first recorded in spring 1994, that is most abundant in the entrapment zone during summer and fall. In 2011, *A. sinensis* was the second most abundant calanoid copepod in the study area. Relative abundance was highest in fall, when it accounted for 41% of the total calanoid copepod CPUE (Figure 3). In 2011, *A. sinensis* abundance increased in spring, summer, and fall from 2010 (Figure 4). Spring abundance has always been highly variable; after declining steadily from 2004 through 2007 abundance increased from 2008 to 2011 (Figure 4A). Summer *A. sinensis* abundance steadily increased from the record lows of 1999 and 2000, and 2011 had the second highest abundance since its introduction (Figure 4B). Fall abundance has been relatively stable since 2001 and increased in 2011 to the third highest on record (Figure 4C). In 2011, *A. sinensis* abundance was highest August through October in Suisun Bay and the lower Sacramento River, with a peak in eastern Suisun Bay in the entrapment zone (3,151 m^{-3}) in August.

The introduced freshwater calanoid copepod *Sinocalanus doerrii* was first recorded in spring 1979. Initially most abundant in summer, *S. doerrii* abundance began to decline during summer and fall in the mid-1980s (Figure 5). This downward trend continued through the mid-1990s, followed by modest increases recently. In 2011, *S. doerrii* was the fourth most abundant calanoid copepod in the study area. Relative abundance peaked in spring, when it accounted for 17% of the total calanoid copepod CPUE (Figure 3). *S. doerrii* abundance decreased sharply in 2011 from 2010 in all seasons (Figure 5). Spring abundance, historically more variable than summer or fall abundance, declined in 2011 to densities similar to 2005 through 2007 (Figure 5A). Although summer and fall 2011 abundance declined, the overall trend was of increasing abundance since 2004 for summer and 2005 for fall (Figures 5B and 5C). In 2011, *S. doerrii* was most abundant May and June in Suisun Bay and Suisun Marsh, peak abundance occurred in June in Montezuma Slough (1,979 m^{-3}).

Tortanus dextrilobatus is an introduced brackish-water calanoid copepod first recorded in spring 1994. *T. dextrilobatus* is a large carnivorous copepod whose abundance increases in the sampling area as flows decrease and salinities increase during summer and fall. In 2011, *T. dextrilobatus* was the least abundant of the common calanoid copepods in the study area; relative abundance peaked in spring when it accounted for 6% of the total calanoid copepod CPUE (Figure 3). *T. dextrilobatus* abundance decreased in all seasons of 2011 from 2010 (Figure 5). Spring abundance rose steadily from the low in 2006, caused by the extremely high flows, and reached the fifth highest abundance in 2009 before dropping sharply in 2010 and 2011 (Figure 5A). In 2008 and 2009, summer abundance was the highest since *T. dextrilobatus* was introduced, before declining in 2010 and 2011 (Figure 5B). Fall 2011 abundance decreased slightly, but remained above the fall mean (Figure 5C). In 2011, *T. dextrilobatus* was found throughout the year in San Pablo Bay and Carquinez Strait. Abundance peaked in May in San Pablo Bay (630 m^{-3}) and in September in Carquinez Strait (429 m^{-3}).

Cladocerans

Bosmina, *Daphnia*, and *Diaphanosoma* are the most abundant cladoceran genera in the upper estuary. Combined, these native freshwater cladocerans had an overall downward trend since the early 1970s, especially in fall (Figure 6). From 2010 to 2011, abundance decreased in all seasons and was below the seasonal means, probably due to higher flows in 2011 resulting in lower residence time. In 2011, cladocerans were common throughout the estuary upstream of the entrapment zone and were most abundant in the East Delta from April through October. Peak densities occurred in Disappointment Slough in September (13,748 m^{-3}).

Rotifers

Synchaeta bicornis is a native brackish-water rotifer that is usually most abundant in the upper estuary in summer and fall, when salinity increases. However, long-term abundance has declined since the 1970s (Figure 7). *S. bicornis* abundance increased in all seasons of 2011. From 2002 through 2007 there was no spring catch at any core stations, followed by an increase in 2008 and 2009. Higher spring outflow in 2010 resulted in no catch at any stations sampled, and although 2011 spring abundance increased slightly, it remained very low (Figure 7A). After dropping to 0 in 2010, for the first time since monitor-

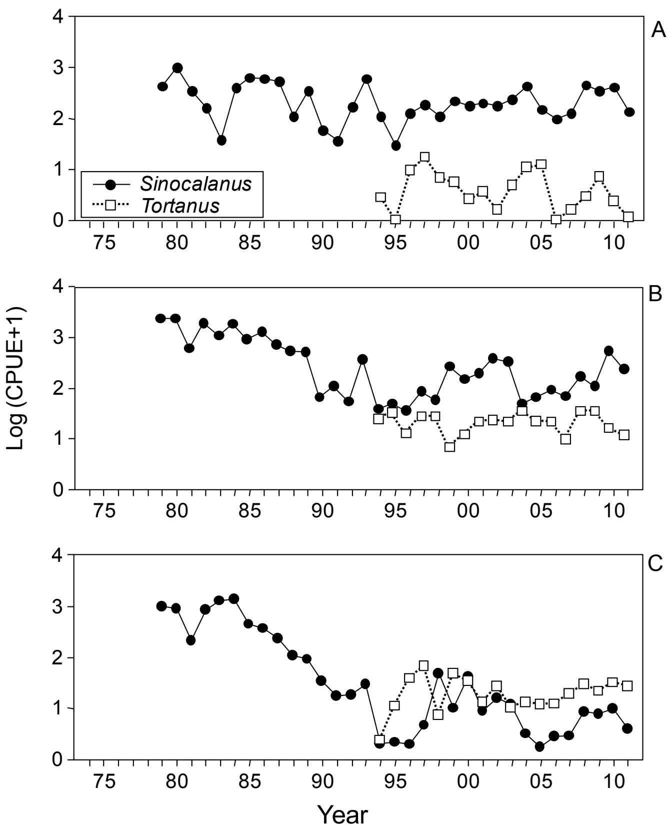

Figure 5 Abundance of *Sinocalanus doerrii* and *Tortanus dextrilobatus* (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 – 2011

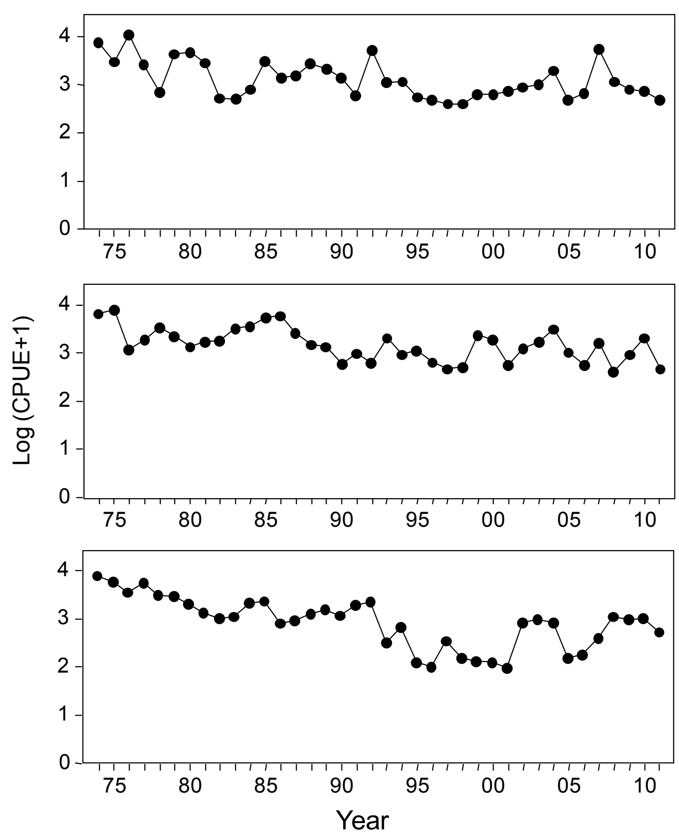

Figure 6 Abundance of Cladocera (Log of mean catch*m^{-3}+1) from the CB net in spring (A), summer (B), and fall (C), 1974 – 2011

ing began, summer 2011 abundance increased sharply and was the highest since 1992 (Figure 7B). Fall 2011 abundance also increased sharply from 2010 and reached the third highest fall abundance recorded (Figure 7C). In 2010, *S. bicornis* was most abundant August through October in Carquinez Strait, Suisun Bay, and Suisun Marsh. Peak densities occurred in Montezuma Slough in Suisun Marsh in September (1,308,452 m^{-3}).

Abundance of all other rotifers, without *S. bicornis*, declined from the early 1970s through the 1980s, but stabilized since the early 1990s (Figure 7). In 2011, rotifer abundance increased in all seasons. After decreasing to the lowest spring abundance in 2009, abundance increased in 2010 and 2011 to the highest since 1978 (Figure 7A). Summer abundance increased slightly in 2011 for the third year in a row (Figure 7B). Fall abundance increased in 2011 from the lowest abundance since the study began (Figure 7C). Rotifers were common throughout the study area in 2011, with the highest density in Suisun Slough, where mean CPUE for the year was 97,951 m^{-3} and peaked at 1,054,909 m^{-3} in April.

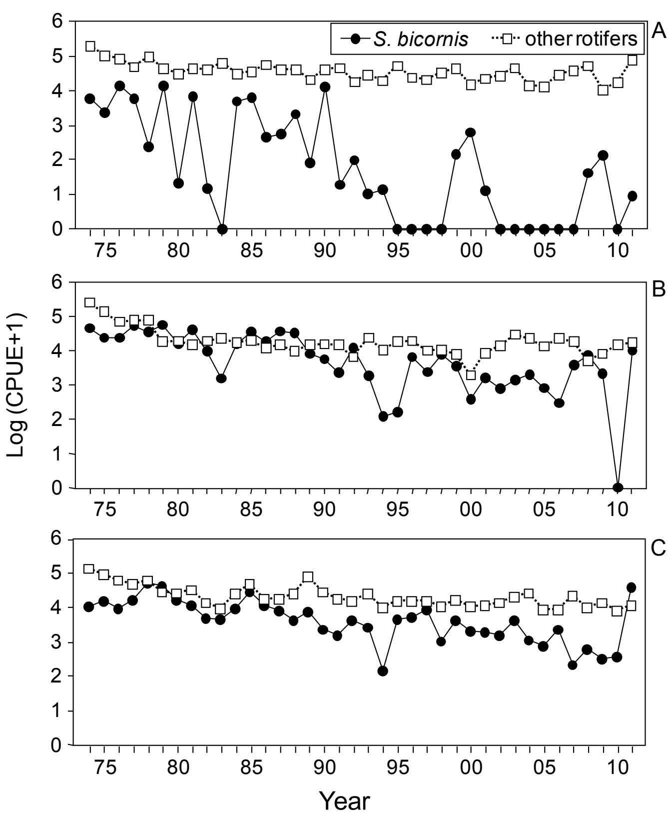

Figure 7 Abundance of *Synchaeta bicornis* and rotifers excluding *S. bicornis* (Log of mean catch*m^{-3}+1) from the pump in spring (A), summer (B), and fall (C), 1974 – 2011

Mysids

Hyperacanthomysis longirostris (formerly *Acanthomysis bowmani*), an introduced mysid first collected by the study in summer 1993, has been the most abundant mysid in the upper estuary since summer 1995 (Table 1). *H. longirostris* is commonly found in densities of more than 10 m^{-3}, and occasionally in densities of more than 100 m^{-3}. Spring *H. longirostris* abundance increased from 1995 to 1998 and fluctuated thereafter, decreasing in 2011 to the second lowest abundance on record. Summer abundance had a downward trend from 2003 to 2009, increased in 2010, then decreased sharply in 2011 to the lowest since its introduction. *H. longirostris* fall abundance declined consistently since 2004, resulting in record low abundances from 2007 through 2009 of less than 1 m^{-3}. Although abundance increased in fall 2010 and 2011, it remained below the study-period mean. In 2011, *H. longirostris* was most abundant in the entrapment zone from June through August in Suisun Bay, and from September and December in the lower Sacramento River. Densities were also high during July in Carquinez Strait, and from August through October in Montezuma Slough in Suisun Marsh. The highest 2011 density occurred during June in the entrapment zone in Suisun Bay (48 m^{-3}).

Neomysis mercedis, historically the only common mysid in the upper estuary, suffered a severe population crash in the early 1990s. In 2011, it was the least abundant mysid species of those shown in Table 1, for the second year in a row. *N. mercedis* is most abundant in spring and summer, and prior to the population crash mean spring and summer densities were more than 50 m^{-3} (Table 1). Since 1994, mean spring abundance has been less than 1 m^{-3}, rendering *N. mercedis* inconsequential as a food source in most open-water areas of the upper estuary. After some of the lowest spring densities on record from 2007 through 2010, abundance increased in 2011 and was the highest since 2006, but remained very low relative to the 1970s and 1980s. Summer abundance has been extremely low, less than 1 m^{-3}, since 1997. After decreasing to the lowest summer abundance on record in 2009, summer abundance increased slightly in 2010, and again in 2011 to the highest since 1996. No *N. mercedis* were caught during fall at any stations sampled from 2005 through 2008. From 2009 through 2011, only 1 *N. mercedis* was caught during fall of each year. Since June 2006, *N. mercedis* has been uncommon throughout the study area with densities less

Table 1 Seasonal abundance of the most common mysid species (mean catch*m^{-3}) from the macrozooplankton net

Year	*H. longirostris*			*N. mercedis*			*N. kadiakensis*			*A. macropsis*		
	Spring	*Summer*	*Fall*	*Spring*	*Summer*	*Fall*	*Spring*	*Summer*	*Fall*	*Spring*	*Summer*	*Fall*
1974-1989				54.506	87.293	18.154						
1990				23.458	7.612	0.436						
1991				32.058	18.331	0.489						
1992				4.223	1.989	0.076						
1993			2.470	7.850	22.503	0.008						
1994	0.932	21.604	2.063	0.449	0.733	0.004						
1995	0.437	7.180	4.407	0.590	0.370	0.000				0.000	0.000	0.004
1996	1.636	11.693	4.432	0.541	1.432	0.001	0.032	0.001	0.017	< 0.001	0.000	0.003
1997	6.939	27.630	7.714	0.565	0.063	0.000	0.011	0.011	0.385	0.006	0.000	0.004
1998	18.136	6.015	18.691	0.181	0.238	0.025	0.108	0.041	0.006	0.005	0.000	0.008
1999	3.888	34.697	14.329	0.264	0.288	0.001	0.037	0.007	0.075	0.014	0.000	0.001
2000	23.580	38.453	9.958	0.880	0.136	0.001	0.074	0.165	0.465	0.003	0.000	0.001
2001	4.767	13.441	8.956	0.422	0.052	0.001	0.285	0.351	0.143	0.013	0.001	0.001
2002	10.121	21.224	7.516	0.022	0.069	0.001	0.209	0.254	0.753	0.005	0.000	0.002
2003	4.342	21.307	4.555	0.022	0.046	< 0.001	0.314	0.209	0.166	0.038	0.000	0.003
2004	9.915	13.725	5.044	0.150	0.016	0.002	0.129	0.106	0.170	0.001	0.000	0.001
2005	4.010	16.281	3.265	0.092	0.141	0.000	0.173	0.104	0.077	0.003	0.000	0.004
2006	7.186	14.143	1.967	0.321	0.137	0.000	0.071	0.727	0.051	0.001	0.000	0.001
2007	0.969	8.997	0.575	0.005	0.023	0.000	0.176	0.306	0.122	0.004	< 0.001	0.025
2008	17.696	14.574	0.715	0.063	0.108	0.000	1.359	0.820	0.154	0.027	< 0.001	0.155
2009	0.729	6.303	0.681	0.016	0.013	< 0.001	0.418	0.240	0.128	0.064	0.003	0.096
2010	2.887	25.975	2.045	0.013	0.174	< 0.001	0.177	0.280	0.081	0.090	0.002	0.183
2011	0.584	4.350	2.815	0.161	0.313	< 0.001	0.142	0.322	0.235	0.040	0.002	0.079
Average:	**6.597**	**17.088**	**5.379**	**24.854**	**38.196**	**7.671**	**0.232**	**0.246**	**0.189**	**0.018**	**0.001**	**0.034**

than 1 m^{-3} at most stations. Peak 2011 densities occurred in May and June in Suisun Slough (3 m^{-3} and 4 m^{-3}, respectively) and in July in the lower Sacramento River near Decker Island (3 m^{-3}). These were the highest densities seen since May 2006, but still very low relative to earlier years.

