Interagency Ecological Program
COOPERATIVE ECOLOGICAL INVESTIGATIONS SINCE 1970

IEP NEWSLETTER

VOLUME 34, NUMBER 1, 2019

Contents

Of Interest to Managers

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1. **Geir Aasen (CDFW)** summarizes the fish salvage during the 2018 water year at fish facilities managed by the State Water Project and the Central Valley Project. This report uses historical salvage data from 1981 until present for context, focusing primarily on the salvage of Chinook Salmon and Steelhead, Striped Bass, Delta Smelt, Longfin Smelt, Sacramento Splittail, and Threadfin Shad. The article highlights the complex relationship between climatic events and fish abundance, with the salvage of Chinook, Striped Bass, and Splittail generally increasing along with greater rainfall in water years 2017 and 2018 while the salvage of other species of focus did not increase.
2. **Rosemary Hartman (formerly CDFW, now CDWR)** examines the tidal and diel patterns of zooplankton abundance in the San Francisco Estuary to better inform zooplankton sampling efforts. By sampling zooplankton abundance regularly over 24-hour periods, the study found significantly more copepods at night than during the day at all tidal states. Statistical models suggest that this is a result of diel vertical migration of zooplankton in general, with calanoid copepods driving tidal vertical migrations. Interestingly, no difference was observed between zooplankton trawls conducted in wetland trawls compared to channel trawls.
3. **Trishelle Tempel (CDFW)** reports on the 2018 Spring Kodiak Trawl Survey (SKT), which is conducted yearly to determine the distribution and relative abundance of adult Delta smelt in the upper San Francisco Estuary. This year's survey found historically-low numbers of Delta smelt, as only 15 adult smelt and a single juvenile were collected across all 40 stations sampled. The presence of only a single Delta smelt in the SKT catch in the Sacramento Deepwater Ship Channel was particularly noteworthy, as the historical average for smelt at this site is 144, with a previously low of 14.

The IEP Newsletter is a quarterly publication that provides IEP program and science highlights as well as in-depth articles on important scientific topics for resource managers, scientists, and the public. Articles in the IEP newsletter are intended for rapid communication and do not undergo external peer review; all primary research results should be interpreted with caution.

If you would like to be notified about new issues of the quarterly IEP newsletter, please send an e-mail to Sarah Lesmeister (DWR), sarah.lesmeister@water.ca.gov, with the following information:

- Name
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Article Submission Deadlines for this Calendar Year

Issue	*Article Submission Deadline*
Issue 1 (Winter)	January 15
Issue 2 (Spring)	April 15
Issue 3 (Summer)	July 15
Issue 4 (Fall)	October 15

Submit articles to Sarah Lesmeister

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Contributed Papers

Fish Salvage at the State Water Project's and Central Valley Project's Fish Facilities during the 2018 Water Year

Geir Aasen (CDFW), Geir.Aasen@wildlife.ca.gov

Introduction

Two facilities mitigate fish losses associated with water export by the federal Central Valley Project (CVP) and California's State Water Project (SWP).
The CVP's Tracy Fish Collection Facility (TFCF) and the SWP's Skinner Delta Fish Protective Facility (SDFPF) divert (salvage) fish from water exported from the southern end of the Sacramento-San Joaquin Delta located in Byron, California (Aasen 2013). Both facilities use louver-bypass systems to divert fish from the exported water. The salvaged fish are periodically loaded into tanker trucks and transported to fixed release sites in the western Delta. Operations began in 1957 at the TFCF and in 1968 at the SDFPF.

This report summarizes salvage information from the 2018 water year (WY) for both the TFCF and the SDFPF while examining data from water years (WYs) 1981 to 2018 for salvage trends over time, emphasizing recent years. The following species were given individual consideration: Chinook Salmon (*Oncorhynchus tshawytscha*), Steelhead (O. mykiss), Striped Bass1 (Morone saxatilis), Delta Smelt1 (Hypomesus transpacificus), Longfin Smelt1 (Spirinchus thaleichthys), Splittail (Pogonichthys macrolepidotus), and Threadfin Shad1 (Dorosoma petenense).

Methods

Systematic sampling was used to estimate the numbers and species of fish salvaged at both facilities. Bypass flows into the fish-collection buildings were sub-sampled generally once every 1 or 2 hours for 1 to 60 minutes (mean= 27.74, sd = 6.42) at the SDFPF and generally once every 2 hours for 30 to 80 minutes (mean = 30.02, sd = 0.91) at the TFCF. Fish with a fork length (FL) of 20 mm or larger were identified, counted, and measured. These fish counts were expanded to estimate the total number of fish salvaged in each 1- to 2-hour period of water export. For example, a subsample duration of 30 minutes over an export period of 120 minutes gives an expansion factor of 4, which is then multiplied by the number of fish per species collected during the fish count. These incremental salvage estimates were then summed across time to develop monthly and annual species- salvage totals for each facility.

The loss of Chinook Salmon is estimated from the number of juvenile Chinook Salmon entrained by the facility less the number of Chinook Salmon that survive salvage operations (California Dept. of Fish and Wildlife 2013). Salmon salvage and loss were summarized by origin (i.e., hatchery fish defined as adipose fin clipped or wild fish defined as non-adipose fin clipped) and race (fall, late-fall, winter, or spring). Race of Chinook Salmon was initially determined by the Delta criteria based on length at date of salvage (California Dept. of Fish and Wildlife 2014). If Coded Wire Tag (CWT) information was available, the race of hatchery Chinook Salmon was updated. If DNA race information was available, the race of wild Chinook Salmon was updated. The Delta criteria was created by the U.S. Fish and Wildlife Service who further modified the California Department of Water Resources's own modified Larval fish were also collected and examined for version of the Fisher Model by changing the upper and lower boundaries for winter-run Chinook Salmon (Matt Dekar, personal communication, see "Notes"). Apparent growth rates and size ranges vary among races, however, leading to potential misclassification with the Delta criteria (Harvey and Stroble 2013). Consequently, a change was made to use CWT tag race in WY 2017 and DNA race in 2018.

Larval fish were also collected and examined for the presence of Delta Smelt and Longfin Smelt with a FL of <20 mm. Larval sampling in WY18 ran from March 29 through June 26 at the SDFPF and from March 29 through June 25 at the TFCF. Larval samples were collected once for every 6 hours of water export. The duration of larval sampling was the same as for counts. To retain these smaller fish, the fish screen used in the routine counts was lined with a 0.5 mm Nitex net. Larval fish from the TFCF were identified to the species level by TFCF personnel, while larval fish from the SDFPF were identified to the lowest taxa possible by California Dept. of Fish and Wildlife personnel.

Water Exports

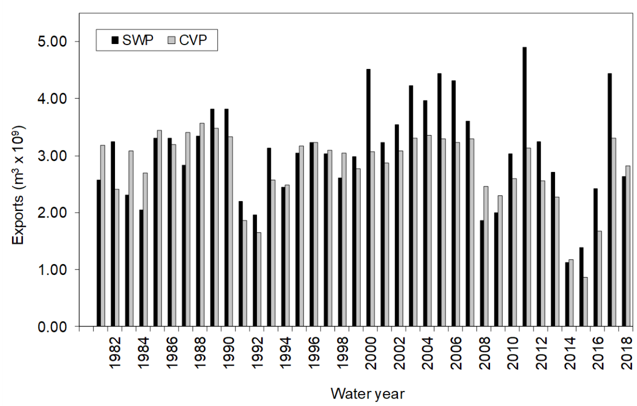
The SWP exported 2.63 billion m3 of water which was a marked decrease from WY 2017 (4.44 billion m3), but an increase from WY 2016 (2.43 billion m3), WY 2015 (1.38 billion m3), and the record low exports in WY 2014 (1.12 billion m3; Figure 1). The CVP exported 2.83 billion m3 of water which was a decrease from WY 2017 (3.31 billion m3), but an increase from WY 2016 (1.68 billion m3), WY 2015 (0.86 billion m3, a record low), and WY 2014 (1.17 billion m3). Exports in WY 2018 at SWP was below the WYs 1981-2017 average (3.09 billion m3) and near equal at CVP (2.80 billion m3).

Exports at the SWP peaked in August-September 2018 (Figure 2). During these periods, the SWP exported 870 million m3, which represented 33% of the total annual export. Exports at the CVP peaked in October 2017 and August 2018. The cumulative water export for those months was 653 million m3, which represented 23% of the annual export. SWP monthly exports ranged from 57 to 436 million m3. CVP monthly exports ranged from 126 to 331 million m3. The pattern of monthly export at both facilities generally follow the same trend year-to-year with higher exports occurring from summer through winter and the lowest exports occurring in spring.

Total Salvage and Prevalent Species

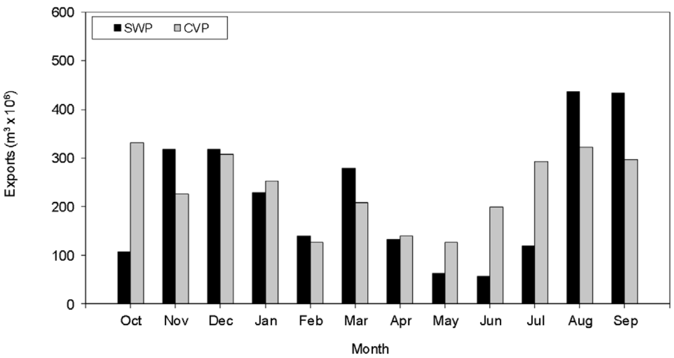
Total fish salvage (all fish species combined) at the SDFPF was 1,041,003 (Figure 3). This was a marked decrease from WY 2017 (2,104,742) and WY 2016 (2,832,631), but a large increase from WY 2015 (347,882) and the record low in WY 2014 (236,846). Total fish salvage at the TFCF was 1,432,489. This was a decrease from WY 2017 (2,061,133) and

Figure 1 Annual water exports in billions of cubic meters for the SWP and the CVP, WYs 1981 to 2018.



WY 2016 (1,437,551), but a large increase from WY 2015 (295,854) and the record low in WY 2014 (160,681). In general, total fish salvage has been influenced by exports in recent years (i.e. higher salvage at higher exports). However, this trend was not found at the SDFPF in the last three years where total fish salvage was higher in WY 2016 than in WY 2018 and WY 2017 despite lower exports.

Figure 2 Monthly water exports in millions of cubic meters for the SWP and the CVP, WY 2018.



Threadfin Shad was the most-salvaged species at both the SDFPF and TFCF (Figure 4 and Table 1). American Shad (*Alosa sapidissima*) and Prickly Sculpin (*Cottus asper*) were the 2nd and 3rd most salvaged fish at SDFPF, respectively. American Shad and White Catfish (*Ameiurus catus*) were the 2nd and 3rd most-salvaged fish at TFCF, respectively. Native species comprised 5.4% of total fish salvage at SDFPF and 2.9% of total fish salvage at TFCF. This was a large decrease from WY 2017 at both the SDFPF (19.5%) and the TFCF (22.1%) which was attributable to increased salvage of Splittail in WY 2017. Relatively few listed species (e.g., Chinook Salmon, Steelhead, and Longfin Smelt) were salvaged at the SDFPF (0.7% combined of total fish salvage). This was a slight decrease from WY 2017 when listed species comprised 1.1% of salvage. Relatively few listed species including Chinook Salmon, Steelhead, and Delta Smelt were salvaged at the TFCF (1.1% combined of total fish salvage). This was equal to WY 2017 when listed species also comprised 1.1% of salvage.

Figure 3 Annual salvage of all fish taxa combined at the SDFPF and the TFCF, WYs 1981 to 2018.

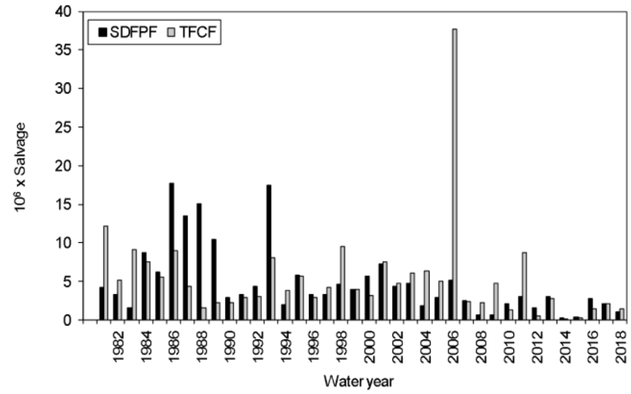
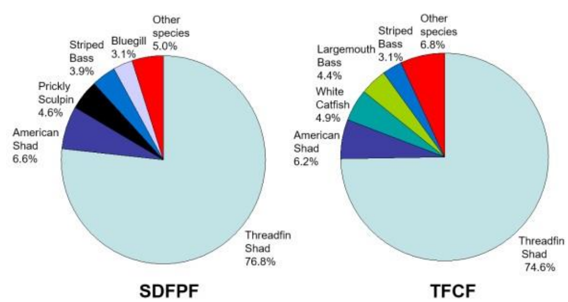


Figure 4 Percentages of annual salvage for the 5 most prevalent fish species and other fish species combined at the SDFPF and TFCF, WY 2018.



Chinook Salmon

Annual salvage estimates of Chinook Salmon (all races and origins combined) at both facilities increased from the low salvage trend seen during drought years 2012-2016 (Figure 5). Salvage of juvenile and large (>300 mm FL) Chinook Salmon (5,964) at SDFPF was less than that in WY 2017 (23,118), but well above salvages in both WY 2016 (362) and WY 2015 (221). Mean salvage for Chinook Salmon in WYs 2001-2018 at SDFPF was only 9.0% of the mean salvage in WYs 1981-2000. Salvage of juvenile and large (>300 mm FL) Chinook Salmon at the TFCF (14,315) was a decrease from WY 2017 (23,633), but a large increase from WY 2016 (970) and the record low in WY 2015 (187). Mean salvage for WYs 2001-2018 was only 10.9% of the mean salvage for WYs 1981-2000.

Salvaged Chinook Salmon at the SDFPF were primarily wild spring run sized fish, which comprised 59.4% of wild fish (Table 2). Salvaged Chinook Salmon at the TFCF were primarily wild, fall run-sized fish, which comprised 54.1% of wild fish caught. Wild spring run fish at the SDFPF were salvaged in March-May with the majority salvaged in April (2,167) while wild fall run fish at the TFCF were salvaged in February-June with the majority salvaged in May (4,027).

Annual loss of Chinook Salmon (all origins and races) was higher at the SDFPF (25,646) than at the TFCF (10,153; Table 2). Greater entrainment loss at the SDFPF than at the TFCF was attributable to greater pre-screen loss (Bob Fujimura, personal communication, see "Notes").

Figure 5 Annual salvage of Chinook Salmon (all races and wild and hatchery origins combined) at the SDFPF and the TFCF, WYs 1981 to 2018. The logarithmic scale is log10.

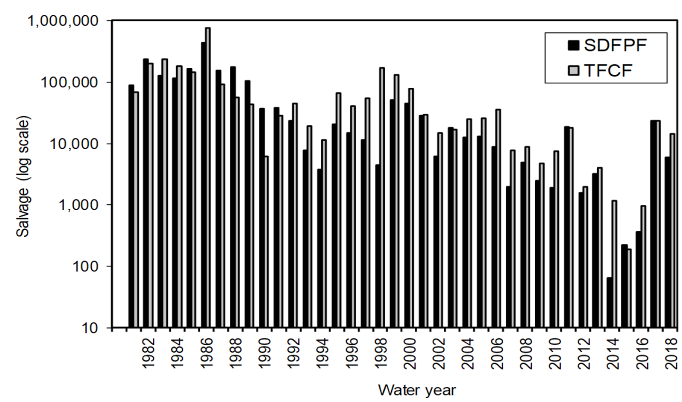


Table 1. Annual fish salvage and percentage of annual fish salvage (%) collected from the SDFPF and TFCF in WY2018.

SDFPF			*TFCF*		
Species	***Salvage***	***%***	***Species***	***Salvage***	***%***
Threadfin Shad	799,776	76.8	Threadfin Shad	1,068,584	74.6
American Shad	68,187	6.6	American Shad	88,497	6.2
Prickly Sculpin	47,814	4.6	White Catfish	69,832	4.9
Striped Bass	40,283	3.9	Largemouth Bass	62,493	4.4
Bluegill	32,206	3.1	Striped Bass	44,481	3.1
White Catfish	12,241	1.2	Bluegill	22,813	1.6
Yellowfin Goby	7,286	0.7	Prickly Sculpin	16,981	1.2
Black Crappie	6,518	0.6	Chinook Salmon	14,315	1.0
Chinook Salmon	5,964	0.6	Channel Catfish	11,858	0.8
Inland Silverside	5,824	0.6	Splittail	7,788	0.5
Bigscale Logperch	5,771	0.6	Inland Silverside	7,287	0.5

Table 1. Continued: Annual fish salvage and percentage of annual fish salvage (%) collected from the SDFPF and TFCF in WY2018.

SDFPF			*TFCF*		
Species	***Salvage***	***%***	***Species***	***Salvage***	***%***
Channel Catfish	911	<0.1	Rainwater Killifish	1,516	0.1
Splittail	756	<0.1	Lamprey Unknown	968	<0.1
Shimofuri Goby	604	<0.1	Steelhead	740	<0.1
Common Carp	230	<0.1	Golden Shiner	707	<0.1
Starry Flounder	159	<0.1	Black Crappie	677	<0.1
Golden Shiner	127	<0.1	Redear Sunfish	509	<0.1
Lamprey Unknown	97	<0.1	Western Mosquitofish	296	<0.1
Goldfish	75	<0.1	Pacific Lamprey	204	<0.1
Rainwater Killifish	42	<0.1	Bigscale Logperch	169	<0.1
Western Mosquitofish	30	<0.1	Common Carp	158	<0.1
Blue Catfish	24	<0.1	Threespine Stickleback	113	<0.1
White Sturgeon	23	<0.1	Brown Bullhead	96	<0.1
Brown Bullhead	14	<0.1	Starry Flounder	76	<0.1
Redear Sunfish	9	<0.1	Black Bullhead	55	<0.1
Longfin Smelt	4	<0.1	Sacramento Sucker	52	<0.1
			Warmouth	36	<0.1
			Pacific Staghorn Sculpin	28	<0.1
			Goldfish	12	<0.1
			Green Sunfish	12	<0.1
			Red Shiner	12	<0.1
			Sacramento Pikeminnow	12	<0.1
			White Sturgeon	12	<0.1
			Blue Catfish	9	<0.1
			Delta Smelt	4	<0.1
			Sacramento Blackfish	4	<0.1
			Shokihaze Goby	4	<0.1
			Tule Perch	4	<0.1
			Wakasagi	4	<0.1
			White Crappie	4	<0.1

Steelhead

Salvage of Steelhead (both wild and hatchery- born) during the months of February to June continued the pattern of low salvage observed since WY 2005 (Figure 6). SDFPF salvage of juvenile and large (>350 mm FL) Steelhead (1,111) increased in WY 2018 from a record low of 78 the previous year. The WY 2018 Steelhead catch was also substantially larger than in WY 2016 (789). The balance of wild (573) versus hatchery (538) Steelhead salvaged at this facility was nearly even, with the majority of salvage occurring in the month of April (264) (Figure 7).

At the TFCF, 740 juvenile and large (>350 mm FL) Steelhead were salvaged during WY 2018, a major increase from the record low of 30 in WY 2017 and slightly larger than the salvage in WY 2016 (652).
The ratio of wild (546) to hatchery (194) Steelhead salvaged at this facility was nearly three-to-one, with most salvaged in March (244) (Figure 7).

Figure 6. Annual salvage of Steelhead (wild and hatchery origins combined) at the SDFPF and the TFCF, WYs 1981 to 2018.

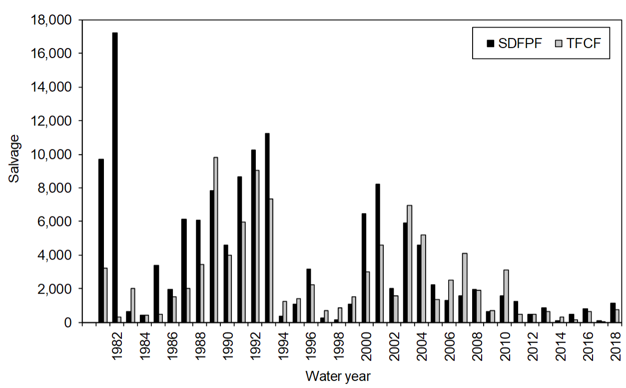
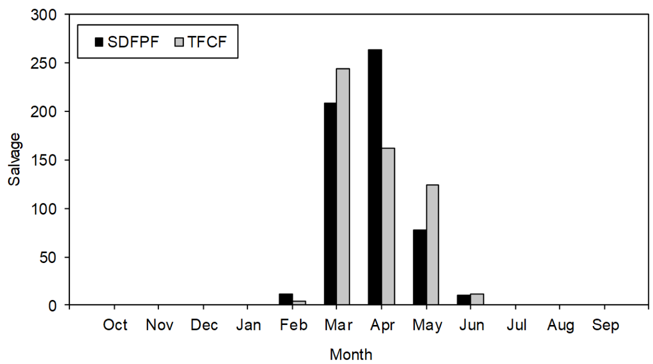


Table 2. Chinook Salmon annual salvage, percentage of annual salvage, race and origin (wild or hatchery), and loss at the SDFPF and the TFCF, WY 2018.