Neomysis kadiakensis is a native brackish-water mysid that regularly appeared in mysid samples beginning in 1996, but was not common until recently (Table 1). From 2001 through 2008, *N. kadiakensis* was the second most abundant mysid in the study area, but from 2009 through 2011 fell to the third most abundant. In 2011, *N. kadiakensis* abundance decreased in spring, but increased in summer and fall from 2010. After reaching a record high in spring 2008, abundance decreased from 2009 through 2011. In 2011, summer abundance increased for the second year in a row, and was above the summer mean for all years. Fall abundance increased sharply in 2011 to the highest level since 2002, and was above the fall mean. In 2011, peak densities occurred in April (4.5 m^{-3}) and May (10.5 m^{-3}) in Carquinez Strait near Benicia. Since the late 1990s, *N. kadiakensis* has extended its range into lower salinity water at the confluence of the Sacramento and San Joaquin rivers, leading to the hypothesis that some of the upper-estuary specimens may be a second species, *N. japonica*. To date no physical characteristics have been published to separate these 2 species.

Alienacanthomysis macropsis is a native brackish-water mysid usually found in San Pablo Bay and Carquinez Strait that was first consistently enumerated by the study in 1995. *A. macropsis* has never been common in the sampling area, and therefore indices were not reported until 2007. Since 2009, *A. macropsis* abundance surpassed *N. kadiakensis* and became the second most abundant mysid in the upper estuary across all stations and surveys, although it remained a minor component of the mysid community due to high *H. longirostris* abundance. After increasing each year from 2007 through

2010, spring abundance decreased in 2011, but remained above the study-period mean (Table 1). After reaching the highest summer abundance on record in 2009, abundance decreased slightly in 2010 and remained steady in 2011. Although fall 2011 abundance decreased from 2010, the highest fall abundance recorded, it remained above the study-period mean. In 2011, *A. macropsis* was most abundant from January through May and again in December in San Pablo Bay, Carquinez Strait, and Suisun Bay. The highest density occurred in January in Carquinez Strait near Benicia (20 m^{-3}).

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2011 Bay Study Fishes Annual Status and Trends Report for the San Francisco Estuary

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Introduction

The 2011 San Francisco Bay Study (Bay Study) Status and Trends fishes report includes demersal species from the entire estuary and pelagic species from the lower estuary. Results for the upper estuary pelagic species collected by the Townet Survey, the Fall Midwater Trawl, and the Delta Smelt 20-mm Survey were reported in the Spring 2012 IEP Newsletter (Contreras et al. 2012). The most recent abundance indices, long-term abundance trends, and distributional information are presented here for common fishes and some less-common species of interest, such as the surfperches. Presented first are the upper estuary demersal fishes, followed by the marine pelagic fishes, surfperches, and marine demersal fishes. Within each section, species are presented phylogenetically.

Methods

The Bay Study has sampled from South San Francisco Bay to the western delta monthly with an otter trawl and midwater trawl since 1980. There are some data gaps, most significantly: limited midwater trawl sampling in 1994, no winter sampling from 1989 to 1997, and limited sampling at stations in and near the confluence of the Sacramento and San Joaquin rivers in 2007 and 2008 to reduce delta smelt take. Abundance indices are routinely calculated for 35+ fishes and several species of crabs and caridean shrimp. Only the fishes are included in this report; the crabs and shrimp are subjects of separate annual reports, to be published in an IEP Newsletter issue later this year. Bay Study midwater trawl data was used to describe abundance trends and distribution of the pelagic fishes while otter trawl data was used for demersal fishes. Catch-per-unit-effort (CPUE), as average catch per tow, was consistently used to analyze and report distribution.

Of the 52 stations currently sampled, 35 have been consistently sampled since 1980 (“core” stations) and are used to calculate the annual abundance indices. Stations are fairly evenly distributed between channels and shoals in most regions, although depths < 3 meters are not sampled. Most stations have a soft substrate, such as mud, sand, or a mix of shells – we intentionally avoid rocky areas and eelgrass beds. Additional information about study methods, including index calculation, can be found in IEP Technical Report 63 (Baxter et al. 1999).

Several physical data sets were used to describe the oceanic and estuarine environmental conditions that were then related to abundance trends and distributional patterns. Daily outflow at Chipps Island was from Dayflow (DWR); the 1979-2011 daily values were averaged to monthly values and plotted. Monthly Pacific Decadal Oscillation (PDO) indices, from Nathan Mantua (University of Washington), and North Pacific Gyre Oscillation (NPGO) indices, from Emanuele Di Lorenzo (Georgia Institute of Technology), were plotted for 1950-2011. Monthly ocean upwelling anomalies (base period 1946-2011, 39 °N), from the NMFS Pacific Fisheries Environ-

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mental Laboratory, were plotted from 1999 to 2011. Daily sea surface temperatures (SSTs), from Southeast Farallon Island (Scripps Institute of Oceanography), were used to calculate monthly values and anomalies (base period 1925-2011). Monthly SST anomalies from 1999 to 2011 and daily SSTs from January 2010 through December 2011 (7-day running mean) were also plotted. See the "Notes" section below for the data download URLs.

Physical Setting

Delta outflow increased substantially in 2011, with a mean January to June daily outflow at Chipps Island of 1,633 cm/s. This was 250% higher than the 2010 outflow for the same period and the highest January to June outflow since 2006, ending a 4-year period of low outflow (Figure 1). There was a small peak in late December 2010 and early January 2011 of about 2,300 cm/s, followed by low outflow through mid March. A second, much larger outflow peak occurred in late March at about 6,200 cm/s and outflow remained relatively high through July 2011. The relatively low outflow through most of the winter resulted in a typical "dry" year fish distribution early in 2011 that proved to be problematic for several species when outflow quickly increased in March (see the Leopard Shark section, below).

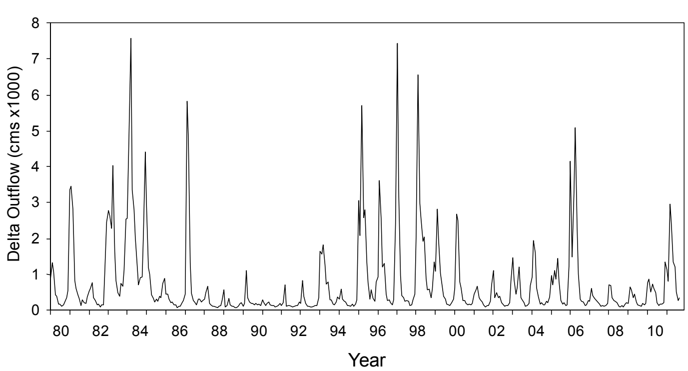

Figure 1 Mean monthly Delta outflow (cms) at Chipps Island, 1979-2011

The San Francisco Estuary is situated between 2 major marine faunal regions, the cold-temperate fauna of the Pacific Northwest and the warm-temperate fauna of southern and Baja California, and is a transitional area with elements of both faunal groups (Parrish et al. 1981). The northern Pacific Ocean reportedly entered a cold-water regime in 1999 (Peterson and Schwing 2003), which is hypothesized to be beneficial to many cold-temperate species, including Dungeness crab, English sole, and many of the rockfishes. This most recent cold-water regime was preceded by a warm-water regime from 1977 to 1998, which resulted in increased abundance of warm-temperate species in San Francisco Estuary, including California halibut, white croaker, Pacific sardine, and California tonguefish.

The PDO and NPGO are 2 basin-scale ocean climate indices. A positive PDO index is associated with warmer ocean temperatures, a stronger Alaska Current, and a weaker California Current, while a positive NPGO index is associated with increased salinity, upwelling, nutrients, and primary production and a stronger California Current (Di Lorenzo et al. 2008, Di Lorenzo et al. 2009). The PDO drives upwelling north of 38 °N while the NPGO drives upwelling south of 38 °N, with the San Francisco Estuary situated at approximately 37 °N. Major ecosystem regime shifts have occurred in the North Pacific when the PDO and NPGO show strong, simultaneous, and opposite sign reversals, such as in 1999 (Di Lorenzo et al. 2008). During cold-water regimes, the PDO indices are generally negative and the NPGO indices positive (Figure 2), resulting in frequent La Niña events; conversely, warm-water regimes generally have positive PDO indices and negative NPGO indices, with frequent and strong El Niño events. However, because the PDO, and to a certain extent, the NPGO indices have fluctuated between cooler and warmer states since the late 1990s, the presence of a sustained cold-water regime is still in question (Bjorkstedt et al. 2011).

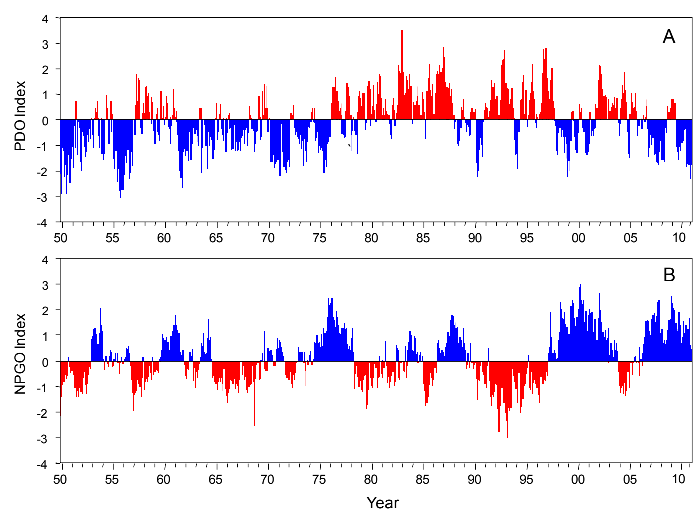

Figure 2 A) Monthly Pacific Decadal Oscillation (PDO) indices, 1950-2011 and B) Monthly North Pacific Gyre Oscillation (NPGO) indices, 1950-2011

There were 2 recent La Niña events in the tropics, one from summer 2010 through spring 2011 that lasted 10 months and another weaker event in fall and winter 2011-12 that lasted 7 months. These events resulted in negative PDO indices and positive NPGO indices (Figure 2). Although the central California coast has been in a cold-water regime since 1999, there were 4 El Niño events ranging from 5 to 10 months in the tropics in this period. Consequently, we observed a number of months during the last decade with above average SSTs and reduced upwelling, mostly from 2003 through 2006 and in early 2010 (Figure 3).

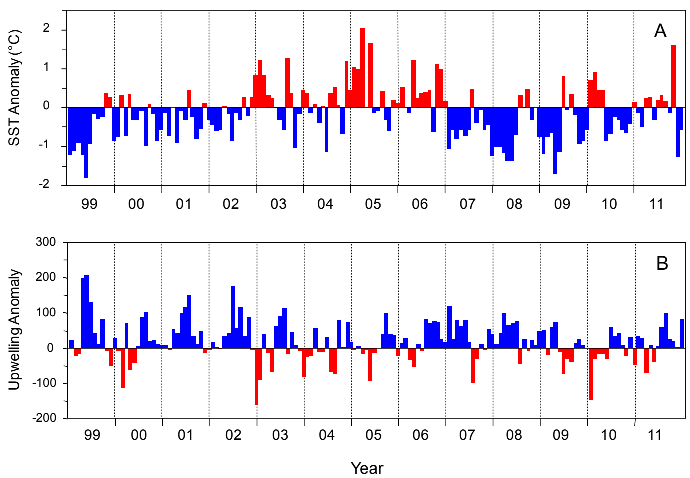

Figure 3 A) Monthly Sea Surface Temperature (SST, °C) anomalies from Southeast Farallon Island, 1999-2010 and B) Monthly upwelling index anomalies (39°N), 1999-2011

Gulf of the Farallones (GOF) SSTs were approximately 0.5 °C cooler than the long-term mean in fall and winter 2010-2011 (Figure 3a), when many marine fishes that rear in San Francisco Estuary spawn in coastal waters. After the La Niña event ended in spring 2011, monthly SSTs were near the long-term mean from March to September (Figure 3a), resulting in the highest summer SST anomalies since 2006. In late September 2011, SSTs increased and were over 15 °C for most of October (Figure 4). The October 2011 SST anomaly was 1.6 °C (Figure 3a), the highest since 1998 for this month. SSTs decreased very rapidly in early November 2011 to about 11 °C (Figure 4) with a negative anomaly for the remainder of the year (Figure 3a), concurrent with the onset of the second La Niña event.

The coastal ocean along central California is marked by 3 seasons: the upwelling season, from spring to late summer; the oceanic season, from late summer to late fall; and the Davidson Current season, from late fall to spring. During the upwelling season, prevailing northwesterly winds result in a southward surface flow, known as the California Current. Due to the Earth's rotation and the Coriolis Effect, there is a net movement of surface waters offshore. These waters are replaced by nutrient-rich, cold water that is transported or upwelled from deeper areas. Upwelling is responsible for the high productivity of the California Current System. When winds weaken in the fall, upwelling stops, surface ocean waters warm, and productivity declines. In winter, southwesterly winds result in a northward surface flow, or the Davidson Current. This current, in conjunction with the Coriolis Effect, produces an onshore and downward transport of surface water, or downwelling. Many coastal fish and invertebrate species in the California Current Region reproduce in winter during the Davidson Current season, when pelagic eggs and larvae are likely to be transported to or retained in nearshore areas. Juveniles of most species settle to the bottom nearshore and enter estuaries to rear before the onset of upwelling, as pelagic life stages present during the upwelling season would be transported offshore, often far from their preferred nearshore nursery areas.

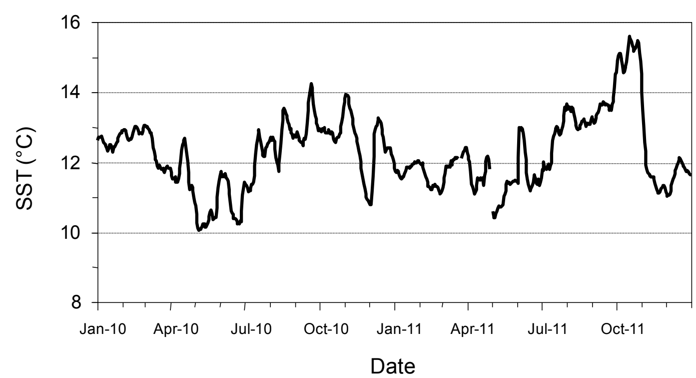

Figure 4 Daily Sea Surface Temperature (SST, °C) from Southeast Farallon Island, January 1, 2010 to December 31, 2011, 7-day running mean

The monthly upwelling anomalies from near San Francisco Estuary were slightly positive for most of fall and winter 2010-2011 (Figure 3b), a period of below average SSTs. When the La Niña event ended in spring 2011, upwelling anomalies became weakly negative (Figure 3b). In early summer 2011, the upwelling anomalies were consistently, but not strongly positive while SSTs were near average (Figure 3). These conditions resulted in lower primary and secondary production in the GOF in 2011 compared to 2010, as reflected by decreased reproductive performance for most seabirds at the Farallon Islands in 2011 (Warzybok and Bradley 2011). Smaller forage fishes, especially juvenile rockfishes, were less abundant in 2011, resulting in decreased, but near average, breeding success or chick survival for the Rhinoceros Auklet, Common Murre, Pigeon Guillemot, Pelagic Cormorant, and Ashy Storm-petrel. While euphausiid abundance declined from 2010, it was high enough to support very high productivity of Cassin's Auklets, a species that preys primarily on euphausiids. The Brandt's Cormorant and Western Gull had very poor reproductive success for the 4th consecutive year, with near complete reproductive failure, likely due to the lack of northern anchovy and larger forage fishes.