Origin	*Race*	*Salvage*	*Percent*	*Loss*
	Facility: SDFPF			
Wild	Fall	2,198	39.5	9,649
	Late-fall	1	<0.1	4
	Spring	3,311	59.4	14,057
	Winter	58	1.0	258
	Large unknown race	4	0.1	*
Total Wild		5,572		23,969
Hatchery				
	Fall	0	0.0	0
	Late-fall	50	12.8	219
	Spring	302	77.0	1,280
	Winter	40	10.2	178
Total Hatchery		392		1,677
Grand Total		5,964		25,646
	Facility: TFCF			
Wild	Fall	7,341	54.1	5,363
	Late-fall	4	<0.1	3
	Spring	6,176	45.5	4,258
	Winter	56	0.4	42
Total Wild		13,577		9,666
Hatchery				
	Fall	0	0.0	0
	Late-fall	21	2.9	17
	Spring	708	95.9	465
	Winter	8	1.1	5
	Large unknown race	1	0.1	*
Total Hatchery		738		487
Grand Total		14,315		10,153

*No loss was calculated for large unknown race Chinook Salmon

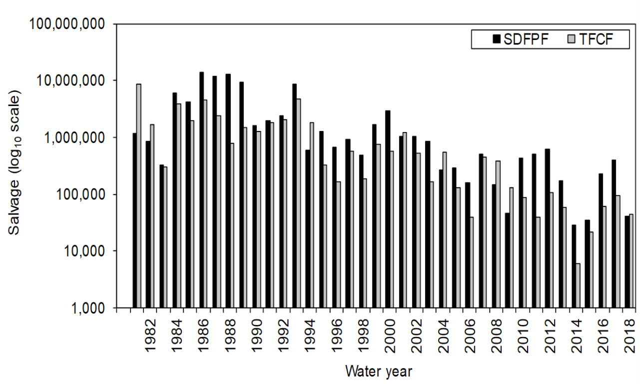
Figure 7 Monthly salvage of wild Steelhead at the SDFPF and the TFCF, WY 2018.



Striped Bass

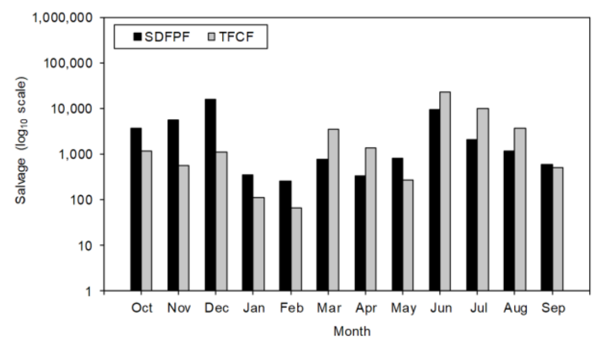
Salvage of juvenile, sub-adult, and adult Striped Bass at the SDFPF (40,283) decreased markedly from both WY 2017 (396,161) and WY 2016 (224,967), remained above the record low of WY 2015 (35,070). Salvage of juvenile, sub-adult, and adult Striped Bass at the TFCF (44,481) also decreased from WY 2017 (94,467) and WY 2016 (61,787) but was still above the near-record low of WY 2015 (21,398). Salvage at the SDFPF and the TFCF continued a declining trend observed since the mid-1990s (Figure 8). Prior to WY 1995, annual Striped Bass salvage estimates were generally above 1,000,000 fish.

Figure 8 Annual salvage of Striped Bass at the SDFPF and the TFCF, WYs 1981 to 2018. The logarithmic scale is log10.



Most Striped Bass salvage at the SDFPF occurred in December and June and in June-July at the TFCF (Figure 9). Salvage at the SDFPF in December (15,725) and June (9,289) accounted for 62.1% of total WY salvage. At the TFCF, salvage in June (22,675) and July (9,646) accounted for 72.7% of total WY salvage. Striped Bass were salvaged every month at both the SDFPF and the TFCF, with the lowest monthly salvages occurring in February at both the SDFPF (252) and the TFCF (64).

Figure 9 Monthly salvage of Striped Bass at the SDFPF and the TFCF, WY 2018. The logarithmic scale is log10.



Delta Smelt

Salvage of adult Delta Smelt continued the pattern of mostly low salvage observed since WY 2005 (Figure 10). Salvage at the TFCF (4) was a record low and less than annual salvages from WY 2017 (32) and WY 2016 (12). However, the WY 2018 salvage was substantially less from WY 2013 (300). No Delta Smelt were salvaged at the SDFPF, a decrease from both WY 2017 (25) and WY 2016 (8). The absence of Delta Smelt at the SDFPF is particularly notable as 1,701 fish were salvaged from this facility as recently as WY 2013.

Salvage of adult Delta Smelt at TFCF occurred in the winter and were only salvaged in early March (4). No juvenile Delta Smelt was salvaged at eitherfacility.

No Delta Smelt less than 20 mm FL was detected at the SDFPF in WY 2018, which also true in both WY 2017 and WY 2016. Only one Delta Smelt of this size was detected in WY 2015. No Delta Smelt less than 20 mm FL was detected at the TFCF in WY 2018, as in WYs 2015-2017.

Figure 10. Annual salvage of Delta Smelt at the SDFPF and the TFCF, WYs 1981 to 2018. The logarithmic scale is log10.

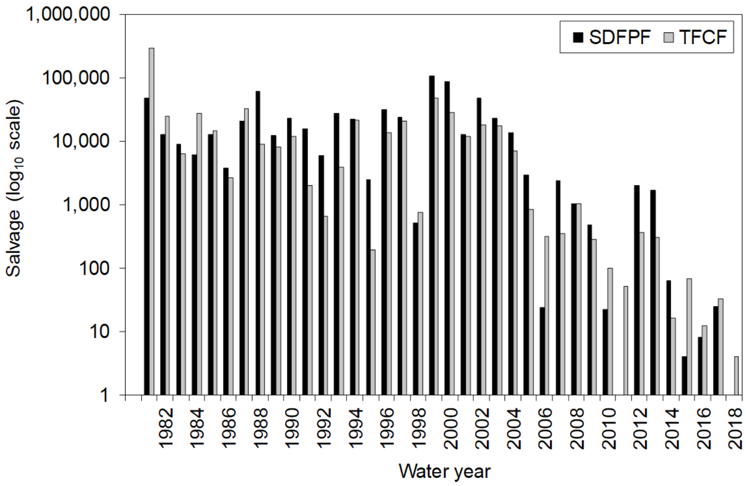


Figure 11. Annual salvage of Longfin Smelt at the SDFPF and the TFCF, WYs 1981 to 2018. The logarithmic scale is log10.

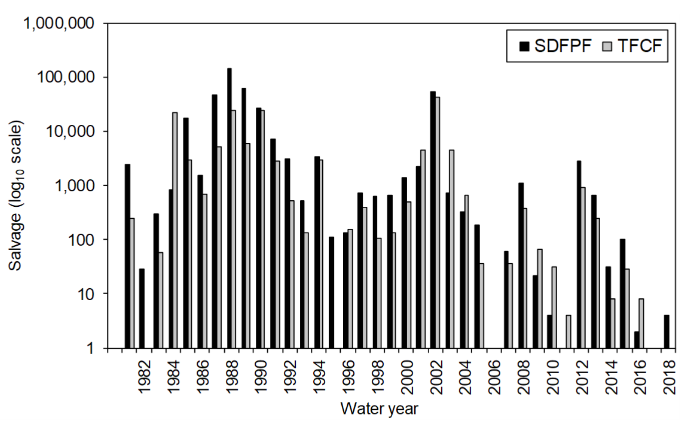
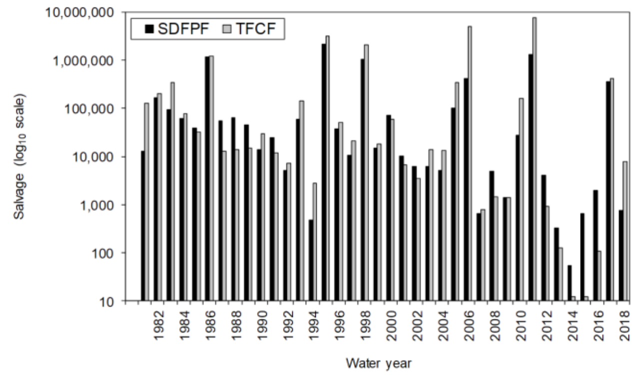


Figure 12. Annual salvage of Splittail at the SDFPF and the TFCF, WYs 1981 to 2018. The logarithmic scale is log10.



Longfin Smelt

Salvage of Longfin Smelt at the SDFPF (4) was low, although it represented a small increase over both WY 2017 (0) and WY 2016 (2). No Longfin Smelt were salvaged in either WY 2006 or WY 2011. No Longfin Smelt was salvaged at the TFCF, which has not detected any since WY 2016, when 8 were salvaged.
No Longfin Smelt were salvaged in WY 1982, WY 1995, and WY 2006 (Figure 11).

Salvage of juvenile Longfin Smelt at the SDFPF occurred in the spring and were only salvaged in late March (4). No adult Longfin Smelt were salvaged at either facility.

Longfin Smelt less than 20 mm FL were detected at the SDFPF on March 31 (1) and on April 2 (1)which was a small increase from WYs 2016-2017 (0). No Longfin Smelt less than 20 mm FL was detected at the TFCF, which was equal to WY 2017 (0) and a small decrease from WY 2016 (1).

Splittail

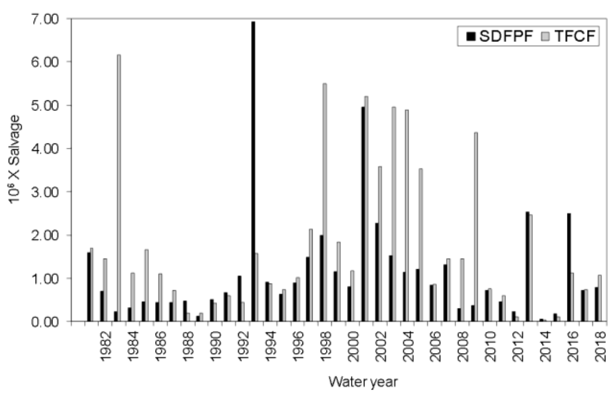
Salvage at the TFCF (7,788) was a marked decrease from WY 2017 (415,517), but an increase from WY 2016 (109) and the record low in WY 2015 (12; Figure 12). Salvage at the SDFPF (756) was a marked decrease from WY 2017

(355,538) and WY 2016 (1,951), but a small increase from WY 2015 (656). Annual Splittail salvage estimates have followed a boom-or-bust pattern, often varying year to year by several orders of magnitude. High Splittail salvage is generally associated with wet years and high young-of- the-year recruitment.

Threadfin Shad

Annual salvage of juvenile and adult Threadfin Shad was lower at the SDFPF (799,776) than at the TFCF (1,068,584; Figure 13). Salvage at the TFCF was higher than in WY 2017 (731,760) but lower than in WY 2016 (1,127,956). Similarly, salvage at the SDFPF was slightly higher than WY 2017 (717,753) but markedly lower than in WY 2016 (2,494,795). Similar to Splittail, annual salvage estimates of Threadfin Shad have varied greatly over time.

Figure 13 Annual salvage of Threadfin Shad at the SDFPF and the TFCF, WYs 1981 to 2018.



Summary

No one parameter controls salvage, but rather is a complex relationship between many parameters including export rate, outflow, climate, droughts, timing of winter storms, population size, Biological opinions for listed species, etc. In general, total fish salvage has been influenced by exports in recent years (i.e. higher salvage at higher exports). This trend was seen at TFCF but was not found at the SDFPF in the last three years where total fish salvage was higher

in WY 2016 than in WY 2018 and WY 2017 despite lower exports. Salvage of species including Chinook Salmon, Striped bass, and Splittail (except for WY 2018 at SDFPF) increased with increased rainfall in WY's 2017-2018 following a prolonged drought, while Steelhead, Threadfin Shad, Delta Smelt, and Longfin Smelt generally did not increase.