Upper Estuary Demersal Fishes

Shokihaze Goby

The Shokihaze goby (*Tridentiger barbatus*) is native to China, Japan, Korea, and Taiwan, and was first collected in San Francisco Estuary by the Bay Study in 1997 (Greiner 2002). It is a short-lived species; age-1 fish spawn in brackish water during spring and early summer, and die in late summer and fall (Slater 2005). Since the Shokihaze goby is most common upstream of the Bay Study original sampling area, abundance is calculated as the annual mean CPUE (#/tow) for all 52 stations sampled by the otter trawl, including the lower Sacramento and San Joaquin river stations added in 1991 and 1994.

In 2011, the Shokihaze goby mean CPUE (all sizes) was 58% of the 2010 index and the lowest index since 2000 (Figure 5), when the species was still establishing itself in the estuary. Since a large abundance spike in 2001, population levels have been fairly consistent relative to other species in the estuary. Shokihaze gobies were collected from San Pablo Bay through the lower Sacramento River in 2011.

Age-0 fish first recruited to the gear in September near the confluence of the Sacramento and San Joaquin rivers and in northern Suisun and Grizzly bays. As with years past, the channel station on the Sacramento River near the southern tip of Sherman Island was the most productive age-0 shokihaze goby station, peaking in September at 44 fish/tow. Age-0 gobies were strongly associated with channels, as CPUE at channel stations was over 30 times higher than at shoal stations (1.57 vs. 0.05 fish/tow, September to December).

Age-1+ Shokihaze goby densities were highest in January and steadily declined through the end of the year. CPUE was consistently highest in Suisun Bay (0.78 fish/tow, January to December). In 2011, 90% of all age-1+ fish were collected in Suisun Bay (n=84). This distribution was typical, as age-1 fish are generally found downstream from age-0 fish.

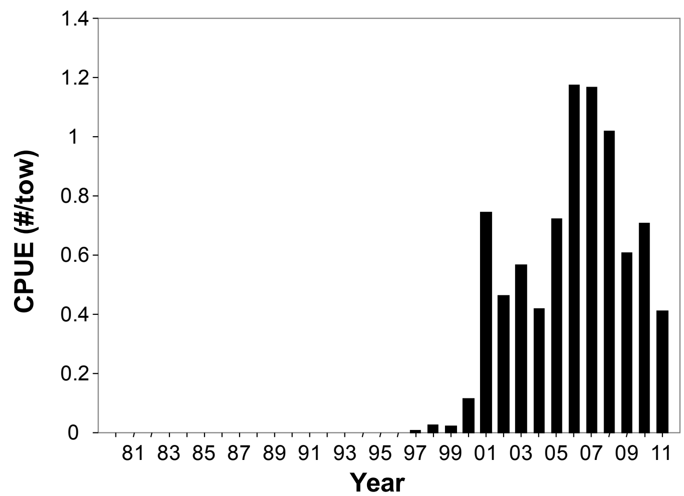

Figure 5 Annual catch-per-unit-effort (CPUE; #/tow) of Shokihaze goby (all sizes), Bay Study otter trawl, January-December

Yellowfin Goby

The yellowfin goby (*Acanthogobius flavimanus*) is an introduced fish from Asia with a partially catadromous life history. Adults migrate to brackish water to spawn from December through July and most die after spawning. Juvenile fish migrate upstream to lower salinity and fresh water habitats to rear through summer and fall (Moyle 2002).

The 2011 age-0 yellowfin goby abundance index was only 21% of the 2010 index and 14% of the study-period mean (Figure 6). 2011 continued the trend of below average indices observed since 2000. This persistent decline may be due in part to competition with or larval predation by other introduced gobies, such as those of the genus Tridentiger. Age-0 fish first recruited to the gear in May, and CPUE peaked in August in Suisun Bay (2.0 fish/tow).

Age-1+ yellowfin gobies were collected from January to May. By June, most age-1+ fish had likely spawned and died, as they were absent from trawl samples through the end of the year. Age 1+ yellowfin gobies were collected from South Bay to the Sacramento River in 2011. Distribution was broadest in January and February, and narrowest in May when age-1+ fish were only collected in San Pablo and Suisun bays.

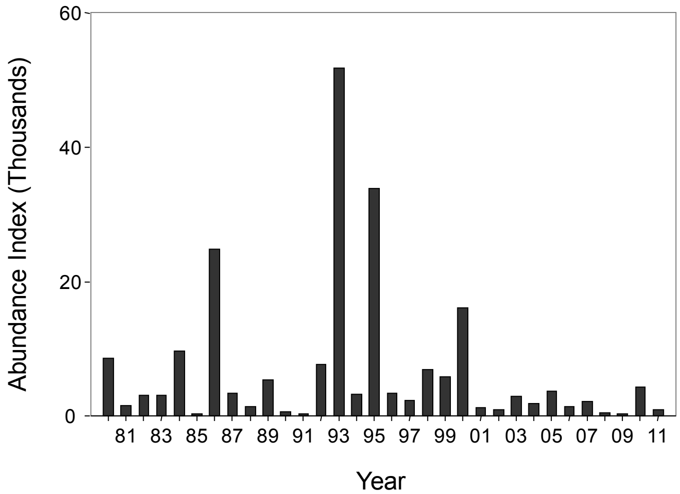

Figure 6 Annual abundance of age-0 yellowfin goby, Bay Study otter trawl, May-October

Starry Flounder

The starry flounder (*Platichthys stellatus*) is an estuary-dependent species that spawns in the ocean, but rears in brackish and fresh water areas of estuaries. In 2011, the age-0 starry flounder index was less than half of the 2010 index and well below the study-period mean (Figure 7A). This was unexpected given the high outflow and previously published positive outflow-abundance relationship for starry flounder (Kimmerer, 2002). The 2011 year class first recruited to the gear in July and was collected through the end of the year.

Age-0 starry flounder were collected from San Pablo Bay to the lower Sacramento River, but were most abundant in Suisun Bay (1.3 fish/tow, July to December). Age-0 starry flounder were primarily associated with shallow water; CPUE at shoal stations was over twice as high as channel stations (0.43 fish/tow vs. 0.18 fish/tow, July to December).

In 2011, the age-1 index was more than 8 times the 2010 index (Figure 7B) as a result of the relatively strong 2010 year class. Although the 2011 age-1 index was the highest since 2008, it was still well below the study-period mean. Age-1 abundance peaked in March and April concurrent with the highest outflows, which likely shifted distribution downstream and into deeper water. Abundance declined from July through the end of the year, when age-1 fish either had emigrated from the estuary or were otherwise inaccessible to the trawls. Age-1 fish were collected from San Pablo Bay through the lower Sacramento and San Joaquin rivers. Age-1 fish were most common in the lower Sacramento River January through March (1.00 fish/tow) and in Suisun Bay for the rest of the year (0.26 fish/tow). CPUE at shoal stations was over 3 times higher than channel stations (0.17 fish/tow vs. 0.05 fish/tow, January to December).

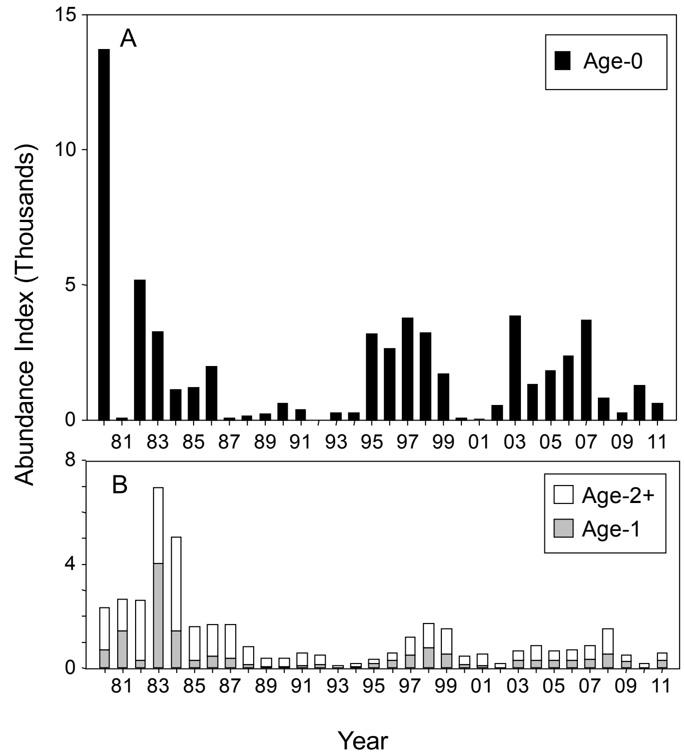

Figure 7 Annual abundance of starry flounder: A) age-0, Bay Study otter trawl, May-October, and B) age-1 and age-2+, Bay Study otter trawl, February-October

The 2011 age-2+ index was more than twice the 2010 index and was the highest since 2008 (Figure 7B). This was unexpected, as the 2010 age-1 index was the lowest since 2002. Although the 2011 age-2+ index showed some improvement, the sample size was still relatively small (38 fish) and abundance remained far lower than levels seen in the early to mid-1980s. Age-2+ fish were collected from Central Bay to the lower Sacramento River, but CPUE was highest in Suisun and San Pablo bays (0.15 and 0.13 fish/tow respectively; January to December). Density was highest at shoals in all regions, but especially in Suisun Bay, where shoal station CPUE was over 3 times higher than channel stations (0.25 vs. 0.07 fish/tow, January to December).

Marine Pelagic Fishes

Pacific Herring

The Pacific herring (*Clupea pallasii*) is an estuary-dependent species that spawns and rears in San Francisco Bay. Spawning occurs in late winter and early spring; the adhesive eggs are deposited on substrates such as aquatic vegetation, rocks, pier pilings, and other man-made structures. After hatching and larval development, young Pacific herring remain in shallow waters and begin to school. Juveniles can be found in shallow subtidal areas and sloughs until late spring, when they migrate to deeper waters within the estuary. By fall, age-0 Pacific herring emigrate from the estuary to spend 2 to 3 years rearing in the ocean before reaching maturity and returning to spawn.

The 2011 age-0 index was nearly twice the 2010 index (Figure 8), and the fifth highest on record. It was also more than twice the study-period mean. Abundance peaked in June, but catches remained high through July. Age-0 fish began recruiting to the gear in March and by late summer, most had emigrated from the estuary. However, a large catch of 191 fish was caught in December near Angel Island. In 2011, age-0 herring were caught from South Bay to near Port Chicago in Suisun Bay. Over all months, CPUE was highest in Central Bay (77 fish/tow, April to December), followed by San Pablo Bay (19 fish/tow, April to December). The high Central Bay CPUE can be in part attributed to 3 separate catches of over 1,000 fish each near Hunter's Point and Alcatraz.

Several factors may have contributed to this year's strong recruitment. Ocean conditions have been favorable since this year's spawning adults entered the ocean as juveniles in 2008. Increased outflow in 2011 resulted in lower salinities in the bay and may have led to an increased number of spawning events and higher embryo and larval survival. Griffin et al. (1998) reported 12-24 ppt as the optimal salinity range for fertilization and embryonic development of Pacific herring in San Francisco Bay.

The CDFW Herring Project has recorded landings for the Pacific herring fishery in San Francisco Bay since 1972. The commercial Pacific herring fishery runs from December through March, targeting adult fish entering the estuary to spawn. The herring fishery in San Francisco Bay was closed in 2009-2010, after a record low spawning biomass estimate the previous year. The fishery was reopened in 2010-2011 with a total quota of 1,900 tons. Season landings totaled 1,727 tons and the spawning biomass estimate for 2010-2011 was 57,082 tons. In 2010-11, 60% of adult fish were age-3, more evidence of the strong 2008 year class returning to the bay to spawn.

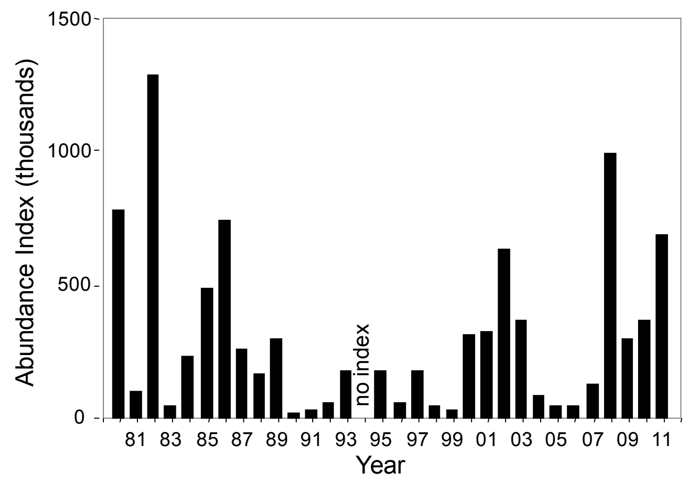

Figure 8 Annual abundance of age-0 Pacific herring, Bay Study midwater trawl, April-September

Northern Anchovy

The northern anchovy (*Engraulis mordax*) is the most common fish in the lower estuary and an important prey species for many fishes and seabirds (Bergen and Jacobson 2001). The 2011 northern anchovy abundance index (all sizes) was only 40% of the 2010 index (Figure 9), and the lowest index on record for the study. Low anchovy abundance was again linked to poor reproductive performance in several seabird species whose diet primarily consists of anchovies, including Brandt's Cormorant and Western Gull (Warzybok and Bradley 2011).

Vrooman et al. (1981) separated the northern anchovy population into northern, central, and southern subpopulations. The San Francisco Estuary is situated between the northern and central subpopulations, and our catches reflect changes in the size and coastal movements of these subpopulations. Although the central subpopulation is the largest and historically the most heavily fished, there are currently no stock assessments, so we cannot confirm subpopulation movements or size from fisheries data. However, there were unpublished reports from CDFW and NMFS that northern anchovy were more common in the Southern California Bight in 2008 and 2009, leading to the conclusion that the central subpopulation shifted south with colder ocean temperatures. Based on GOF SST anomalies (Figure 3a), less of a population shift to the south would be predicted in 2010 and 2011.

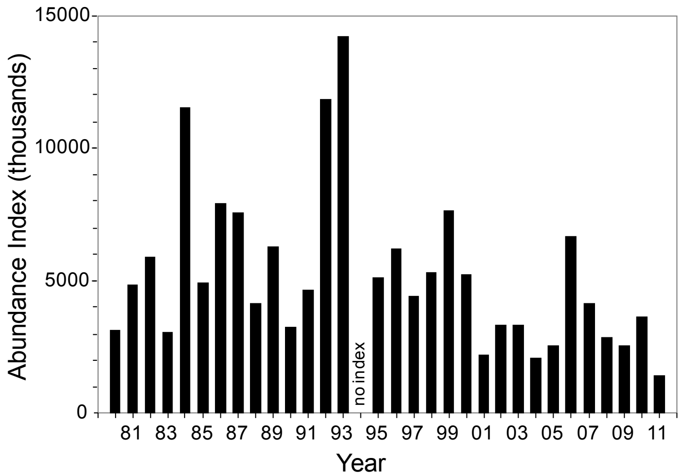

Figure 9 Annual abundance of northern anchovy (all sizes), Bay Study midwater trawl, April-October

Northern anchovies were collected every month in 2011, although few fish were collected during the first part of 2011. After outflow increased in early spring (Figure 1), anchovy abundance increased through summer, peaked in September, and declined thereafter. As freshwater outflow decreased through spring and upwelling increased through summer, CPUE in the estuary increased dramatically. Fish were collected from South Bay near the Dumbarton Bridge to Suisun Bay near the Mothball Fleet, with CPUE highest in Central Bay (170 fish/tow; April to December), followed by South (143 fish/tow) and San Pablo (106 fish/tow) bays. The highest regional CPUE was in South Bay in September, where anchovy catches averaged 629 fish/tow. This high CPUE was in part attributed to a large catch of over 3,000 fish near Coyote Point in one tow. There was no obvious depth preference in 2011, with channel-shoal CPUE very similar most months.

Jacksmelt

The jacksmelt (*Atherinopsis californiensis*) seasonally migrates from nearshore coastal waters to bays and estuaries to spawn and rear. Most reproduction within San Francisco Estuary occurs from September to April based on the presence of ripening and ripe females in San Pablo Bay (Ganssle 1966). Juvenile jacksmelt rear in shallow (< 2 m) areas of South, Central, and San Pablo bays in late spring and summer. After growing to about 50 mm FL, they begin to migrate to deeper water, where they become vulnerable to the midwater trawl.

The 2011 age-0 jacksmelt abundance index was almost double the 2010 index (Figure 10). It was above the study-period mean and the seventh highest index on record. In 2011, 99% of the total catch was collected between July and November, with the highest catch in November. However, over half of the age-0 fish collected in 2011 were from a single tow near San Quentin (n=832) in November. Age-0 fish were collected from South Bay near the Dumbarton Bridge to Point Pinole in San Pablo Bay. Overall, CPUE was highest in Central Bay (18.3 fish/tow, June to November), followed by South Bay (6.4 fish/tow). No seasonal channel-shoal movement was evident in 2011.

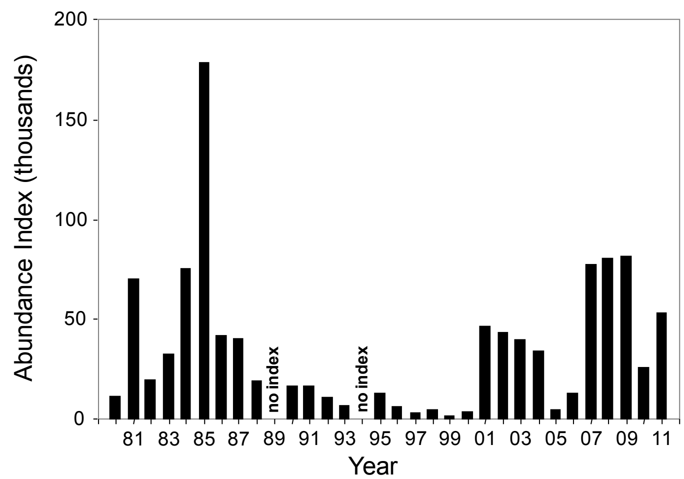

Figure 10 Annual abundance of age-0 jacksmelt, Bay Study midwater trawl, July-October

Surfperches

Most surfperches are transient species, migrating into bays and estuaries to give birth to live, fully formed young in late spring and summer, and returning to the coastal ocean in fall and winter. All of the surfperches common to San Francisco Estuary underwent abundance declines in the 1980s per Bay Study trawl and sport fish survey data (DeLeón 1998). Consequently, in 2002, CDFW changed the sport fish regulations for San Francisco and San Pablo bays, adopting a closed season for all surfperches, except shiner perch (*Cymatogaster aggregata*), from April 1 to

July 31, and a 5-fish combination bag limit for all species except shiner perch, which was given a 20-fish bag limit throughout the year.

Shiner Perch

The 2011 age-0 shiner perch (Cymatogaster aggregata) abundance index decreased 63% from 2010, and was only 8% of the study period mean (Table 1). It marks the lowest index on record. No age-0 fish were caught until July, and abundance peaked in August. Age-0 shiner perch were collected in South and Central bays in 2011, but overall were most common in Central Bay, where CPUE averaged 0.5 fish/tow (July to December). Seasonal movement was apparent, as CPUE was higher at shoal stations during summer (0.4 fish/tow, July to September), and channel stations in fall and winter (0.2 fish/tow, October to December).

Nearly 85% of the total shiner perch catch were age-1+ fish, mostly collected in Central Bay. Although recruitment was low in 2011, shiner perch still utilized the estuary. Low age-0 abundance can be in part attributed to high outflows through early summer 2011, as shiner surfperch prefer higher salinity waters.

Walleye Surfperch

The 2011 age-0 walleye surfperch (*Hyperprosopon argenteum*) abundance index was almost identical to the 2010 index, and the third consecutive year of below average abundance (Table 1). Only 20 age-0 walleye surfperch were collected in the midwater trawl in 2011, all from 2 tows near Berkeley. The 2011 age-1+ index was nearly 2.5 times the 2010 index and was the highest index since 1999 and the third highest index on record (Table 1). Thirty-two age-1+ walleye surfperch were collected in the midwater trawl during 2011, ranging from South Bay to San Pablo Bay; almost 90% were from Central Bay near Berkeley. All age-0 and age-1+ walleye surfperch were collected from shoal stations.

Other Surfperches

The 2011 barred surfperch (*Amphistichus argenteus*) abundance index for all sizes was over 4.5 times the 2010 index (Table 1) and was the third highest index on record. In 2011, the Bay Study collected 17 barred surfperch in

Table 1 Annual abundance indices for selected surfperch species from the Bay Study. The age-0 shiner perch, age-0 and age-1+ walleye surfperch, age-0 pile perch, and white seaperch (all sizes) indices are from May-October. The barred perch (all sizes), black perch (all sizes), and dwarf perch (all sizes) indices are from February-October.

	shiner perch	*walleye surf-perch*	*walleye surf-perch*	*barred surf-perch*	*pile perch*	*white sea-perch*	*black perch*	*dwarf perch*
Year	age-0	age-0	age-1+	all sizes	age-0	all sizes	all sizes	all sizes
1980	19515	1277	642	415	857	588	0	439
1981	42760	8089	1757	691	998	1248	129	543
1982	43703	1640	992	223	471	349	54	259
1983	16147	663	135	1030	778	271	88	460
1984	14386	3846	922	502	110	873	216	50
1985	16616	362	1031	81	301	138	66	0
1986	24617	322	880	0	254	309	17	0
1987	18069	1453	2624	159	0	265	0	0
1988	7746	486	502	90	0	148	62	66
1989	6953	2046	493	109	153	48	101	97
1990	8181	516	341	105	0	95	48	26
1991	2724	22	505	75	0	0	0	15
1992	6142	443	297	27	0	0	100	0
1993	6341	617	112	29	0	0	97	0
1994	3241	no index	no index	53	0	0	125	0
1995	6661	405	269	36	0	0	0	0
1996	4404	684	380	39	0	0	225	0
1997	23897	231	643	104	0	0	231	0
1998	4383	537	911	32	75	0	65	0
1999	6237	848	2985	30	0	0	36	0
2000	4640	1229	114	29	31	0	119	0
2001	20594	8121	1003	41	0	106	248	0
2002	26131	12277	2079	76	42	260	95	0
2003	15898	2439	567	302	0	371	63	111
2004	24849	896	1438	76	0	487	253	94
2005	6225	2916	655	34	0	47	93	32
2006	4911	1568	26	46	0	0	62	34
2007	5193	241	1205	123	0	0	36	42
2008	5935	4128	529	105	0	61	69	0
2009	3408	257	289	318	0	0	26	0
2010	2652	1252	949	126	0	0	0	0
2011	998	1274	2346	572	0	0	36	0
1980 -2011 Mean	**12630**	**1970**	**891**	**177**	**127**	**177**	**86**	**71**

the otter trawl at shoal stations; all but 1 were collected in South Bay. Historically, the majority of barred surfperch have been collected from South Bay shoal stations, especially stations along the eastern shore. Barred surfperch is commonly associated with eelgrass beds in San Francisco Bay (Merkel & Associates 2005), a habitat not sampled by our trawls.

The 2011 age-0 pile perch (*Rhacochilus vacca*) abundance index was 0, showing no sign of recovery in the estuary and continuing the trend of very low or 0 indices since 1987 (Table 1). This was the third year in a row that no fish were collected.

The 2011 white seaperch (*Phanerodon furcatus*) index was 0 for the third year in a row (Table 1). One fish was collected in the otter trawl, but during a non-index month. Two additional white seaperch were collected, but did not contribute to the index, as they were from the midwater trawl. These 3 fish were collected from shoal stations in South and Central bays.

Black perch (*Embiotoca jacksoni*) was the only surfperch common in the estuary that did not show a distinct decline during the late 1980s or early 1990s (Table 1). However, black perch catches have remained low relative to the most common surfperches throughout the study period. The 2011 black perch index (all ages) increased for the first time in 3 years. Three fish were collected in Central Bay; however, two fish were from a non-index station.

For the fourth year in a row, the 2011 dwarf perch (*Micrometrus minimus*) index was 0 (Table 1); no dwarf perch were collected. Historically, dwarf perch were commonly collected from shoal stations in Central and South bays. Dwarf perch is another species strongly associated with eelgrass beds in San Francisco Bay, a habitat that is not sampled by our trawls.

Marine Demersal Fishes

Leopard Shark

The leopard shark (*Triakis semifasciata*) is a popular sportfish that migrates to very shallow areas of the estuary, especially South Bay, to pup in late spring and early summer. The Bay Study does not effectively sample age-0 leopard sharks because they are born and rear in areas too shallow to navigate with our boat. Catches are often very low, so we report age-0, age-1+, and total catch (February-October) rather than abundance indices. Our 2011 otter trawl age-0 February-October catch was 1, and our age-1+ catch was 6, resulting in a combined catch that was the lowest since 2003 and the 6th lowest for the study period (Figure 11). There has been a downward trend in catch beginning in 1984. Catch averaged 38 fish per year from 1980 to 1983, declined to 14 fish per year from 1984 to 1998, and declined again to only 9 fish per year from 1999 to 2011. Because of potential over-harvest of leopard sharks, a 36-inch minimum size and a 3-fish bag limit was implemented in 1991 for the sport fishery. We collected a total of 9 leopard sharks during 2011, from South Bay to San Pablo Bay near Point Pinole, with 78% (n=7) from South Bay.

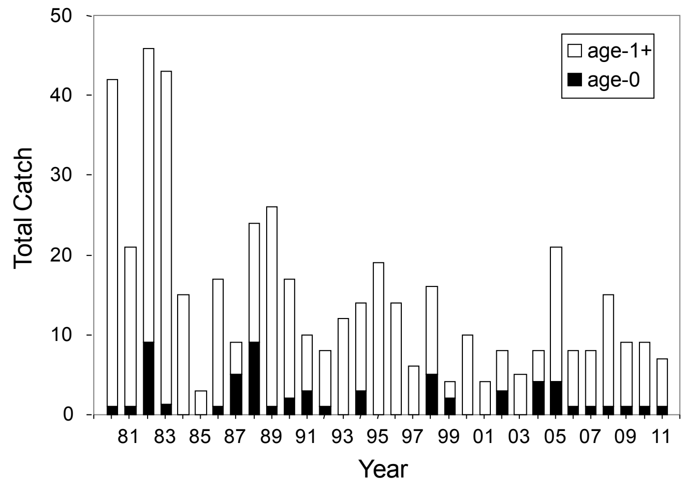

Figure 11 Annual catch of leopard shark (age-0 and 1+), Bay Study otter trawl, February-October

From mid April to early July 2011 many leopard sharks and a lesser number of bat rays were found disoriented, stranded, or dead in South and Central bays. Fish were necropsied by CDFW pathologists and internal hemorrhaging was a consistent finding. Although the cause of this die off was not determined, anticoagulants, such as Warfarin, and microcystins were eliminated. Osmotic shock due to reduced salinities from high freshwater outflow was likely a contributing factor. Leopard sharks cannot osmoregulate, and show signs of osmotic stress when exposed to salinities less than 17‰ for prolonged periods of time (Dowd et al. 2010). South Bay bottom salinities were below 17‰ in April 2011, ranging from 12.8‰ in the channel south of the Dumbarton Bridge to 16.4‰ at the shoal near Candlestick Park per Bay Study data. From January to March 2011, before the largest storms, bottom salinities at these same stations ranged from 22.0 to 27.3‰.

Stranded or dead leopard sharks were reported from open water and lagoons with tide gates designed to capture stormwater runoff, such as Redwood Shores Lagoon and Berkeley's Aquatic Park, soon after the largest storms in late March and early April. By late April 2011, salinities were 13 to 17‰ in Redwood Shores Lagoon (Redwood City, unpublished data), low enough to cause osmotic stress in leopard sharks. Note that no salinity data was available from the lagoons before or immediately after the peak stormwater flows, but based on CDFW and USGS South Bay salinity data and stream discharge data, salinities in these lagoons likely dropped rapidly in late March and April 2011, some to near freshwater. In 2006, another year with a wet spring following a dry winter, there were numerous reports of stranded and dead leopard sharks in northern South Bay and Central Bay.

Plainfin Midshipman

The plainfin midshipman (*Porichthys notatus*) migrates from coastal areas to bays and estuaries in late spring and summer to spawn. Most juveniles rear in the estuary through December, with some fish remaining until spring. The 2011 age-0 abundance index was 80% of the 2010 index and well below the study-period mean (Figure 12). The 7 highest abundance indices for the study period occurred in the last 11 years; although we are not certain of the mechanism, these strong year classes were associated with cool ocean temperatures (Figures 2 and 3a). The coastal adult plainfin midshipman distribution possibly shifted southward during the current cold-water regime, increasing the relative abundance of spawning stock entering San Francisco Estuary (Cloern et al. 2010). Slightly warmer ocean conditions in 2010 and 2011 (Figure 3a) may partially explain the recent abundance decline.

Age-0 plainfin midshipmen first recruited to the gear in July, abundance peaked in October and remained high through December. Age-0 fish were collected from South through lower Suisun bays in 2011, with the highest CPUEs in Central and San Pablo bays in October (38 and 20 fish/tow, respectively). Age-0 fish were consistently channel oriented (10 fish/tow vs. 2 fish/tow in the shoals, July to December).

Age-1 plainfin midshipmen were collected from January through September 2011. As in other years, all age-1+ fish emigrated from the estuary by fall, leaving only the age-0 fish to rear. Age-2+ fish were first collected in March and none were collected after September. This pattern was typical, as age-2+ fish migrated from the coast in late spring to spawn inside the Bay.

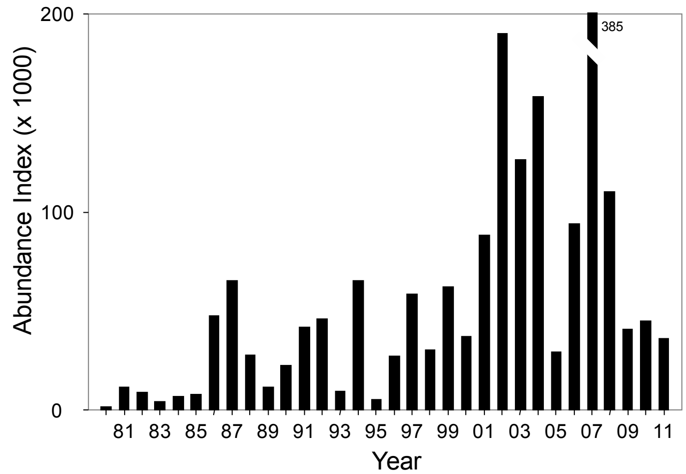

Figure 12 Annual abundance of age-0 plainfin midshipman, Bay Study otter trawl, February-October

Brown Rockfish

The brown rockfish (*Sebastes auriculatus*) is one of the more common rockfish species that utilize San Francisco Bay as a nursery habitat. It is a live-bearing fish, with some fish reaching sexual maturity as early as 3 years. Larvae are born in coastal waters in winter and early spring. Juveniles immigrate to the estuary where they remain for several years before moving to deeper waters, and eventually to coastal habitats. Brown rockfish are often associated with structures such as pilings and rocks, and are thus under sampled by the trawl gear.

The 2011 age-0 brown rockfish index was only 1.5% of the record high 2010 index (Figure 13). Brown rockfish indices had been at zero for several years in the mid-2000s, but increased through 2010, concurrent with the recent cool water regime. High fresh water outflow in the estuary led to lower than average salinities, and may be a contributing factor to 2011's low abundance index.

Age-0 brown rockfish began recruiting to the gear in May, but were only collected in May, June, September and October. Five fish were collected in Central and South bays in 2011, but one was from a non-index station and did not contribute to the index.