Footnotes

1. Pelagic Organism Decline (POD)species

Notes

Dekar, M. 2015. U.S. Fish and Wildlife Service. 850 South Guild Ave, Suite 105 Lodi, CA 95240

Fujimura, B. 2008. California Department of Fish and Wildlife. 2109 Arch Airport Road Suite 100, Stockton, CA 95206

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24 Hour Bugs: Tidal and diel changes in zooplankton distribution in the Sacramento River

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Introduction

The California Department of Fish and Wildlife's Fish Restoration Program Monitoring Team (FRP) is tasked with monitoring tidal wetland restoration sites of the upper San Francisco Estuary for the benefits they provide to at-risk fishes, particularly the Delta Smelt (*Hypomesus transpacificus*), Longfin Smelt (*Spirinchus thaleichthys*), and Chinook Salmon (*Oncorhynchus tshawytscha*). One of the major hypothesized benefits of these sites is export of production in the form of phytoplankton and zooplankton (Sherman et al. 2017, and references therein). In particular, wetland restoration may increase abundance of mesozooplankton, such as copepods and cladocera, which are recognized as the largest component of Delta Smelt diets (Slater and Baxter 2014) and a significant component of salmon diets (Sommer et al. 2001).However, many zooplankton migrate through the water column in response to tidal and diurnal changes to avoid predators and/or maintain position (Kimmerer et al. 1998, 2002, Burks et al. 2002). Vertical migration patterns make characterizing the contribution of tidal wetlands to zooplankton in fish diets difficult, because a sample collected at a single time point may not represent the abundance of zooplankton at other times of day.

FRP must choose a scheme for sampling zooplankton that provides the best data on fish food resources given limited staff time. By sampling during times when fish of concern are most active, FRP can characterize zooplankton most available for fish consumption. However, salmon are most active either at night (Wilder and Ingram 2006, Plumb et al. 2016), or at dawn and dusk (Clark and Levy 1988), while Delta Smelt are most active during the day (Young et al. 2004, Hasenbein et al. 2013). Though Delta Smelt feed chiefly during daylight hours, they have been documented feeding on more adult *Pseudodiaptomus forbesi* than would be expected based on the relative abundance of this species in zooplankton samples taken during the day (Slater and Baxter 2014). Additional feeding by Delta Smelt during dawn and dusk, when adult *P. forbesi* and other copepods have migrated to the surface (as seen in Kimmerer et al. 2002, Kimmerer and Slaughter 2016), may explain part of this discrepancy. Furthermore, when trying to characterize export of production from the wetland, daytime sampling may miss important components of the community that enter the pelagic food web of the surrounding channel at different times of day (as suggested in Dean et al. 2005, Kimmerer et al. 2014).

Much of the previous research on zooplankton vertical migration has occurred in open water. The wetlands in which FRP samples are generally shallower, more turbid, and have a higher cover in vegetation than surrounding channels. Higher turbidity often decreases vertical migration (Dodson 1990), and in very shallow water there may be less space for zooplankton to migrate. Therefore, diel patterns of zooplankton distribution may be less critical in wetlands than open-water sampling.

Regardless of when sampling occurs, any measurement of zooplankton catch will be an estimate of the true density in the water column. Net avoidance, sampling error, subsampling error, patchy distributions, difference in towing speed, net clogging, and flowmeter error mean that the catch-per-unit-effort (CPUE) calculated from our samples will be, at best, an index of actual density (Harris et al. 2000). Therefore, it is not possible to know exactly how much production is exported from the wetland even with continuous sampling. Instead, we want to find a sampling strategy that gives the best index of total zooplankton export. In this study, we ask two major questions:

1. What are the tidal and diel patterns of zooplankton abundance?
2. When should zooplankton sampling occur during the tidal and diel cycle?

Methods

We conducted an intensive comparison of zooplankton catch-per-unit-effort (CPUE) and community composition at a single location within the estuary during a single 24-hour period. Because zooplankton exhibit considerable plasticity in migratory behavior, this single study is not sufficient to characterize zooplankton behavior for the entire year, however it adds an example of zooplankton behavior near a wetland to previous documentation of vertical migration (such as Kimmerer et al. 2002, Kimmerer et al. 2014, Kimmerer and Slaughter 2016).

We chose to sample in Horseshoe Bend, an offshoot of the Sacramento River adjacent to Decker Island (Figure 1), because it is centrally located in the North Delta Arc, an area targeted for native fish habitat restoration (Moyle et al. 2016). Furthermore, Decker Island is one of the sites restored under the Fish Restoration Program (CDWR and CDFW 2012), and it was a muted tidal wetland at the time of this study. Once during June, when *P. forbesi* abundance (a known vertical migrator) is at its peak (Hennessy and Enderlein 2013, Merz et al. 2016), we collected eight sets of replicate samples throughout the day and night at different depths (Table 1).

Figure 1. Location of sampling stations in Horseshoe Bend. Each station (rep 1, rep 2, and rep3) was sampled once per sampling period. Stations were included as blocking variables in models of catch and community composition.

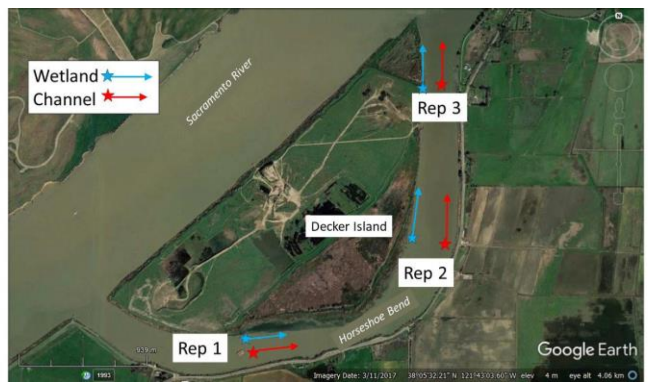


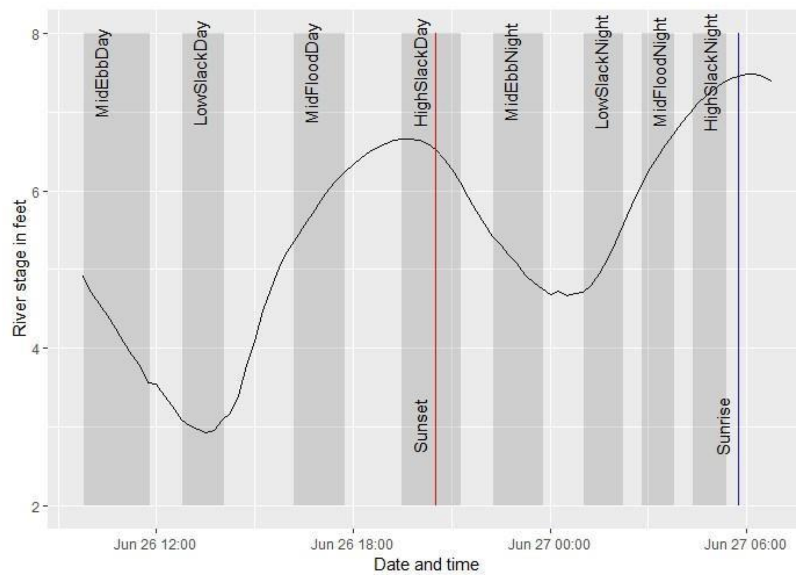
Table 1. Sample size for each sample type at each time period

	Day				Night			
	Mid ebb	*Low slack*	*Mid flood*	*High slack*	*Mid ebb*	*Low slack*	*Mid flood*	*High slack*
Sample Type	9:45	12:45	16:15	19:30	22:15	1:00	2:45	14:22
Benthic channel	3	3	3	3				
Surface channel	3	3	3	3	3	3	3	3
Wetland	3	3	3	3	3	3	3	3
				Total trawls: 72				

Sampling occurred approximately every four hours from 9:00am on June 26th, to 6:00am on June 27th. Sampling bouts occurred slightly closer together during the night to ensure at least four sampling bouts could occur in relative darkness. Because of the relative time of sunset and sunrise, the “High Slack Day” sampling period overlapped with sunset, and the “High Slack Night” sampling period was slightly before high slack to avoid overlapping with sunrise (Figure 2).

Three sampling stations were sampled during each sampling bout, and each sampling station included one wetland-adjacent trawl (a surface trawl along the edge of a bed of submersed *Egeria densa* found outside fringing *Schoenoplectus* marsh in 1-3 m of water) and two channel trawls (concurrent surface and benthic trawls in center of channel in 6-10 m of water). Channel stations had surface and benthic trawls during daylight, and surface trawls-only during the night. All trawls were 5-minutes long, and were collected against the tide, when possible. Some of the trawls were taken with the tide due to high winds, and two trawls were cut to four minutes due to hazardous conditions. Samples were rinsed in their entirety from nets into jars and preserved in 70% ethanol dyed with rose Bengal. Water quality (pH, dissolved oxygen, temperature, conductivity, chlorophyll florescence, and turbidity) was collected using a YSI 6600 at the bottom, middle, and top of the water column at each station.

Figure 2. Tidal stage versus time for the Rio Vista USGS tide gauge (Site Number 11455420, data available: https://waterdata.usgs.gov/nwis/inventory?agency_ code=USGS&site_no=11455420). Gray periods indicate when sampling bouts occurred.



Laboratory methods

All samples were filtered and washed in a 150 µm mesh sieve. Filtered zooplankton samples were diluted depending on the concentration of zooplankton and/or detritus, with a final concentration of 150-200 organisms per milliliter. One milliliter subsamples were placed on Sedgewick-Rafter cell glass slides. All organisms were identified to the lowest relevant taxonomic unit and life stage but grouped into larger categories for analysis. At least 5 slides, but no more than 20 slides were processed for each sample, targeting 6% of the total sample. Subsamples were extrapolated to estimate the total number of organisms in the sample in individuals per cubic meter.

Analysis

We calculated CPUE using the following formula:

$$\mathbf{CPUE = \frac{N}{P \times V}}$$

Where:

N = Number of organisms counted

P = fraction of sample processed

V = volume of water sampled

$$\mathbf{V = (FM_e – FM_s) \times \mathit{k} \times A}$$

Where:

FM_e= Ending flow meter reading

FM_s= Start flow meter reading

k = flow meter constant

A = net mouth area

When analyzing the effect of tidal stage and time of day, we excluded benthic trawls because these were not collected at night. To test whether benthic trawls had higher abundances than surface trawls, we subset the data to include only daytime trawls.

For each data subset, we performed a series of linear models on the log-transformed total zooplankton CPUE using the predictor variables listed in (Table 2 or 3, depending on the subset). We ranked all possible models using Akaike's Information Criterion, corrected for small sample sizes (AICc), to choose which predictor variables to use in the final model using the R package "MuMIN" (Barton 2018). We also performed a Permutational Multivariate Analysis of Variance (PerMANOVA) using the "adonis" function from the R package "vegan" (Oksanen et al. 2016) to see whether the same predictor variables would have an effect on community composition. We calculated differences in community composition using the Bray-Curtis dissimilarity index and plotted these differences using a Non-Metric Multi-Dimensional Scaling ordination (NMDS) to see whether the communities grouped together.). We overlaid the results of the PerMANOVA tests on these plots to indicate the significance of the observed grouping.

Because calanoid copepods, specifically *P. forbesi*, was the numerically dominant taxonomic group in most of the samples, we repeated the analysis of log- transformed CPUE on the dataset of adult calanoid copepods alone, and on the dataset of everything besides calanoid copepods. This allowed us to see whether the vertical migration in *P. forbesi* extended to other groups of zooplankton.

Results

We found strong differences in total catch at different times of day and different stages of tide. The best performing model of log-transformed total zooplankton CPUE (surface samples only), included Day/Night, Station, Tide, and the interaction between Day/Night and Tide (Table 4). There was significantly higher catch at high slack tide during the day than the other tidal stages during the day, but all tide stages had equally high catch at night (Figure 3). AICc model selection did not support inclusion of Wetland/Channel as a predictor variable.

Table 2. Predictor variables for day/night comparison models. (using data from surface tows only).

Variable	*Variable type*	*Description*	*Interpretation*
Tide	Categorical	Tidal stage at which sampling occurred: High Slack, Low Slack, Mid Ebb, or Mid Flood	Tidally-driven vertical migration
Day/Night	Categorical	Whether sample was collected during the day or at night.	Diurnal vertical migration
Wetland/Channel	Categorical	Whether the sample was collected in shallow water (< 3 m) adjacent to the wetland, or in the center of the channel (> 6 m deep).	Different abundances in shallow water versus the deep channel.
Day/Night* Tide interaction	Interaction		ect of Day/Night is different at different tidal stages
/Night* Channel interaction	Interaction		The effect of Day/Night is different in the channel than the wetland.
Station	Categorical	sition along horseshoe bend (see Figure 1)	Blocking variable

Table 3. Predictor variables for surface/benthic comparison models. (using data from daytime tows only).

Variable	*Variable type*	*Description*	*Interpretation*
Tide	Categorical	Tidal stage at which sampling occurred: High Slack, Low Slack, Mid Ebb, or Mid Flood	Tidally-driven vertical migration
Surface/benthic	Categorical	Whether sample was collected from the surface of the channel or the bottom of the channel	Differing abundance at the top versus bottom of the water column
Wetland/Channel	Categorical	Whether the sample was collected in shallow water (< 3 m) adjacent to the wetland, or in the center of the channel (> 6 m deep).	Different abundances in shallow water versus the deep channel.
* Surface/benthic interaction	Interaction		The effect of the tide is different at the top of the water column than the bottom
Station	Categorical	sition along horseshoe bend (see Figure 1)	Blocking variable

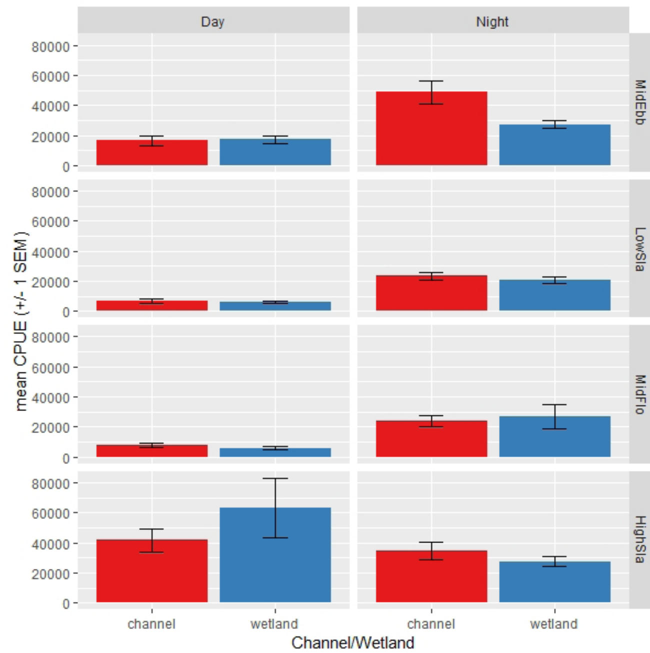
Table 4. Coefficients of the top model of log total CPUE for daytime samples. The terms supported by the model selection process were Day/Night, Station, and Tide, plus the interaction of Day/Night and Tide.Wetland/channel was not supported. Adjusted R-squared = 0.739, overall F-statistic 15.81 on 9 and 38 DF, p-value <0.0001.

Term	*Estimate*	*SE*	*t-value*	*p-value*	
Intercept - Day, HighSlack, Rep1	10.860	0.203	53.473	<0.0001	*
Night	-0.354	0.257	-1.379	0.176	
Low Slack	-1.919	0.257	-7.471	<0.0001	*
Mid Ebb	-1.035	0.257	-4.027	0.0002	*
Mid Flood	-1.937	0.257	-7.54	<0.0001	*
Rep2	-0.004	0.157	-0.026	0.979	
Rep3	-0.692	0.157	-4.396	<0.0001	*
Night*LowSlack	1.603	0.363	4.413	<0.0001	*
Night*MidEbb	1.210	0.363	3.33	0.0019	*
Night*MidFlood	1.641	0.363	4.517	<0.0001	*

PerMANOVA also indicated significant differences in community composition at different times of day and different stages of the tide. NMDS plots show separation of the Day/Night and Tide sample groups, driven by the relative abundance of calanoid copepods (Table 5, Figure 4A, B). However, there was no significant difference in community composition in channel versus wetland habitat (Table 5, Figure 4C).

Because of the dominance of calanoid copepods, and previous research on vertical migration in *P. forbesi* (the dominant calanoid in our samples), were-ran the analysis of log-transformed CPUE on adult calanoid copepods, and a separate model for the data set with no calanoid copepods. For adult calanoids, AICc model selection supported the same top model as the overall zooplankton model, with the same general trends in abundance: higher catch at night and

Figure 3. Mean zooplankton CPUE ± 1 SEM of surface samples at each tide and time of day (mean of the three sampling stations). All taxa have been combined in this graph, but note that over 90% of the abundance was juvenile or adult calanoid copepods. Tidal stage abbreviations: MidEbb =Mid Ebb tide, LowSla = Low slack tide, MidFlo = Mid Flood Tide, HighSla = High Slack tide.



higher catch at slack tides (Figure 5, Table 6). When calanoid copepods were removed from the analysis, the top model chosen via AICc only supported Day/ Night and Station (Table 7), with significantly higher catches at night (Figure 7). Neither Tide nor Wetland/ Channel were supported. The lack of support for tide in the model without calanoids indicates that many zooplankton exhibited diel vertical migration, but calanoid copepods were driving the tidal vertical migration patterns.

Table 5. Results of a PerMANOVA on relative abundance of major taxa in all the surface samples. Results showed a significant effect of Tide and Day/Night, but not Channel/Wetland.

Term	*DF*	*ums of Sqs.*	*Mean Sqs.*	*f-value*	*R2*	*p-value*	
Day/Night	1	0.163	0.164	26.417	0.332	0.001	*
Tide	3	0.068	0.022	3.667	0.138	0.005	*
Channel/ Wetland	1	0.001	0.001	0.207	0.003	0.845	
Residuals	42	0.260	0.006	0.527			
Total	47	0.493	1				

Figure 4. NMDS plot of relative abundance of zooplankton in all surface (stress = 0.0379). Points represent samples, text represent species. Sample point size varies by the proportion of adult calanoid copepods A) NMDS plot with hulls around day and night samples. PerMANOVA supports these groups being significantly different. B) NMDS plot with hulls around samples from different tidal stages. PerMANOVA supports these groups being significantly different. C) NMDS plot with hulls around channel and wetland sample. These groups are not significantly different. See Table 5 for PerMANOVA results.

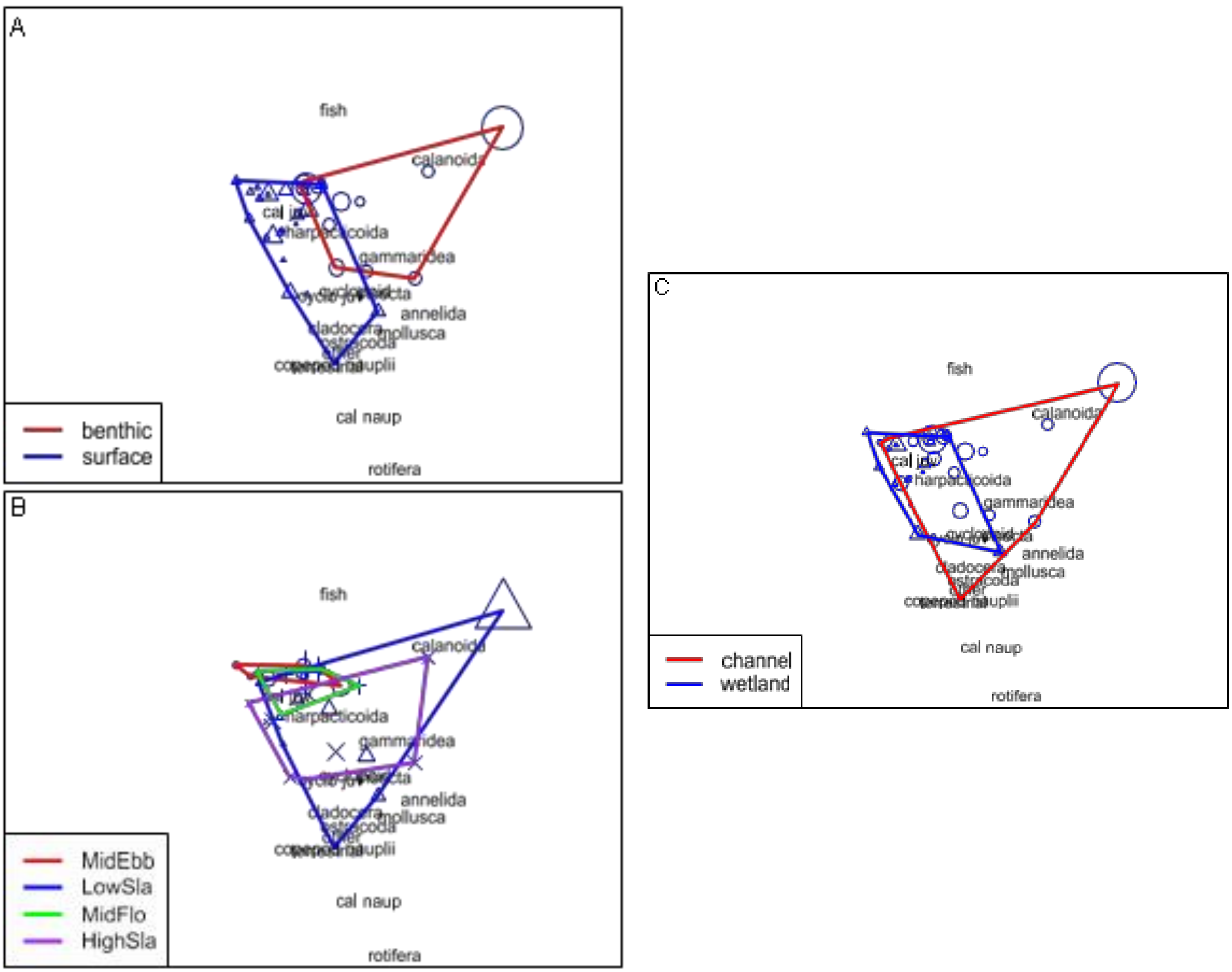


Figure 5. Mean (± 1 SEM) of the adult calanoid copepod CPUE by habitat, time of day, and tidal stage. See Table 6 for significant differences.