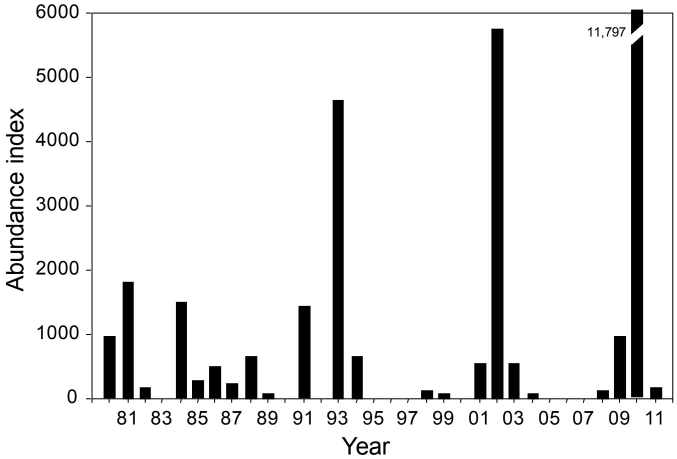

Figure 13 Annual abundance of age-0 brown rockfish, Bay Study otter trawl, April-October

Pacific Staghorn Sculpin

The Pacific staghorn sculpin (*Leptocottus armatus*) is a common native species that usually rears in higher salinity areas, but is also found in brackish and occasionally fresh water. Throughout the estuary, it rears in intertidal and shallow subtidal areas from late winter to early spring and migrates to deeper water through summer. The 2011 age-0 staghorn sculpin index was nearly 20% higher than the 2010 index and was the fourth highest index on record (Figure 14). The 8 highest indices on record have all occurred in the past 13 years, in association with cool ocean temperatures (Figure 3a). As with other cold-temperate species, it is likely that the coastal adult distribution expanded southward with the recent shift in climate regime, resulting in increased spawning stock abundance inside and surrounding San Francisco Estuary (Cloern et al. 2010).

In 2011 age-0 fish were collected from South Bay through the lower Sacramento River near Decker Island. Age-0 staghorn sculpin first recruited to the gear in March and were collected through the end of the year, with peak abundance in July and August. These peaks were driven by large catches at Central Bay channel stations just east of Angel Island and Tiburon. The location of these catches and lack of proportional catches of smaller fish earlier in the year indicate that most of these fish were likely summer visitors that had emigrated from the near shore coast. This use of Central Bay during summer may be in a movement from the colder ocean during the most intense upwelling period. Age-0 fish collected in 2 tows in July and August near Angel Island and Tiburon amounted to 30% of the total catch for the year (n=441). Since these fish were likely immigrants, the 2011 index may be driven by local coastal production rather than in-bay production. Age-0 fish in Central and South bays were more common at channel stations (13.1 and 0.9 fish/tow respectively) whereas fish in the upper estuary were more common at shoal stations (1.4 fish/tow).

Age-1+ staghorn sculpin were collected from South Bay through lower Suisun Bay in 2011. Age-1+ staghorn sculpin were consistently more common at channel than shoal stations across all regions and months (0.19 fish/to vs. 0.04 fish/tow; January to August). Geographic distribution was widest the first 3 months of the year, contracted from April through August to Central Bay, and no age-1+ staghorn sculpin were collected from September through the end of the year.

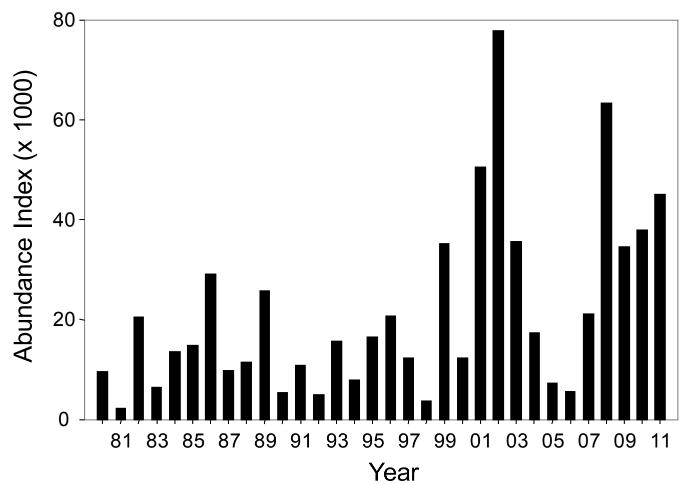

Figure 14 Annual abundance of age-0 Pacific staghorn sculpin, Bay Study otter trawl, February-September

White Croaker

The white croaker (*Genyonemus lineatus*) is a common coastal species that frequents bays and estuaries. It is a member of the subtropical fish fauna more commonly found south of Point Conception. It spawns from November through April in shallow, nearshore waters, and juveniles progressively move into deeper water as they grow.

The 2011 age-0 white croaker index was only 10% of the 2010 index (Figure 15). Age-0 fish were not collected until April, with abundance peaking in July. In 2011, age-0 white croaker were collected from South Bay through Carquinez Strait in spring and summer, but by September, most had migrated into Central Bay. Overall, CPUE was highest in Central Bay at 0.2 fish/tow (April to December). Age-0 white croaker were more common in channels (0.1 fish/tow, April to December) than shoals (0.03 fish/tow).

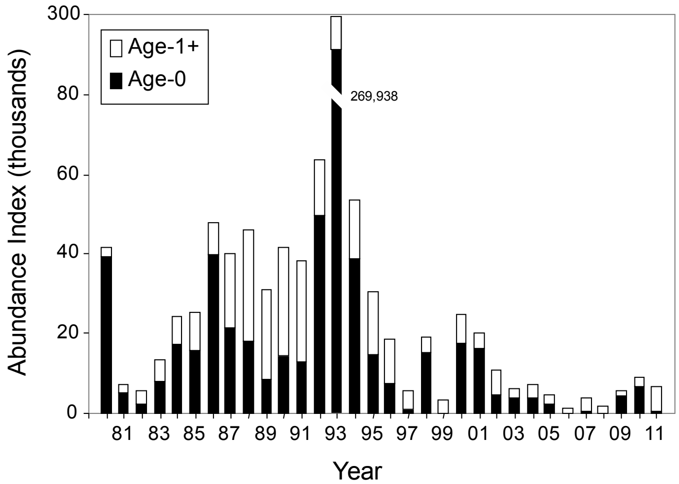

Figure 15 Annual abundance of age-0 and age-1+ white croaker, Bay Study otter trawl, February-October

The 2011 white croaker age-1+ index was nearly 3 times the 2010 index (Figure 15), following the relatively high age-0 index in 2010. Although the age-1+ index was the highest since 2002, it was still less than the study-period mean. In 2011, age-1+ fish were collected throughout the year from South through San Pablo bays and 1 was collected in Suisun Bay near the Mothball Fleet in December. Annual CPUE was highest in Central Bay (1.2 fish/tow, January to December), followed by South Bay (0.3 fish/tow). Age-1+ white croaker were more commonly caught in the channels than the shoals, with average annual channel CPUE 6 times the shoal CPUE (0.6 vs. 0.1 fish/tow).

Bay Goby

The bay goby (*Lepidogobius lepidus*) is one of the most common gobies in the estuary. It is a native resident species that rears in the higher salinity areas and has a 2 to 3 year life span. The 2011 bay goby index (all sizes) was only 24% of the 2010 index and was the lowest index since 2007 (Figure 16). Bay gobies were collected throughout the year, but abundance was highest from April through September.

Bay gobies were collected from South through Suisun bays, but were most abundant in Central Bay in 2011. Central Bay CPUE averaged 19 fish/tow (January to December) and peaked at 52 fish/tow in June. Bay gobies in Central Bay were more common at shoal stations from January through June, and at channel stations all other months. The 2011 bay goby distribution was consistent with the long-term trend of increased Central Bay CPUE observed for plainfin midshipman, Pacific staghorn sculpin, and several other marine demersal species.

Age-0 bay gobies were collected all months of 2011 and belonged to 2 cohorts: one that recruited to the gear in the spring, and a second that recruited in late-fall. Strongest recruitment occurred in May and June at San Pablo Bay shoal stations (24 fish/tow).

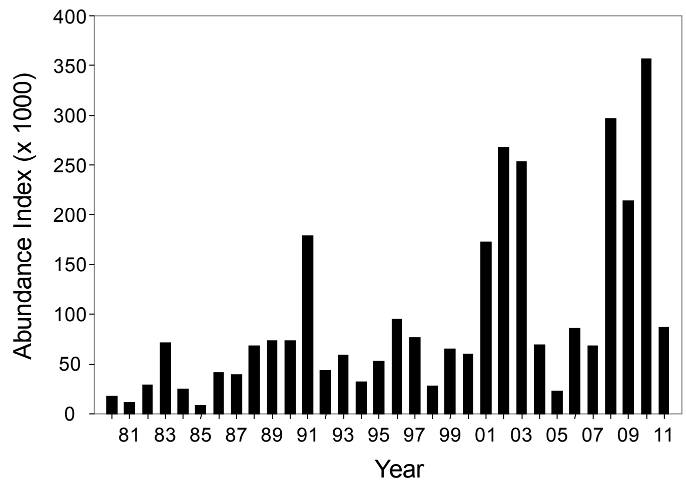

Figure 16 Annual abundance of bay goby (all sizes), Bay Study otter trawl, February-October

California Halibut

The California halibut (*Paralichthys californicus*) is a member of the subtropical faunal group that became common in San Francisco Estuary in the 1980s and 1990s, concurrent with the most recent warm-water regime (Figure 2). It spawns in shallow coastal waters and juveniles rear in very shallow subtidal and intertidal areas of bays and estuaries, and to a much lesser extent on the open coast.

The 2011 juvenile (age-0 & 1) California halibut index was 0 for the fourth consecutive year (Figure 17). Two juvenile halibut were collected in 2011, but since both were collected in December, outside of the index period, neither contributed to the index. Continued cool ocean conditions through 2010 (Figures 3a and 4) likely limited local recruitment, exemplified by Bay Study's collection of only 9 juvenile halibut since early 2006. The last substantial recruitment occurred in 2004-2005, concurrent with the most recent prolonged period of warm SSTs.

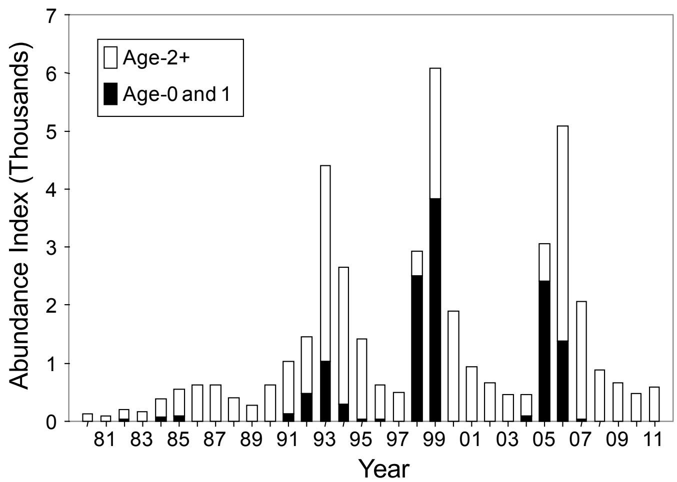

Figure 17 Annual abundance of juvenile (age-0 and age-1) and age-2+ California halibut, Bay Study otter trawl, February-October

The 2011 adult (age-2+) California halibut index increased slightly, but remained below the study-period mean (Figure 17). Twenty-five adult halibut were collected in 2011 ranging from South Bay through San Pablo Bay, but were most common in Central Bay all months. Age-2+ fish ranged up to 856 mm, though most were below the minimum length for recreational harvest (< 559mm). Most of the fish collected in 2011 were smaller than the 2004-05 cohort, which indicated recruitment that is more recent. Considering we did not document substantial in-bay recruitment since 2004-05, these fish may have migrated from near shore coastal rearing areas, possibly from the south. Over the past several years, the publicity of high angler success rates and lack of other fisheries placed considerable pressure on the San Francisco Bay halibut fishery. This fishing pressure and associated harvest mortality was likely a key contributor to the continuation of low adult halibut abundance in 2011.

English Sole

The English sole (*Pleuronectes vetulus*) is a common flatfish that spawns along the coast in winter and rears in both the coastal ocean and estuaries. The 2011 age-0 English sole abundance index was slightly lower than the 2010 index and marked the third consecutive year of declining indices (Figure 18). Although age-0 English sole abundance declined in 2011, the index was still nearly 60% higher than the study-period mean. Except for 2005 and 2006, abundance has been very high in the past decade, with the 11 highest indices for the study period occurring in the last 13 years. During the current cold-water regime (Figure 2), coastal adult English sole distribution likely shifted southward, increasing the abundance of spawning stock adjacent to San Francisco Estuary (Cloern et al, 2010). In addition, cooler SSTs (Figure 3a) and strong upwelling (Figure 3b) likely enhanced egg and larval survival and growth.

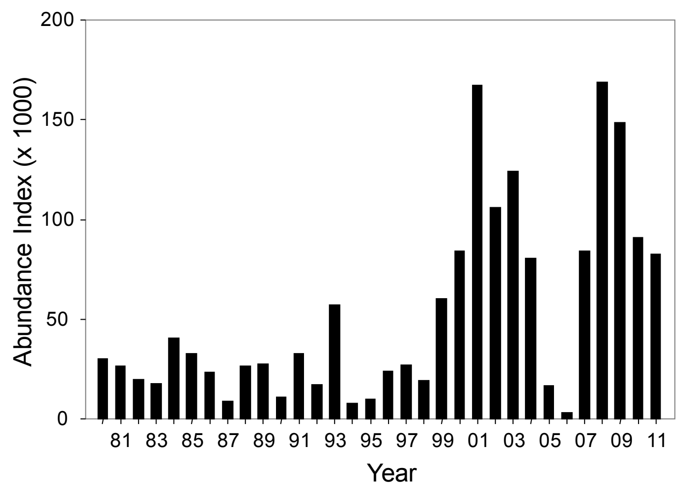

Figure 18 Annual abundance of age-0 English sole, Bay Study otter trawl, February-October

In 2011, age-0 abundance peaked in April, remained high through August, and then decreased through the end of the year. Age-0 English sole were collected from South through Suisun bays in 2011, but were most abundant in Central Bay (23 fish/tow, January to December). From April to June, the period of most intense recruitment, age-0 English sole were most common at shoal stations in Central and San Pablo bays (59 and 11 fish/tow, respectively). In contrast, during this same period in South Bay, age-0 English sole were far more common at channel stations than shoal stations (19 vs. 6 fish/tow). This South Bay pattern was not typical, as shoal stations in all 3 bays usually have higher CPUE than channel stations these months. This atypical pattern may have been the result of a mass emigration from South Bay as salinity dropped with increased freshwater runoff in late spring. Although salinity dropped similarly in San Pablo Bay, English sole collected in San Pablo Bay were smaller on average than those collected in South Bay and may have been more tolerant to the low salinity.

Following a typical pattern, age-1+ abundance was highest in January and decreased sharply through summer, as age-1+ fish emigrated from the estuary. Only 4 age-1+ English sole were collected after August 2011. Age-1+ densities were consistently highest at Central Bay channel stations (8 fish/tow, January to August).

Speckled Sanddab

The speckled sanddab (*Citharichthys stigmaeus*) is one of the most abundant flatfishes in the estuary. It is a short-lived species with an estimated maximum age between 36 and 42 months. Spawning occurs along the coast and peaks in summer. In southern California, spawning is coincident with a sudden drop in bottom temperature due to upwelling (Ford 1965). Larvae may be pelagic for many months, riding ocean currents first offshore then onshore, before settling to the bottom in or near coastal and estuary rearing areas, generally in less than 40 m of water (Rackowski and Pikitch 1989, Kramer 1990). Juveniles rear for up to a year in the estuary before migrating to the ocean.

The 2011 speckled sanddab abundance index (all sizes) was less than half of the 2010 index, but was still nearly twice the study-period mean (Figure 19). High indices over the past decade were likely the result of cooler ocean temperatures associated with the recent regime shift. 2011 lacked a strong summer influx of larger speckled sanddabs into Central Bay, as is common in many years. This may have in part been due to the abnormally large volume of delta outflow in the spring 2011.

Speckled sanddab were collected from South Bay through Carquinez Strait in 2011. Abundance was relatively high in all months of 2011, but peaked in April and May and again in July and August. Speckled sanddab were most common in Central Bay (30.5 fish/tow January to December), with the highest CPUE (51.7 fish/tow) in July. Fish densities in South and Central bays were higher at channel stations (4.8 and 35.5 fish/tow respectively) than shoal stations (0.7 and 24.6 fish/tow respectively, January to December). In contrast, San Pablo Bay CPUE was higher at shoal stations than channel stations (2.1 vs. 0.4 fish/tow January to December). These were likely newly settled fish rearing on the San Pablo shoals before migrating to deeper water, as fish in San Pablo Bay were smaller on average (57mm, n=190) than fish in Central Bay (68mm, n=4,032) or South Bay (66mm, n=267).

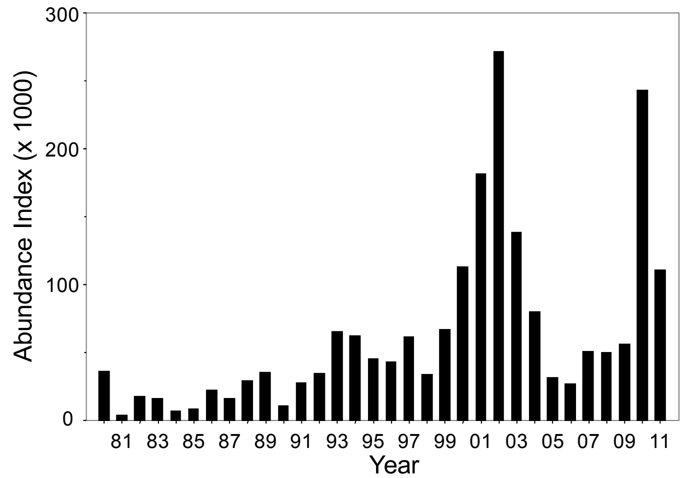

Figure 19 Annual abundance of speckled sanddab (all sizes), Bay Study otter trawl, February-October

Notes

Dayflow data from water.ca.gov/dayflow/
PDO indices from jisao.washington.edu/pdo/PDO.latest
NPGO indices from www.o3d.org/npgo/data/NPGO.txt
Upwelling indices and anomalies from www.pfeg.noaa.gov/products/PFEL/modeled/indices/upwelling/NA/data_download.html
Sea Surface Temperatures from shorestation.ucsd.edu/

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2010-2011 Yolo Bypass Fisheries Monitoring Status and Trends Report

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Introduction

Largely supported by IEP, DWR has operated a fisheries and invertebrate monitoring program in the Yolo Bypass since 1998. The project has provided a wealth of information regarding the significance of seasonal floodplain habitat to native fishes. Basic objectives of the project are to collect baseline data on lower trophic levels (phytoplankton, zooplankton, and aquatic insects), juvenile fish and adult fish, hydrology, and physical conditions. As the Yolo Bypass has been identified as a high restoration priority by the National Marine Fisheries Service Biological Opinions for delta smelt (*Hypomesus transpacificus*), winter and spring-run Chinook salmon (*Oncorhynchus tshawytscha*), and by the Bay Delta Conservation Plan (BDCP), this baseline data is critical for evaluating success of future restoration projects. In addition, the data has already served to increase our understanding of the current role of the Yolo Bypass in the life history of native fishes, and its ecological function in the San Francisco Estuary. Key findings include: (1) Yolo Bypass is a major factor regulating year class strength of splittail, *Pogonichthys macrolepidotus* (Sommer et al. 1997; Feyrer et al. 2006; Sommer et al. 2007a); (2) Yolo Bypass is a key migration corridor for adult fish of several listed and sport fish (Harrell and Sommer 2003); (3) it is one of the most important regional rearing areas for juvenile Chinook salmon (Sommer et al. 2001a; 2005); (4) and Yolo Bypass is a source of phytoplankton to the food web of the San Francisco Estuary (Jassby and Cloern 2000; Schemel et al. 2004; Sommer et al. 2004).

This report describes the fisheries sampling effort for the 2011 water year (October 1, 2010 – September 30, 2011), as well as a summary of the fisheries catch by species and gear type. We highlight significant results from the 2010-11 sampling period for Sacramento splittail and elevated chlorophyll-*a* concentrations.

Methods

Since 1998, juvenile fish have been sampled with an 8-foot rotary screw trap located in the Toe Drain approximately 9 miles south of the Lisbon Weir (Figure 1) for up to 7 days a week during the months of January – June. In 2011, high flows carrying heavy debris loads caused irreparable damage to the rotary screw trap and this resulted in a data gap from March 20 through April 27 (Figure 2), when a replacement trap was obtained. For the rotary screw trap, it is possible to create rough estimations of the sampling time (total hours based on set and pull times) in order to calculate catch per unit effort (CPUE). At this time, volume of water sampled is unknown.

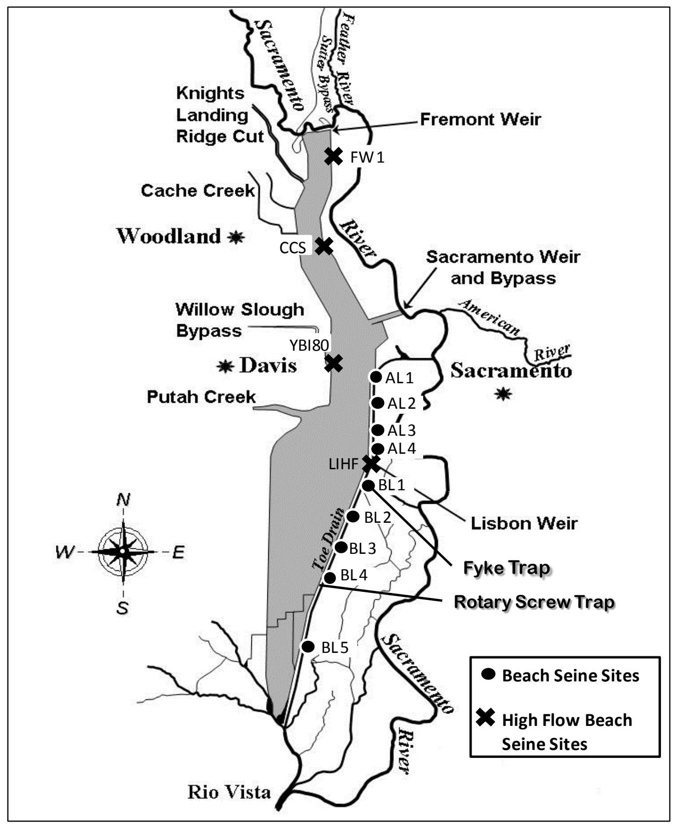

Figure 1 Map of Yolo Bypass

Upstream migrating, large, adult fish in the Toe Drain are monitored using a 10-foot fyke trap, designed after the Department of Fish and Wildlife's (CDFW) fyke traps used for sampling sturgeon and striped bass in the Sacramento River. The fyke trap is operated up to 7-days a week during the months of October – June. The trap is located ¾ of a mile below Lisbon Weir and 13 miles to the north of the terminus of the Toe Drain (Figure 1). In 2011, the fyke trap was pulled from the Toe Drain March

18 through April 14, to protect the trap from heavy flows (≥ 5,000 cfs) and debris loads during the inundation of the Bypass (Figure 2).

We have supplemented the collection of small adult and juvenile fish in the Yolo Bypass by conducting bi-weekly beach seine surveys at various site locations within the Toe Drain and a perennial pond on the west side of the Bypass (Figure 1). Weekly sampling is conducted during inundation periods such as the one that occurred in 2011 at four site locations only accessible during flood conditions (Figure 1). In the summer of 2010 the beach seine survey increased to include seven additional stations, some above and below Lisbon Weir, to capture at a higher resolution the fish assemblage above and below the weir. Dimensions of all beach seine hauls are recorded, in order to calculate catch per unit volume of water sampled.

To provide data on ambient water quality conditions field crews collect data on several water quality parameters including: temperature, conductivity, dissolved oxygen, pH, and secchi depth. Data loggers recording continuous water temperature at 15-minute intervals are deployed the rotary screw trap (January – June only) and Lisbon Weir (year-round) in the Toe Drain, and for comparison purposes, in the Sacramento River at Sherwood Harbor, also year-round. In addition, chlorophyll-*a* grab samples (to estimate phytoplankton biomass), zooplankton, larval fish, and invertebrate drift samples are collected on a bi-weekly basis at the rotary screw trap and at Sherwood Harbor. Lower trophic level sampling frequency is increased to weekly during periods of inundation.

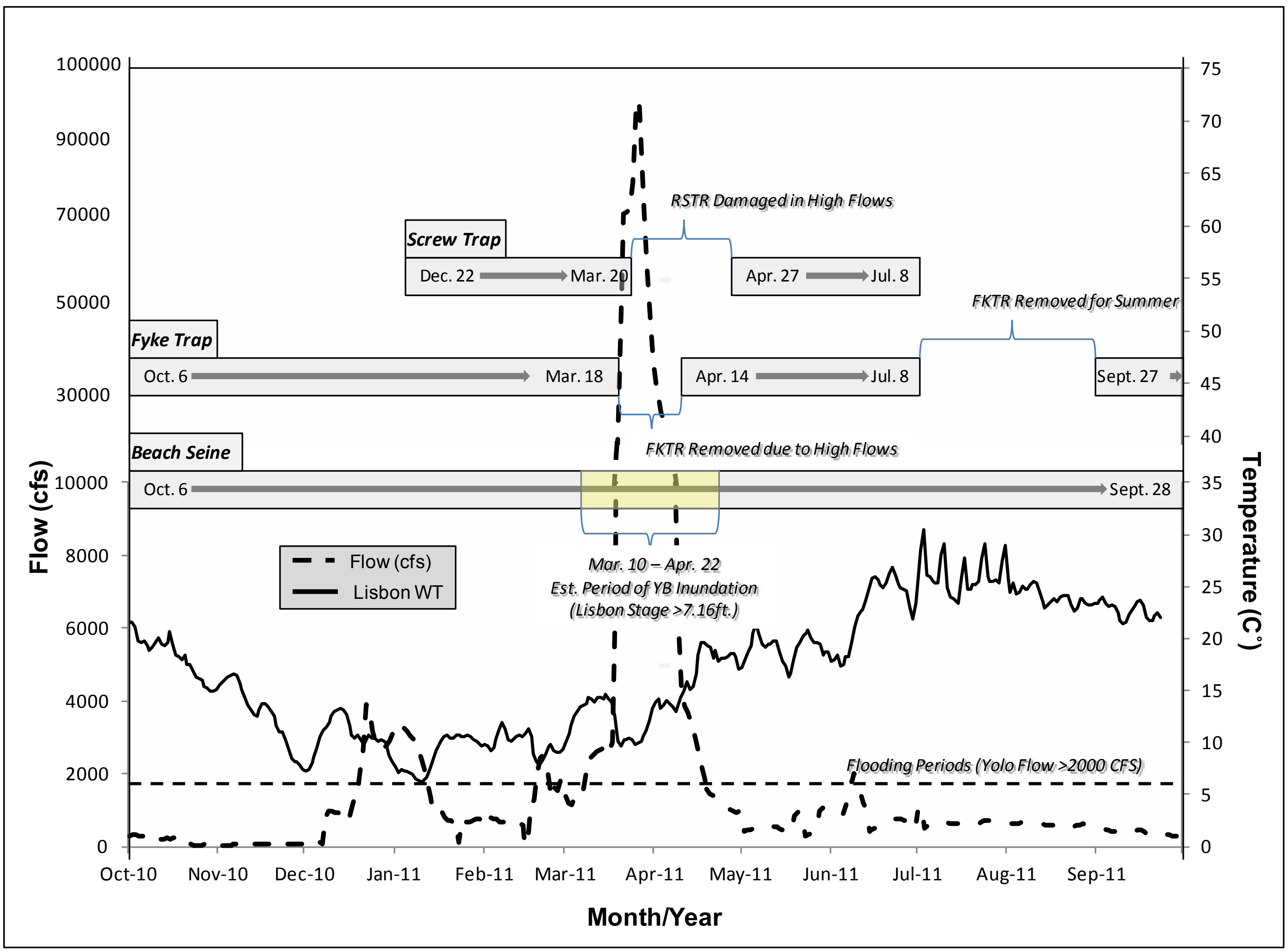

Figure 2 Fishing effort for every gear type summarized against flow (source: Yolo Dayflow) and water temperature

Results and Discussion

Hydrology

The water year 2011 had the third-highest flow conditions in the Yolo Bypass since the inception of the monitoring program (Figure 3), resulting in substantial inundation during the spring months. The flooding of the Yolo Bypass typically occurs when the total flow from the Sutter Bypass and Sacramento and Feather rivers surpasses 1,600 (m^3/sec) and Fremont Weir stage exceeds 10.2 m (Sommer et al. 2001a). The estimation of timing and length of inundation period of the Yolo Bypass was calculated using Fremont and Lisbon Weir stage data, as well as Dayflow data for flow estimates. The Dayflow flow estimates in the Yolo Bypass are calculated using combined data from the Yolo Bypass flow at Woodland, Fremont Weir spill, and South Putah Creek flow (DWR, 2012).

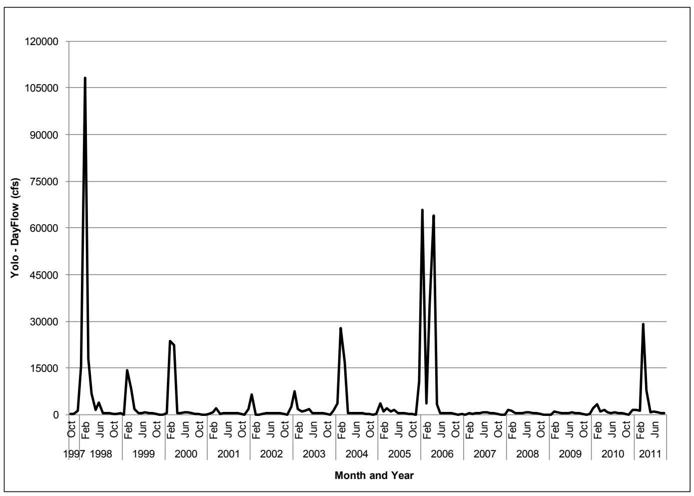

Figure 3 Average monthly Yolo Dayflow WY 1998-2011

The Fremont Weir crested for short periods in 2011 during the months of December, January, and February, causing some localized flooding of the Yolo Bypass, but widespread inundation did not occur until the stage at Lisbon Weir exceeded and maintained ≥ 2.5 m on March 10 – April 22. The flows in the Yolo Bypass during the inundation period (March 10 – April 22) averaged 25,176 (cfs) and peaked on March 26, with estimated flows of 93,354 cfs (Figure 2).

Water Quality

Water Temperature

The extreme hydrologic variability of the Yolo Bypass, with its susceptibility to floodplain inundation, can cause significant differences in the water temperature when compared with the Sacramento River. When the entire Yolo Bypass is inundated, the wetted area of the delta is doubled (Sommer et al. 2001a), and this flooded habitat is made up of large shallow (< 2m) vegetation (Sommer, 2004a). The inundation timing and duration of the Yolo Bypass varies annually, but with longer hydraulic residence times. The increased surface area of the floodplain habitat allows for warmer water temperatures to persist (Sommer et al. 2004b).

In water year 2011, water temperature on the Sacramento River at Sherwood Harbor and Yolo Bypass at Lisbon Weir followed typical seasonal trends, with the highest temperatures occurring in the summer and the lowest temperatures in the late fall and winter (Table 1). However, the Yolo Bypass experienced a greater variation in maximum and minimum water temperatures and this can be attributed to: (1) shallow inundated floodplain, (2) average lower velocity flows, (3) shallower, and narrower channel composition of the Toe Drain.