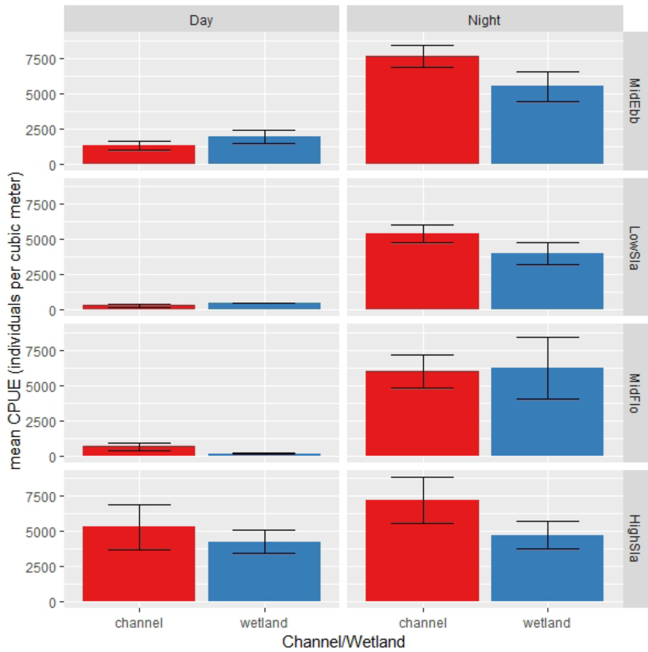


Figure 6. Mean zooplankton CPUE of surface samples with calanoid copepods removed.

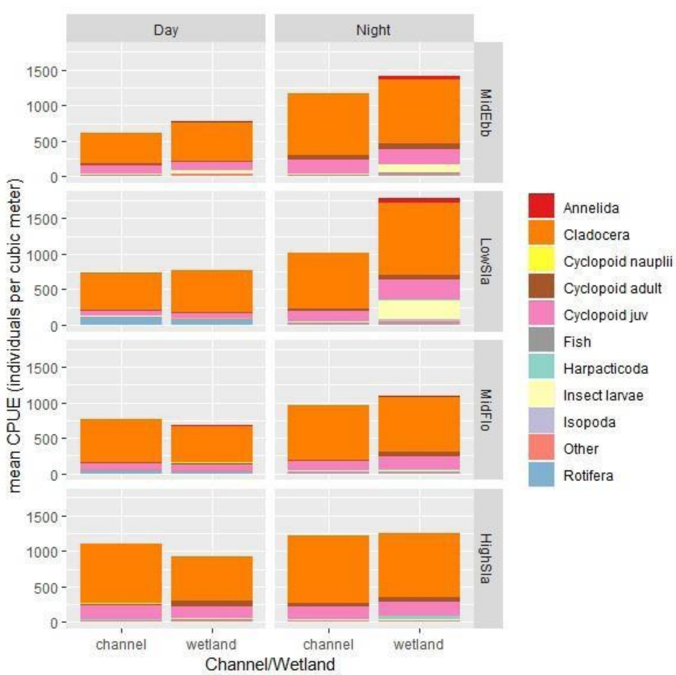


Table 6. Coefficients of the top model of log calanoid copepod CPUE for surface samples. The terms supported by the model selection process were thesame as the total CPUE model: Day/Night, Station, and Tide, plus the interaction of Day/Night and Tide). Wetland/ channel was not supported. Adjusted R-squared = 0.799, overall F-statistic 21.74 on 9 and 38 DF, p-value <0.0001.

Term	*Estimate*	*SE*	*t-value*	*p-value*
Intercept - Day, High Slack, Rep1	8.639	0.292	29.603	<0.0001*
Night	0.278	0.369	0.752	0.457
Low Slack	-2.469	0.369	-6.687	<0.0001*
Mid Ebb	-1.010	0.369	-2.979	0.005 *
Mid Flood	-2.780	0.369	-7.531	<0.0001*
Rep2	-0.149	0.226	-0.659	0.514
Rep3	-1.000	0.226	-4.425	<0.0001*
Night* LowSlack	2.314	0.522	4.432	<0.0001*
Night* MidEbb	1.275	0.522	2.441	0.0194 *
Night* MidFlood	2.653	0.522	5.081	<0.0001*

Table 7. Coefficients of the top model of log zooplankton CPUE for surface samples with calanoid copepods removed. The only terms supported by the model selection process were Day/Night and Station. Wetland/ channel and Tide were not supported. Adjusted R-squared = 0.387, overall F-statistic 10.91 on 3 and 44 DF, p-value <0.0001.

Term	*Estimate*	*SE*	*t-value*	*p-value*
Intercept - Rep1, Day	6.454	0.088	72.997	<0.0001 *
Night	0.466	0.088	5.268	<0.0001 *
Rep2	0.222	0.108	2.052	0.046 *
Rep3	0.194	0.108	1.791	0.080 .

We also found a slight trend towards higher catch in benthic samples when compared with surface samples during the day, though abundance was highest at high slack tide at all water depths (Figure 7). The top model of log-transformed total zooplankton catch (daytime samples only), included Surface/Benthic, Station and Tide (Table 8). There was no significant effect of Channel/Wetland and there was no interaction between Tide and Surface/Benthic.

While the effect on overall abundance was relatively small, PerMANOVA results indicated significant differences in community composition between surface and benthic samples, and between different stages of the tide. NMDS plots show separation of the Surface/Benthic and Tide sample groups, driven by the relative abundance of calanoid copepods (Table 9, Figure 8A, B). Unlike data from the surface samples, there was also a trend towards a significant effect of Channel/Wetland (Table 9, Figure 8C).

Figure 7. Mean zooplankton CPUE (± 1 SEM) of daytime samples for each habitat type at each tide. Table 8 for significant differences.

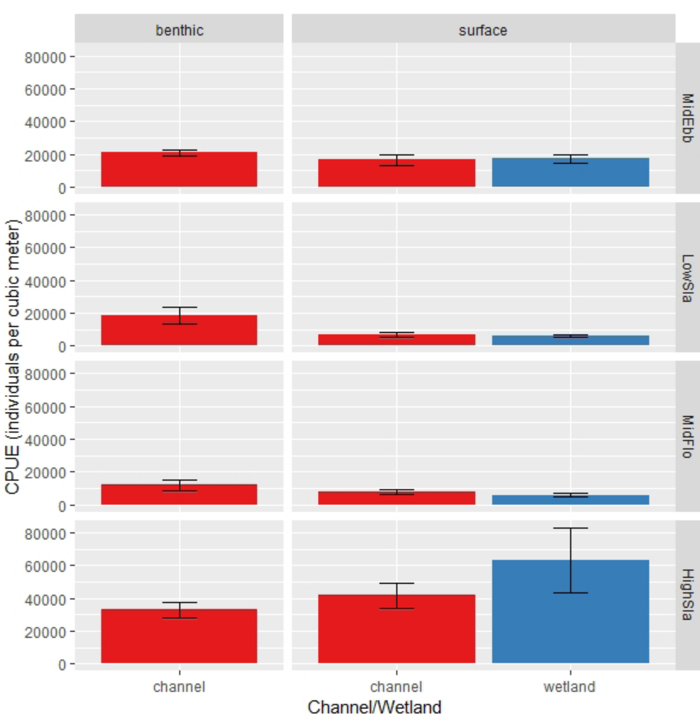
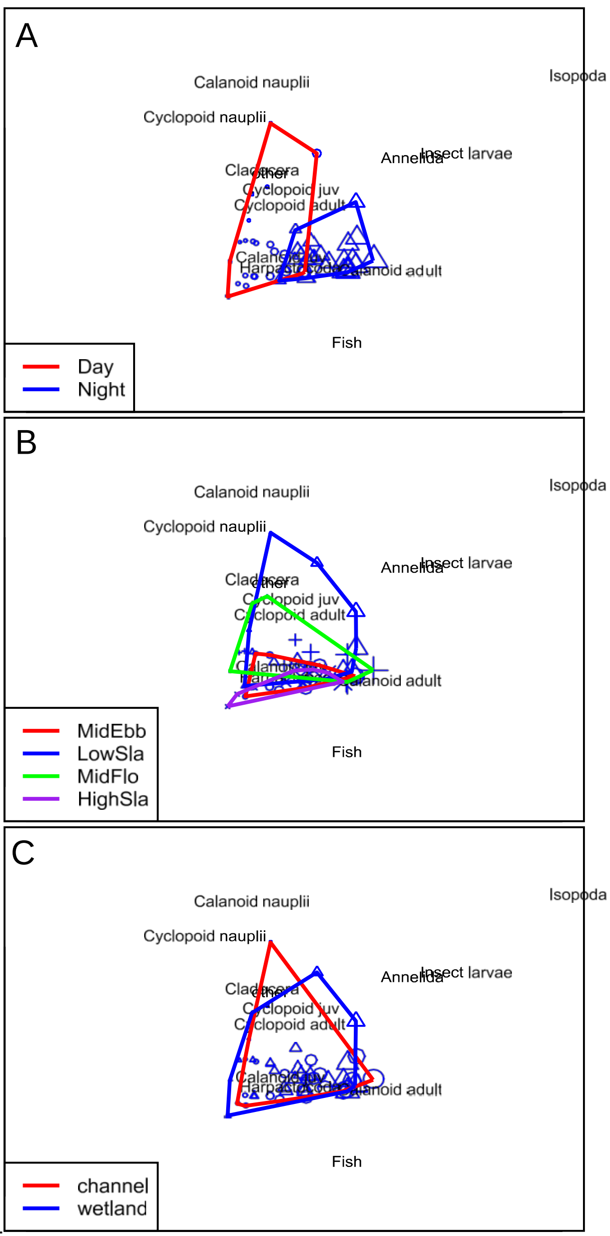


Table 8. Coefficients of the top model of log total CPUE for daytime samples. The terms supported by the model selection process were station, surface versus benthic, and tide. Wetland versus channel and any interaction terms were not supported. Adjusted R-squared = 0.705, overall F-statistic 14.92 on 6 and 29 DF, p-value <0.0001

Term	*Estimate*	*SE*	*t-value*	*p-value*	
Intercept - Rep1, Benthic, HighSlack	10.726	0.237	45.235	<0.001	*
Rep2	0.524	0.205	2.550	0.016	*
Rep3	-0.461	0.205	-2.244	0.032	*
Surface	-0.334	0.178	-1.875	0.070	.
Low Slack	-1.529	0.237	-6.448	<0.001	*
Mid Ebb	-0.824	0.237	-3.476	0.002	*
Mid Flood	-1.678	0.237	-7.076	<0.001	*

Figure 8. NMDS plot of relative abundance of zooplankton in all daytime samples from the 24-hour study (stress = 0.032). Points represent samples, text represents species. Sample point size varies by the proportion of adult calanoid copepods. A) NMDS plot with hulls around benthic and surface samples. PerMANOVA supports these groups being significantly different. B) NMDS plot with hulls around samples from different tidal stages. PerMANOVA supports significant differences. C) NMDS plot with hulls around channel and wetland sample. These groups had a trend toward being different (p = 0.054). See table 9 for PERMANOVA results.



Discussion

Tidal and diel patterns of zooplankton abundance

We found strong evidence for both tidal and diel migration in calanoid copepods during the summer in a side channel of the lower Sacramento River. The significant main effects of tide in CPUE models indicates adult calanoid copepods are more abundant during high slack tide. However, the interaction with time of day shows this effect is less pronounced at night, when calanoid copepods are more common in the water column at all tidal stages (Figure 3, Figure 5, Table 4). This is similar to results of studies by Kimmerer et al. (1998), who found higher abundance of all zooplankton at night than during the day, and a higher abundance on flood tides than ebb tides. This pattern is much more common in copepods than other zooplankton (Figure 6, Kimmerer et al. 2002). Tidal migration by zooplankton is thought to be an important mechanism for maintaining position in the estuary (Orsi 1986, Kimmerer et al. 2014, and references therein), or transport to more favorable salinities (Manuel and O'Dor 1997), and may also be important in calculating zooplankton export from wetlands (Dean et al. 2005). One important caveat: the high slack samples during our study were taken at dusk and dawn, rather than truly day and night, so additional work is needed to determine the extent to which this data represents overall trends.

With the calanoid copepods removed from the dataset, we still found evidence for diel migration, with higher abundances of other zooplankters in the surface water at night (Table 7, Figure 6), but no longer found evidence for tidal migration. Diel migration is thought to chiefly be a predator avoidance mechanism sinking during the day to avoid visual predators and rising at night to graze on phytoplankton

Table 9. PerMANOVA on the relative abundance of major zooplankton taxa in daytime samples. Analysis does show differences between community composition in surface versus benthic samples, and a trend toward a difference in wetland versus channel samples

Term	*DF*	*Sums of Sqs.*	*Mean Sqs.*	*f-value*	*R2*	*p-value*	
Tide	3	0.108	0.036	3.290	0.191	0.006	*
Wetland/ Channel	1	0.033	0.033	3.016	0.058	0.054	.
Surface/ Benthic	1	0.097	0.097	8.880	0.172	0.001	*
Residuals	30	0.329	0.011	0.580			
Total	35	0.567	1				

(Lampert 1989, Manuel and O'Dor 1997). Diel migration has been found more frequently than tidal migration in a wider variety of invertebrates, including copepods, mysids, cladocera, amphipods, and even chironomid larvae (Kimmerer et al. 1998, Marklund et al. 2001, Rollwagen-Bollens et al. 2006).

With the decrease in abundance of zooplankton, particularly adult calanoid copepods, during the day for most tidal stages, there was a corresponding increase in zooplankton in benthic samples (Figure 8, Figure 7,Table 8), similar to the abundance of zooplankton at night (Figure 3, Figure 7). This suggests zooplankton were sinking to bottom where they could better escape both predation and strong currents. While the wetland samples were taken in relatively shallow water (< 3 m), and so had only a single tow, a future study could try to better target both surface and benthic samples in shallow water adjacent to wetlands.

This study was conducted over a single 24-hour period, during which environmental parameters were relatively homogeneous (data not shown), so we cannot make inferences about what other factors influence vertical migration. However, high turbidity has been shown to decrease incidence of vertical migration in other studies (Dodson 1990). Some organisms, including the mysid shrimp *Neomysis mercedis*, may or may not exhibit vertical migration, depending on environmental circumstances (Orsi 1986, Kimmerer et al. 2002). The lunar cycle may also influence vertical migration, with a lower incidence of migration on full moons (Manuel and O'Dor 1997). The San Francisco Estuary has mixed semi-diurnal tides, meaning each daily tidal cycle has a “high-high” and a “low-high”. In our study, we sampled on the new moon, with the low-low tide occurring during the day, and the high-high tide occurring during the night (Figure 2).The magnitude of the change in tide and amount of moonlight may have affected the prevalence of vertical migration.

Given the previous research showing tidal migration in a variety of zooplankton species using a variety of sampling techniques, our results are most likely explained by migration. However, it should be noted that the same results could be caused by differential catch efficiency at different tidal stages. Trawl speed is known to effect trawl efficiency and catchability for some species (Colton Jr et al. 1980, McQueen and Yan 1993), and while we attempted to standardize trawling speed during this study, changes in water and wind speed at different tidal stages made it difficult to maintain a consistent effective flow rate through our nets.

Wetland-channel differences

We found few differences in zooplankton community composition or abundance in the wetland trawls versus the channel trawls. This is similar to a study by Grimaldo et al. (2004), who found some differences in channel versus wetland abundance by species, but no overall differences in zooplankton abundance, including for the dominant taxa, *P. forbesi*. Kimmerer and Slaughter (2016) also studied fine-scale distributions of *P. forbesi*, and did not find significant differences in channel versus shallow-water habitat, but shallow-water samples were not along wetlands. Our samples were along edges of wetlands in a relatively well-mixed river channel, but we may have found greater differences in zooplankton communities deeper into the wetland, at fully tidal wetlands, or at larger wetland sites.

We predicted that shallow-water samples might exhibit less evidence for vertical migration than channel samples, because the water was shallow and largely vegetated. However, the lack of a significant interaction between the Channel/Wetland term and Day/Night term in our model demonstrated no difference in migration patterns (Table 4). Some invertebrates associated with vegetation do exhibit vertical migration even within dense stands of submerged aquatic vegetation (Marklund et al. 2001), and previous studies showing higher larval fish abundance in shallow water (Grimaldo et al. 2004) and vegetation (Young et al. 2018) may mean vertical migration for predator avoidance is even more important in shallow water than the open channels.

Timing of zooplankton sampling

Fish Restoration Program sampling should be timed to best characterize fish food availability, and many fishes exhibit patterns of vertical migration similar to those of their zooplankton prey. Larval Delta Smelt have shown some evidence of diel vertical migration, though few studies have been able to sample with adequate replication to fully explore the issue. One study found higher larval smelt abundances at night than during the day at any depth, with no evidence for tidal migration (Rockriver 2004), while another study found greater abundances at the surface during the day, though there is potential for ontogenetic shifts in migration patterns (Bennett et al. 2002). Longfin Smelt larvae sometimes exhibit tidal migration (Bennett et al. 2002), which may help fish maintain their position in the estuary as well as track their zooplankton food supply. Adult smelt also move in response to tides, moving into shallow-water embayments on high tides (Aasen 1999), and moving to channel edges during ebb tides during high flow events (Bennett and Burau 2015). Salmonids frequently have crepuscular movement patterns, feeding mostly at dawn and dusk (Clark and Levy 1988), though this pattern is highly seasonal and dependent on where they are in their smoltification (Ibbotson et al. 2006). The interplay of fish movements with invertebrate migration may impact when productivity is most available for the fish of interest to eat.

Moving forward in monitoring tidal wetland restoration sites, this study demonstrates that tidal and diel migration may greatly influence export rates of certain zooplankton taxa, especially *P. forbesi*. The difference in abundance between day and night was much lower during high slack tides, so sampling during high slack may give the best overall picture of copepod abundance. While we may not be able to sample night and day on a regular basis, knowing that daytime abundances of copepods are an underestimate will help in making inferences about the community as a whole.

Acknowledgements

I would like to thank the field crew and volunteers who pulled long hours collecting the data: Dr. Stacy Sherman, Matt Siepert, Phillip Poirier, Alison Furler, Curtis Hagen, Ryan Kok, and Karen Kayfetz. Special thanks are due to Ryan Kok for identifying all the zooplankton. (72 samples, over 200,000 individuals). Thank you to California Department of Parks and Recreation for letting us use the Brannon Island dock and campground. Stacy Sherman and Dave Contreras helped design the experiment and commented on the manuscript. Daniel Ellis and Ted Flynn also provided helpful comments on the manuscript. I would also like to thank Dr. Wim Kimmerer for always reminding us that daytime zooplankton is only half the story. This project and the Fish Restoration Program were funded by the California Department of Water Resources' State Water Project fund.

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2018 Spring Kodiak Trawl Summary

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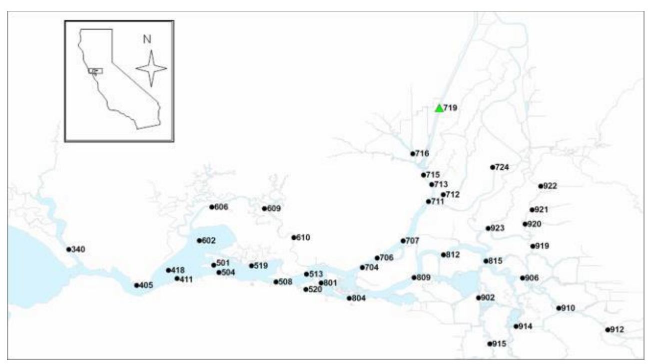
The California Department of Fish and Wildlife (CDFW) conducts the Spring Kodiak Trawl Survey (SKT) annually to determine the distribution and relative abundance of adult Delta Smelt (*Hypomesus transpacificus*), which is endemic to the San Francisco Estuary, and is listed under the California and United States Endangered Species Acts. The SKT also monitors the gonadal maturation of Delta Smelt, which can indicate when and where spawning is likely to be occurring. The SKT is routinely conducted from January to May but was expanded into December starting in 2014 to increase coverage during drought years and allow for equipment comparisons with another CDFW survey, the Fall Midwater Trawl. The SKT conducts one survey each month, which consists of sampling 40 stations throughout the upper San Francisco Estuary (Figure 1). Each station is sampled using a Kodiak Trawl, which is towed between two boats at the water's surface for 10 minutes. At each station, crews measure the electrical conductivity, temperature, and turbidity of the surface water, along with the water depth, Secchi depth, and tidal direction. In 2018, all stations were sampled during Surveys 1-3 and Survey 5. During Survey 4, one station was not sampled in the Sacramento Deepwater Shipping Channel. More information on the SKT's gear, objectives, methods, and prior year summary reports, are available in previous articles by Souza (2002, 2003) and in other articles on our CDFW online bibliography.

The 2018 SKT collected 2,885 organisms representing 27 species (Table 1). Threadfin Shad, American Shad, and Pacific Herring were the most abundant species, together comprising about 58% of the total catch. Longfin Smelt, which is listed as a threatened species under the California Endangered Species Act, was the 7th most abundant species (n=151). Adult Longfin Smelt (FL ≥ 85mm) were collected in April and early May, all at Station 405 in Carquinez Strait (n=10). Young-of-the-year Longfin Smelt (FL ≤ 37mm) were also collected in April and May, in Suisun Bay and Montezuma Slough (n=134). Seven older juvenile Longfin Smelt (FL ranging from 60-84) were collected throughout the sampling season in Suisun Bay, Montezuma Slough, and the Lower Sacramento River. Chinook Salmon were observed throughout the sampling area (Figure 2) and were the 8th most abundant species (n=124). 95% of the Chinook Salmon were collected in April and May.