The March 10 – April 22 floodplain inundation period facilitated a significant increase in the water temperature in the Yolo Bypass as compared to the Sacramento River. The water temperature in the Toe Drain of the Yolo Bypass at Lisbon Weir reached a maximum of 20.8 ˚C on April 17, substantially higher than the Sacramento River, which had a temperature of 14.5 ˚C on the same day. This higher temperature of the Yolo Bypass can be attributed to the extensive flooded shallow water of the Bypass that experienced extended residence time during the forty-four days of estimated inundation and drainage. The warmer temperatures in the Bypass are an important aid in developing higher levels of phytoplankton biomass compared to main river channels (Sommer, 2004a; Montagnes and Franklin, 2001; Jassby, 2000). This improved production of the lower trophic levels provides an improved food supply for two native fishes that utilize the Bypass floodplain for rearing: juvenile Chinook salmon (Sommer, 2001b; Sommer, 2005) and Sacramento splittail (Feyrer, 2006a; Ribeiro et al. 2004).

Table 1 Statistical summary of Yolo Bypass and Sacramento River at Sherwood Harbor water temperature, conductivity, and Secchi depth (Sherwood Harbor conductivity and secchi was not collected Oct. – Dec 2010)

Month	Avg.		Min.		Max.		Std. Dev.	
	Sac	Yolo	Sac	Yolo	Sac	Yolo	Sac	Yolo
Water Temperature (°C)								
Oct	17.1	18.3	13.8	14.7	20.0	22.5	1.7	2.0
Nov	12.7	12.8	9.0	7.2	15.9	17.1	2.1	2.8
Dec	10.6	10.5	8.9	7.0	12.1	13.3	0.9	1.6
Jan	8.9	8.8	7.5	6.1	10.0	11.0	0.8	1.7
Feb	9.5	9.9	7.9	7.7	11.1	12.4	0.8	1.0
Mar	10.4	12.2	8.6	9.4	12.7	14.8	1.1	1.8
Apr	13.3	16.4	12.1	12.2	14.7	20.8	0.6	2.3
May	14.9	19.1	12.8	15.9	16.5	22.1	0.8	1.3
Jun	16.9	22.7	14.0	17.0	19.3	27.9	1.6	3.2
Jul	20.0	26.1	17.5	20.8	21.2	31.4	0.7	2.2
Aug	21.2	24.2	20.6	21.2	21.6	29.0	0.2	1.2
Sept	19.9	22.9	17.6	20.8	21.4	25.5	0.9	0.9
Conductivity (µS/cm)								
Oct	-	567	-	320	-	795	-	175
Nov	-	425	-	359	-	558	-	54
Dec	-	352	-	201	-	421	-	60
Jan	110	478	101	313	119	654	13	137
Feb	121	600	102	428	139	713	26	93
Mar	93	501	79	311	106	611	19	76
Apr	96	515	86	392	104	590	9	71
May	76	565	74	415	77	636	2	53
Jun	77	648	73	400	81	901	4	176
Jul	109	669	90	638	127	697	26	25
Aug	132	842	129	789	136	869	5	46
Sept	134	751	132	699	135	797	2	45
Secchi Depth (m.)								
Oct	-	0.23	-	0.15	-	0.32	-	0.05
Nov	-	0.24	-	0.18	-	0.34	-	0.05
Dec	-	0.27	-	0.18	-	0.70	-	0.11
Jan	0.64	0.24	0.56	0.15	0.72	0.31	0.11	0.04
Feb	0.56	0.23	0.44	0.15	0.69	0.35	0.18	0.04
Mar	0.42	0.24	0.35	0.20	0.49	0.31	0.10	0.04
Apr	0.54	0.26	0.50	0.14	0.57	0.32	0.04	0.05
May	0.94	0.23	0.93	0.15	0.96	0.29	0.02	0.04
Jun	0.87	0.24	0.82	0.13	0.96	0.30	0.08	0.04
Jul	0.91	0.32	0.74	0.20	1.08	0.63	0.24	0.17
Aug	0.86	0.20	0.84	0.12	0.89	0.27	0.04	0.08
Sept	0.87	0.24	0.86	0.20	0.88	0.27	0.01	0.03

Conductivity

Conductivity is used as a surrogate measurement for the seasonal variation of salinity in the water moving through the Yolo Bypass and Sacramento River. The variations in salinity strongly effect the geographic distribution (Bulgar et al. 1993; Nobriga et al. 2008) of several listed and nonlisted fishes of the San Francisco Estuary. The discrete collection of conductance data within the Toe Drain of the Yolo Bypass at the Fyke trap site location and the Sacramento River at Sherwood Harbor occurred upon each site visit throughout the entire 2011 water year. The lowest conductance values occurred in the Toe Drain during March and this is likely due to the inundation by the Sacramento River at Fremont Weir (Table 1). During this same time period the conductance in the Sacramento River at Sherwood was equivalent. The variation in conductance values observed in water year 2011 in the Toe Drain of the Bypass is likely due to the influence of local tributaries and the timing of floodplain drainage and agricultural practices (Sommer, 2004a).

Secchi Depth

The collection of seasonal variation in water clarity conditions in the Yolo Bypass as compared to the Sacramento River was measured using secchi depth. Secchi depth was recorded at the fyke trap site and beach seine sites in the Toe Drain throughout the year and in the Sacramento River at Sherwood Harbor during lower trophic sampling January – September 2011. The average water clarity in the Toe Drain (0.23 m) is substantially lower than Sacramento River (0.73 m) year-round (Table 1). Lower water clarity is representative of a seasonally dynamic and abiotically-driven environment such as the Yolo Bypass. The seasonal hydrologic variability of the Yolo Bypass can cause reduced water clarity through increased suspended particle concentrations and higher fluctuating temperatures that can increase algal biomass (Sommer et al. 2004a). Low water clarity has shown to be beneficial to key fish species in the Delta, such as the delta smelt (Nobriga, 2008).

Chlorophyll

The chlorophyll-*a* concentrations on the Sacramento River at Sherwood Harbor reached a maximum of 4.66

μg/L on April 6 and a minimum of 1.05 μg/L on January 12 (Figure 4). The chlorophyll-*a* concentration had an overall standard deviation from the mean of 0.85 μg/L. In comparison, the Toe Drain of the Yolo Bypass at the rotary crew trap reached a maximum chlorophyll-*a* concentration of 162.34 μg/L on April 6 and a minimum concentration of 3.17 μg/L on January 12 (Figure 4). The chlorophyll-*a* concentration had an overall standard deviation of the mean of 34.71 μg/L. In the Toe Drain, seven samples were collected with chlorophyll-*a* concentrations that were > 10 μg/L, compared to the Sacramento River site, where no samples were collected with values exceeding 5 μg/L.

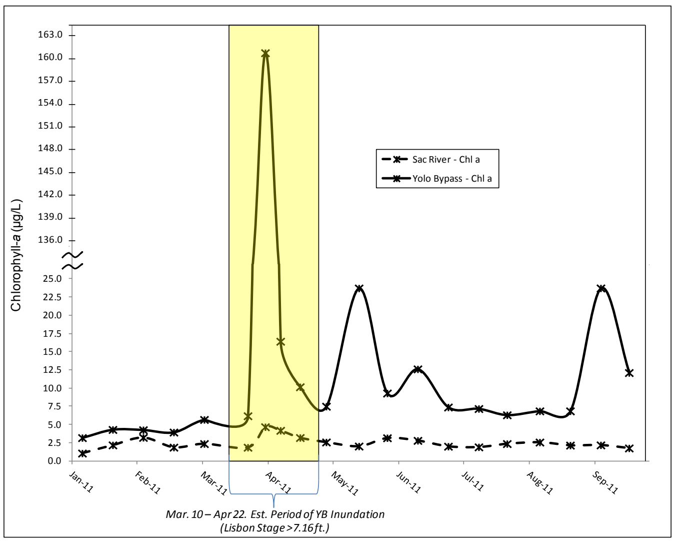

Figure 4 Chlorophyll-*a* concentration Jan. – Sept. 2011 at Toe Drain of Yolo Bypass and Sacramento River

The substantially lower values of chlorophyll-*a* in the Sacramento River are consistent with previous analyses comparing the Yolo Bypass with the Sacramento River (Sommer et al., 2004a), and a likely a result of longer residence times, greater shallow water surface area, and warmer water temperatures. However, the highly elevated concentration of chlorophyll-*a* concentration sampled on April 6 in the Toe Drain (Figure 4) is much higher than any samples taken Delta-wide by the Environmental Monitoring Program in 2010-11 (maximum value of 59.2 μg/L (T. Brown, DWR, personal communication). While these instances of elevated chlorophyll-*a* concentrations are outstanding, they are not unprecedented in our sampling history in the Yolo Bypass: a similar spike in chlorophyll-*a* concentration in the Bypass also occurred on March 30, 2010, when the concentration reached 159 μg/L. The cause of these elevated chlorophyll-*a* levels in the Yolo Bypass is not well-understood; however, it is possible that rapid and prolific phytoplankton production is favored during periods of warm temperatures in shallow floodwaters. In addition, inputs from agricultural drainage and small west-side tributaries may contribute to local peaks in phytoplankton production. While these observations are important given that floodplains may subsidize productivity in neighboring systems (Junk et al., 1989), we do not fully understand why these instances of elevated chlorophyll-*a* values are so short-lived, what species of phytoplankton contribute to them, or what causes their occurrence. Increases in the spatial and temporal frequency of sampling will aid in the understanding of conditions in the Bypass that support periods of high phytoplankton production.

In addition to the spring peak in chlorophyll-*a*, elevated levels were also observed in May and September of 2011. While these events did not coincide with flooded conditions, they may result from agricultural drainage events in Yolo Bypass. In particular, the September event coincided with elevated flows in the Bypass resulting from rice field drainage. Shortly after this event, a phytoplankton bloom occurred in the lower Sacramento River. Isotopic studies indicated that the bloom came largely from the Cache Slough corridor of which Yolo Bypass is a part (C. Kendall, USGS, 2012 IEP Workshop oral presentation). These observations from separate studies suggest a critical role of the Yolo Bypass in supporting productivity in downstream locations; however, increased sampling will be necessary to understand if and how agricultural drainage indeed contributes to elevated chlorophyll-*a* concentrations.

Fish

More than 40 fish species were sampled during the course of all fish sampling activities in water year 2011, 16 of which are native to the San Francisco Estuary region (Table 2). The total catch of fish species from Yolo Bypass was dominated by the nonnative Mississippi silverside (*Menidia beryllina*), with 15,757 sampled. The high catch of nonnative inland silversides in the Yolo Bypass is not surprising as they have become one of the most abundant fishes in the shallow-water habitats throughout the estuary (Moyle, 2002). In addition, the high catch in the beach seine effort in 2011 (Table 1) is consistent with high catch per unit effort (CPUE) in the favorable shallow perennial

Table 2 Species catch summarized by gear type for the 2011 WY. Sorted by descending order of total catch.

Species	*Screw Trap*	*Fyke Trap*	*Beach Seine*	*Total Catch*
Mississippi Silverside	4,593 (25.37%)	0	11,164 (45.62%)	15,757
Splittail	11,295 (62.39%)	204 (10.25%)	1,193 (4.87%)	12,692
Threadfin Shad	311 (1.72%)	16 (0.8%)	3,572 (14.6%)	3,899
Bluegill	8 (0.04%)	1 (0.05%)	2,077 (8.49%)	2,086
Western Mosquitofish	74 (0.41%)	0	1,472 (6.01%)	1,546
Bigscale Logperch	0	0	1,507 (6.16%)	1,508
White Catfish	37 (0.2%)	910 (45.71%)	482 (1.97%)	1,429
Striped Bass	985 (5.44%)	321 (16.12%)	119 (0.49%)	1,425
Black Crappie	32 (0.18%)	26 (1.31%)	1128 (4.61%)	1,186
Shimofuri Goby	9 (0.05%)	0	503 (2.06%)	512
American Shad	321 (1.77%)	54 (2.71%)	23 (0.09%)	398
Common Carp	13 (0.07%)	250 (12.56%)	131 (0.54%)	394
Chinook Salmon	202 (1.12%)	3 (0.15%)	78 (0.32%)	283
Sacramento Pikeminnow	8 (0.04%)	6 (0.3%)	145 (0.59%)	159
Largemouth Bass	3 (0.02%)	0	128 (0.52%)	131
Tule Perch	0	0	112 (0.46%)	112
Sacramento Blackfish	1 (0.01%)	20 (1%)	88 (0.36%)	109
Threespine Stickleback	106 (0.59%)	0	2 (0.01%)	108
Prickly Sculpin	15 (0.08%)	0	92 (0.38%)	107
Fathead Minnow	6 (0.03%)	0	100 (0.41%)	106
Channel Catfish	4 (0.02%)	91 (4.57%)	9 (0.04%)	104
White Crappie	6 (0.03%)	14 (0.7%)	74 (0.3%)	94
Sacramento Sucker	4 (0.02%)	35 (1.76%)	25 (0.1%)	64
Yellowfin Goby	22 (0.12%)	0	37 (0.15%)	59
Hitch	2 (0.01%)	1 (0.05%)	42 (0.17%)	45
Delta Smelt	15 (0.08%)	0	24 (0.1%)	39
Redear Sunfish	0	0	38 (0.16%)	38
Warmouth	3 (0.02%)	0	27 (0.11%)	30
Golden Shiner	3 (0.02%)	0	23 (0.09%)	26
Black Bullhead	0	5 (0.25%)	16 (0.07%)	21
White Sturgeon	0	20 (1%)	0	20
Pacific Staghorn Sculpin	9 (0.05%)	0	10 (0.04%)	19
Hardhead	1 (0.01%)	3 (0.15%)	6 (0.02%)	10
Pumpkinseed Sunfish	1 (0.01%)	0	8 (0.03%)	9
Yellow Bullhead	0	4 (0.2%)	4 (0.02%)	8
Brown Bullhead	0	4 (0.2%)	3 (0.01%)	7
Pacific Lamprey	5 (0.03%)	0	0	5
Goldfish	0	2 (0.1%)	1 (0%)	3
Green Sunfish	0	0	3 (0.01%)	3
Rainwater Killifish	3 (0.02%)	0	0	3
Red Shiner	0	0	3 (0.01%)	3
River Lamprey	3 (0.02%)	0	0	3
Spotted Bass	0	0	3 (0.01%)	3
Lamprey Unknown	2 (0.01%)	0	0	2
Rainbow / Steelhead Trout	1 (0.01%)	1 (0.05%)	0	2
Wakasagi	1 (0.01%)	0	1 (0%)	2
Longfin Smelt	1 (0.01%)	0	0	1
Grand Total	18,105	1,991	24,473	44,570

channels and ponds of the Yolo Bypass that has been observed historically (Feyrer, 2004; Feyrer, 2006a; Nobriga, 2005). Sacramento splittail was the second-most abundant species captured, while other native species included Chinook salmon, Sacramento pikeminnow (*Ptychocheilis grandis*), tule perch (*Hysterocarpus traski*), Sacramento blackfish (*Orthodon microlepidotus*), and delta smelt.

Sacramento Splittail

The total catch of Sacramento splittail in water year 2011 was the highest total on record (Figure 5), at 12,692 (Table 2). The majority of this total was comprised of the juvenile catch in the rotary screw trap. In an effort to account for the significant gap in screw trap operation March 20 – April 27, as well as gaps in operation in other years, we estimated the total hours of rotary screw trap operation for each sampling year, and compared the number of splittail caught per sampling hour among years (Figure 5). Even after accounting for the loss of the rotary screw trap for over a month in the spring, 2011 still had the highest number of splittail caught per hour among all years sampled. The timeframe of juvenile splittail catch in the Yolo Bypass can occur as early as mid-April and continues through June, but is variable and largely affected by hydrologic conditions. The success of splittail in water year 2011 is supported by the presence of two key elements: 1) the occurrence of early pulse flows in winter (December-January) to bring up spawning adults, and 2) the extended duration of floodplain inundation in Yolo Bypass for splittail spawning and rearing (Harrell, 2003; Feyrer, 2006b). These two elements are the driving factors for the overall splittail year-class strength in the Yolo Bypass (Sommer, 1997; Sommer, 2007). The importance of extensive floodplain inundation in splittail spawning and recruitment is supported by the highest catch rates of juveniles in the rotary screw trap having occurred during the wettest of sampling years (1998, 2006, 2011), since rotary screw trap operation began in 1998 (Figure 5).