Figure 1. Station locations for the 2018 CDFW Spring Kodiak Trawl in the upper San Francisco Estuary. Black dots represent stations that have been sampled since the survey's inception; the green triangle represents a station added in 2005.



Delta Smelt made up 0.6% of the total SKT catch and was the 14th most abundant species collected. Only fifteen adults (FL ≥ 55mm) and one juvenile (FL=34mm) were collected in 2018, a historic low (Figure 3). Ten Delta Smelt were collected in January, nine in the lower Sacramento River and one in

Montezuma Slough (Table 2). Four were collected in February, all in Montezuma Slough, and one was collected in March in the Sacramento Deepwater Ship Channel (SDWSC). No Delta Smelt were observed in April, and one juvenile was collected in May in the SDWSC. All adult Delta Smelt collected were in pre-spawn condition. The scarcity of Delta Smelt in the SDWSC is another first for the SKT. Delta Smelt have been consistently detected in that location since sampling began there in 2005, with prior annual catch ranging from 14 to 459 (average of 144). 2018 was also the first year that no reproductively mature or post-spawn individuals were collected, likely due to the scarcity of Delta Smelt, particularly in February, March, and April, which is typically when most spawning occurs (Damon 2016). CDFW's Smelt Larva Survey first detected larvae in mid-March, which suggests spawning began in early March (Tempel, 2018)

Figure 2. Geographic bubble plot of Chinook Salmon catch and adipose fin status from April and May of the 2018 CDFW Spring Kodiak Trawl. Bubble size is proportional to total catch and ranges from 1 to 9.

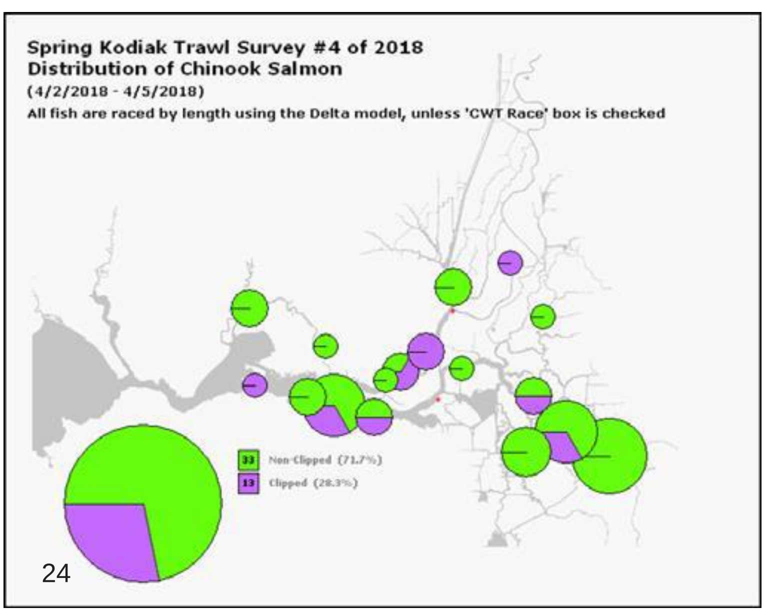


Table 1. 2018 CDFW Spring Kodiak Trawl organism catch for all stations and surveys combined.

Common Name	*Catch*	*Percent*
Threadfin Shad	1044	36.2
American Shad	363	12.6
Pacific Herring	272	9.4
Crangon Shrimp	250	8.7
Inland Silverside	211	7.3
Palaemon Shrimp	175	6.1
Longfin Smelt	151	5.2
Chinook Salmon	124	4.3
Northern Anchovy	98	3.4
Steelhead	40	1.4
Threespine Stickleback	25	0.9
Splittail	25	0.9
Siberian Prawn	17	0.6
Delta Smelt	16	0.6
Topsmelt	15	0.5
Striped Bass	13	0.5
Pleurobrachia	11	0.4
Prickly Sculpin	8	0.3
Blackfordia	8	0.3
Golden Shiner	6	0.2
Wakasagi	5	0.2
Shimofuri Goby	2	<0.1
Starry Flounder	2	<0.1
Bell Jelly	1	<0.1
Bluegill	1	<0.1
Mosquitofish	1	<0.1
Yellowfin Goby	1	<0.1

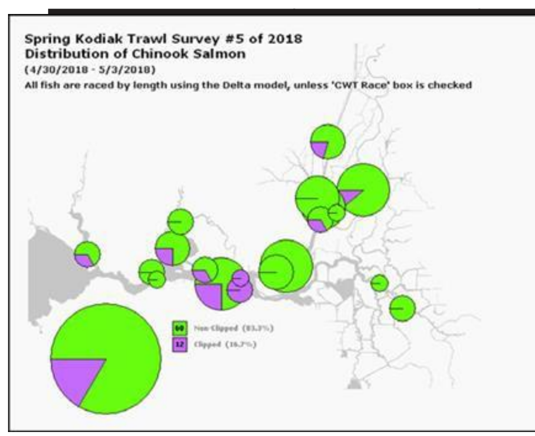


Table 2. Delta Smelt catch and fork length by date, station, and region from the CDFW Spring Kodiak Trawl from December 2017 - May 2018.

Date	*Station*	*Region*	*Catch*	*Range of Fork Length*
12/13/2017	706	Lower Sacramento River	2	59
12/13/2017	704	Lower Sacramento River	3	54-65
12/14/2017	609	Montezuma Slough	1	61
1/10/2018	704	Lower Sacramento River	9	55-69
1/11/2018	609	Montezuma Slough	1	61
2/8/2018	610	Montezuma Slough	2	68-76
2/8/2018	609	Montezuma Slough	2	69-70
3/7/2018	719	Sacramento Deepwater Ship Channel	1	66
5/2/2018	719	Sacramento Deepwater Ship Channel	1	34

In December 2017, all 40 of the SKT stations were sampled during an additional week-long survey. A total of 3,515 organisms representing 14 species were collected (Table 3). Threadfin Shad and American Shad were by far the most abundant species, followed by Inland Silverside and Northern Anchovy. Together these four species comprised over 99% of the total catch. Six Delta Smelt were collected, all in the Lower Sacramento River and Montezuma Slough. These fish were dissected for gonadal staging; three had not yet developed identifiable gonads and three were in pre-spawn condition. This is an expected pattern for December, as water temperatures during this time tend to be lower than optimal for spawning (Damon 2016).

The United States Fish and Wildlife Service (USFWS) conducts the Enhanced Delta Smelt Monitoring program (EDSM), which began in December 2016 and conducts high-frequency sampling targeting Delta Smelt using equipment similar to that used during SKT[1]. SKT and EDSM both sampled the estuary from December 2017 through March 2018 and showed similar catch patterns for Delta Smelt (Figure 4). During this time, Delta Smelt were collected in Montezuma Slough, the Lower Sacramento River, the Cache Slough complex, and the Sacramento Deep Water Ship Channel.

Figure 3. Annual Delta Smelt catch from the CDFW Spring Kodiak Trawl. Catch from supplemental surveys, including December sampling, is not included.

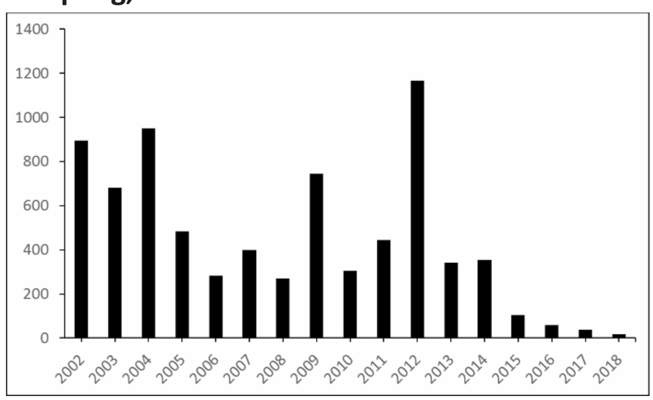
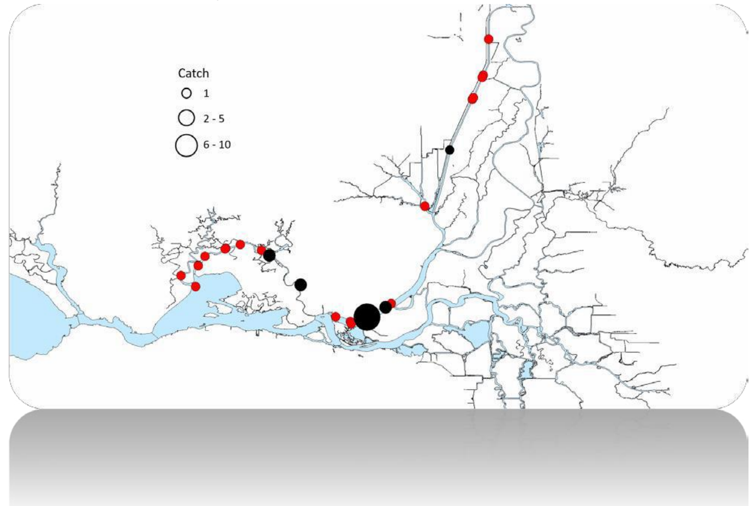


Table 3. December 2017 CDFW Spring Kodiak Trawl organism catch.

Common Name	Catch	Percent
Threadfin Shad	1923	54.7
American Shad	1127	32.1
Inland Silverside	301	8.6
Northern Anchovy	134	3.8
Topsmelt	8	0.2
Delta Smelt	6	0.2
Bell Jelly	4	0.1
Wakasagi	3	<0.1
Golden Shiner	3	<0.1
Striped Bass	2	<0.1
Threespine Stickleback	1	<0.1
Splittail	1	<0.1
Siberian Prawn	1	<0.1
Jacksmelt	1	<0.1

Data from the SKT is reported in near real-time to the Smelt Working Group (SWG), the Delta Operations for Salmonids and Sturgeon Work Group (DOSS), and the Data Assessment Team (DAT) to help inform adaptive management decisions. SKT catch summaries are publicly available through the SKT webpage, typically within a week of sampling efforts. The webpage provides catch distribution maps for all species collected, along with information on Delta Smelt gender and reproductive maturity, and Chinook Salmon adipose fin status and race information based on length-at-date and coded wire tag (CWT) results.

Figure 4. Delta Smelt catch from CDFW's Spring Kodiak Trawl and USFWS's Enhanced Delta Smelt Monitoring from December 2017 through March 2018. Total CDFW catch is in black, total USFWS catch in is red



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The 2019 Spring Kodiak Trawl is scheduled to begin in December 2018 and run through May 2019. Data and metadata are available on the FTP website.

[1]USFWS EDSM data, metadata, and weekly summaries are available from the USFWS webpage.

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■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

Theodore Flynn, California Department of Water Resources, Lead Editor Sarah Lesmeister, California Department of Water Resources, Managing Editor

The Interagency Ecological Program for the San Francisco Estuary is a cooperative effort of the following agencies:

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California Department of Fish and Wildlife
State Water Resources Control Board
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