High-Flow Beach Seine Catch

In water year 2011 and during other years of extended floodplain inundation, the Yolo Bypass Fisheries Program increases the beach seine effort to include four additional sites (Figure 1). These sites are sampled to improve the spatial monitoring of fish use of the available shallow-water floodplain habitat. The Chinook salmon is one of the key migratory Central Valley juvenile fishes with documented survival and growth benefits during floodplain inundation (Sommer, 2001b; Sommer, 2005). Though the total catch of fish species at the four high flow sites during the six weeks of sampling was dominated by non-natives, there was a consistent catch of juvenile Chinook salmon at the upper most beach seine site below Fremont Weir (FW1) during the inundation period (Table 3). This weekly catch presence of Chinook salmon below Fremont Weir provides evidence of young salmon from the Sacramento River using the alternate path of the Yolo Bypass floodplain for outmigration. Through future acoustic telemetry studies, it is expected that these juvenile salmon will spread throughout the broad floodplain rearing in the variety of vegetated habitat types in an effort to maximize growth for survival (Sommer, 2001a; Sommer, 2005).

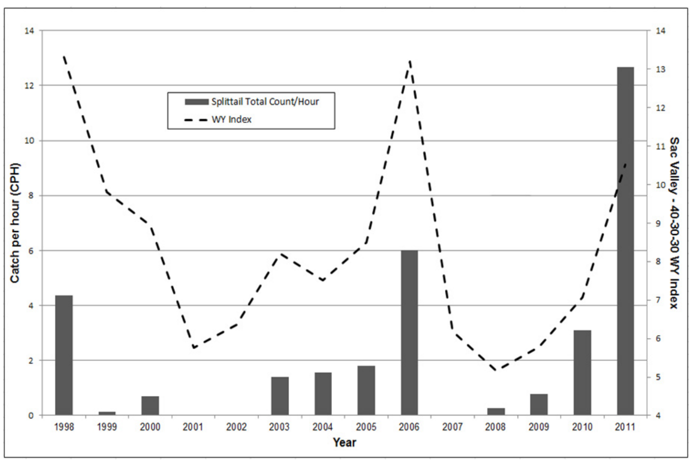

Figure 5 Rotary screw trap total juvenile splittail catch by year since the inception of Yolo Bypass monitoring program

Future Work

In spring of 2012 the DWR, UC Davis, and USBR will be starting the DFW-funded Ecosystem Restoration (ERP) project entitled: Evaluation of Floodplain Rearing and Migration in the Yolo Bypass. This project uses acoustic telemetry technology to understand movement patterns of adult salmon and sturgeon, as well as juvenile salmon migration patterns and residence times in the Yolo Bypass, genetics to determine run classifications of Chinook salmon that use the Bypass, and investigates the possibility of an isotopic signature of Bypass residence on the otoliths of juvenile salmon. In addition, the project supports the analysis of over a decade of data on lower trophic organisms and juvenile salmon usage of the Bypass.

Table 3 Species catch summarized by high flow beach seine site location for the 2011 WY. Sorted by descending order of total catch.

Species	*CCS*	*FW1*	*LIHF*	*YBI80*	*Total Catch*
Inland Silverside	5 (9.8%)	5 (2.2%)	567 (80.8%)	702 (47.5%)	1279
Western Mosquitofish	18 (35.3%)	144 (63.4%)	31 (11.3%)	587 (39.7%)	780
Bluegill	6 (11.8%)	17 (7.49%)	79 (11.3%)	15 (1.0%)	117
Threadfin Shad			7 (1.0%)	62 (4.19%)	69
Sacramento Pikeminnow			7 (1.0%)	52 (3.51%)	59
Fathead Minnow	8 (15.68%)	1 (0.44%)	3 (0.43%)	35 (2.37%)	47
Chinook Salmon	3 (5.88%)	17 (7.49%)	1 (0.14%)		21
Largemouth Bass		19 (8.37%)	2 (0.29%)		21
Sacramento Blackfish	3 (5.88%)	3 (1.32%)	1 (0.14 %)	12 (0.81%)	19
Golden Shiner		5 (2.2%)		7 (0.47%)	12
Black Crappie	2 (3.92%)	5 (2.2%)	2 (0.29%)	1 (0.07%)	10
Pumpkinseed Sunfish	3 (5.88%)	2 (0.88%)		3 (0.2%)	8
Splittail		4 (1.76%)			4
Redear Sunfish	2 (3.92%)	1 (0.44%)			3
Sacramento Sucker	1 (1.96%)	1 (0.44%)			2
White Crappie		1 (0.44%)	1 (0.14%)		2
Bigscale Logperch		1 (0.44%)			1
Brown Bullhead				1 (0.07%)	1
Common Carp				1 (0.07%)	1
Wakasagi		1 (0.44%)			1
Warmouth			1		1
Grand Total	51	227	702	1478	2458

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Delta Smelt Captive Refuge Population Update

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Introduction and Overview of Refuge Population

Following alarmingly low abundance estimates of the delta smelt *Hypomesus transpacificus*, a captive refuge population was initiated in 2008 at the Fish Culture Conservation Laboratory (FCCL) - University of California, Davis (UC Davis) (Fisch et al. 2009, 2010, 2012). In collaboration with the Genomic Variation Laboratory (GVL) – UC Davis, the refuge population is genetically managed and monitored with specific objectives to minimize genetic drift from the wild population, minimize inbreeding, and maintain the genetic diversity of the captive population (Fisch et al. in press). The goal of the delta smelt breeding program is to maintain a captive population that is genetically representative of the wild population as a safeguard in the event of species extinction.

The founder generation (F_0) of the captive refuge population consisted of 164 pair crosses from wild-caught individuals. The recovery of the founder alleles is important in maintaining the genetic diversity of the captive refuge population and is an integral component of the delta smelt breeding program. Offspring from select pair crosses (one male and one female) create a full sibling group (FSG), and 750 eggs from each of eight FSGs are reared together forming a multi-family group (MFG). The recovery of individuals from each of the eight FSGs comprising a MFG is assessed in each generation. Prior to the beginning of the spawning season (January – May), fish that are becoming sexually mature are tagged (unique alpha numeric tags) and simultaneously fin-clipped for genetic analysis at the GVL according to the methods described previously (Fisch et al. 2009, 2010, 2012a, 2012b). Using the microsatellite genotypes of individuals, a pedigree is reconstructed and pairwise kinship values are calculated. Select pair crosses (one male and one female) are then made with the aim to minimize average coancestry, minimize inbreeding and maintain an equal representation of founder alleles in the captive population using a modified method of minimal kinship selection (Fisch et al. 2012b). Wild caught fish are also spawned and incorporated into the captive refuge population. This allows gene flow from the wild delta smelt population into the captive refuge population and aids in maintaining the genetic diversity of the captive population. To date, the delta smelt captive refuge population has progressed to the fifth generation (F_5).

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2012 Season Summary and Update

Tagging

Tagging of the wild and captive delta smelt population initiates the spawning processes each year. The tagging strategy for 2012 was to tag 20 individuals (10 females and 10 males) from each multi-family group, and then continue to tag the multi-family groups throughout the spawning season until individuals from all the desired 2011 FSGs were "recovered," i.e. identified offspring from all the 2011 families. A total of 2,288 fish were tagged over the 2012 season. During the 2012 season two multi-family groups (eleven and twelve) were diagnosed with mycobacteriosis in early January, and as a precaution these two MFGs were not tagged or spawned and were later euthanized as advised by our UC Davis veterinarian. Although this was the first significant outbreak of the disease, the number of fish showing symptoms of the disease were quite low (1.2% over the spawning season), and it did not spread quickly to the other fish. Therefore the disease appears to be manageable. The FCCL has been working with the veterinarian to develop best management practices for mycobacteriosis.

In order to evaluate and summarize the last two spawning seasons, the tagged broodfish pools were compared in terms of the number of individuals tagged from each multi-family group, the female to male ratio of fish tagged, the recovery of the eight full sibling groups in each multi-family, and the number of recovered fish that were successfully spawned from each FSG (Figure 1). In general, more fish were tagged from each MFG in 2012 than 2011, in part due to the two multi-families lost to disease. There were also a higher number of males tagged than females from MFGs in 2012 than 2011. The tagging strategy of tagging more males than females has developed over the past few seasons. The males tend to remain in spawning condition continuously, as opposed to females that are only periodically available to mate. A larger pool of tagged males results in (1) improved flexibility to minimize kinship values when selecting mates for the ripe females, and (2) the potential to increase recovery percentages because the tagged males are readily available to spawn.

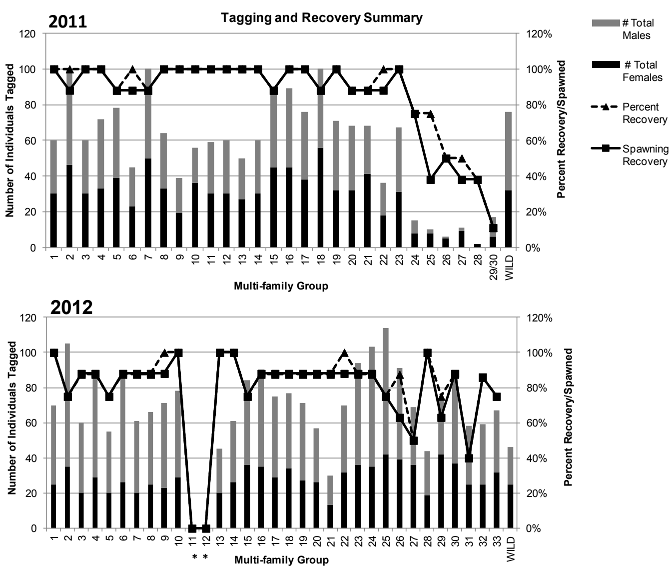

Figure 1 Number of individuals tagged from each multi-family group (black is the proportion female, and grey is the proportion male), the recovery of individuals in the tagged broodfish pool (solid black line, 100% = at least one fish from each of the 8 parental pair crosses is recovered as an adult), and the spawned recovery (dotted black line). Asterisked (*) multi-families indicate those that were lost to disease in 2012.

Recovery

Each year the recovery of the offspring from pair crosses made in the previous season is assessed (where recovery is limited to fish from the tagged broodfish pool). Of the 256 pair crosses made in the 2011 spawning season, individuals were recovered from 206 of these pair crosses resulting in an overall recovery in our tagged broodfish pool of 80%. Recovery of individuals from each of the eight FSGs in a MFG is also calculated, i.e. 100% recovery in a MFG is achieved when at least one individual was tagged from each FSG (Figure 1).

In recent years, families that were spawned later in the season commonly had poor recovery due to low survival rates. These fish were also younger, generally smaller, and matured later in the spawning season, which also impacted the recovery (Fisch et al. 2010). In an effort to increase the recovery of the later MFGs, the younger fish (e.g., those with higher multi-family group numbers) were kept at warmer temperatures (16 °C) approximately one month longer to help promote growth and maturation. Comparing the spawning summaries for both years, it appears that this change in rearing methodology did help the recovery of those younger multi-family groups (Figure 1). The recovery percentages for the later MFGs were not only higher in 2012 than 2011, but more individuals became sexually mature from the younger multi-families and were able to be included in the tagged broodfish pool. This summary also highlights that while individuals may have been recovered from the full-sibling groups in the multi-family, the recovered individuals are not always available to spawn either due to the timing of the fish becoming ripe or gravid, the quality of the eggs and milt, mortality of given individuals, or they may have not spawned successfully.

Spawning

The 2012 spawning season began on February 3rd, 2012 and concluded on May 29th, 2012, during which the F_4 adults were spawned to produce the F_5 generation. In the 2012 season, 281 pair crosses were made, including a total of 45 wild caught fish creating the F_5 generation. During each spawning season considerable effort is made to maintain the genetic diversity by minimizing mean kinship and maximizing the retention of the founder generation alleles in the population. This year, there were twenty-three families in the parental F_4 generation whose alleles were over-represented in our population and therefore no individuals from these families were spawned. Excluding those twenty-three pair crosses, 196 of the initial parental F_4 233 pair crosses (including the 16 lost to disease) were successfully spawned, resulting in an 84% spawned recovery for the season. Additionally, four FSGs in one of the euthanized MFGs were from wild x wild pair crosses. In an effort to recover these FSGs, five two-year-old wild fish (retained at the facility) from this MFG were spawned with 1-year-old cultured fish. The recovery of these five respawned FSGs will be assessed in the 2013 spawning season.

Genetic Monitoring

Genetic diversity indices of the captive F_4 generation and supplemental wild fish were estimated to assess and monitor the delta smelt refuge population (Fisch et al. 2010; Fisch et al. 2012b). A total of 328 alleles were scored across the 12 loci genotyped, and the allelic richness (A_R) ranged from 6.48 to 39.37 alleles across all loci (Table 1). The mean expected heterozygosity (H_E), including the wild-caught fish spawned into the population, was 0.845 and ranged between 0.484 - 0.957 (Table 1). Population pairwise comparisons of Wright's Fixation Index, F_{ST} (Wright 1951), a measure of genetic differentiation, did not reveal any significant differentiation between the F_4 generation and any of the previous generations (Table 2).

Table 1 The allelic diversity and heterozygosity of the F_4 generation of captive delta smelt at 12 microsatellite loci. For each of the 12 loci, indicated is the number of individuals genotyped (N), the number of alleles (A), the allelic richness (AR), the averaged allelic richness for each locus including all generations, the observed heterozygosity (H_o), and the expected heterozygosity (H_e)

F4 Generation						
Locus	***N***	***A***	***AR***	***Average AR over all generations***	***Ho***	***He***
Htr103	505	31	23.88	20.05	0.90	0.90
Htr104	543	09	07.74	09.53	0.48	0.48
Htr109	504	16	14.14	16.45	0.91	0.88
Htr114	513	26	25.01	26.87	0.91	0.94
Htr115	543	26	23.55	23.56	0.87	0.93
Htr116	535	07	06.48	08.24	0.53	0.51
Htr117	454	21	18.74	20.15	0.90	0.92
Htr119	529	47	39.37	36.81	0.94	0.95
Htr120	546	43	35.12	26.00	0.86	0.87
Htr126	504	41	33.85	31.48	0.89	0.95
Htr127	539	32	30.20	32.28	0.91	0.96
Htr131	528	29	27.26	27.31	0.94	0.95
Average		27.3	23.78	23.23	0.84	0.85

Table 2 The lower diagonal is the F_{ST} values for each generation, and the upper diagonal are the associated p-values

	F0	***F1***	***F2***	***F3***	***F4***
F0	-	0.999	0.308	0.052	0.107
F1	-0.010	-	0.999	0.999	0.999
F2	0.000	-0.010	-	0.946	0.826
F3	0.001	-0.008	0.000	-	0.980
F4	0.001	-0.007	0.000	-0.001	-

Conclusions

The overall recovery for the 2012 season (84%) was quite good given the loss of the sixteen FSGs to disease. Recovery of individuals in the higher numbered MFGs (younger fish) improved over similar aged groups in 2011, and can most likely be attributed to the changes in rearing methodology which helped promote the growth and maturation in these fish. Additionally, the new tagging method of tagging more males than females, allows more flexibility when choosing a mate for a sexually mature female.

Maintaining the genetic diversity of the captive delta smelt population and ensuring that genetic drift from the wild population does not occur are important objectives of the captive delta smelt population breeding program. To date, the captive refuge population has maintained the genetic diversity of the founding wild population, and future generations will continue to be managed following the same conventions and methods.

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