Aquatic Species Response to Restoring Tidal Flows to the Pond A8 Complex

Alviso Marsh, South San Francisco Bay

Final Report

Survey Years 2014-2018

Prepared by:

James Hobbs,
Department of Wildlife, Fish and Conservation Biology
University of California-Davis

Prepared for:

Santa Clara Valley Water District
&
South Bay Salt Pond Restoration Project Don Edwards San Francisco Bay NWR
1 Marshlands Rd.
Fremont, CA 94555

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Background

The South Bay Salt Pond Restoration Project (http://www.southbayrestoration.org/), the largest wetland restoration project in the western United States, is conducting an adaptive management experiment to restore tidal flows to the pond A8 complex (EDAW 2007). The A8 pond complex is a series of interconnected ponds (A8, A7, and A5) located at the interface of the Guadalupe River with Alviso Marsh in Lower South San Francisco Bay, that has had a legacy of mercury contamination from cinnabar open-pit mining in the Guadalupe River watershed (Thomas et al. 2002; Beutel and Abu-Saba 2004). Mercury and its organic form, methylmercury is a neurotoxin that is highly toxic to wildlife and a pervasive contaminant issue in the San Francisco Estuary (Conway et al. 2003; Davis et al. 2003). The inorganic form of mercury is known to become bioavailable (methylated) under low oxygen conditions (anoxia) and the presence of organic carbon and sulfate reducing bacteria, conditions commonly found in shallow tidal marshes (Zillioux et al 1993; Lacerda and Fitzgerald 2001). Thus, restoring tidal flows to the A8 complex could increase mercury concentrations in fish and wildlife inhabiting the Alviso Marsh (EDAW 2007). To adaptively manage restoration of tidal flows to the pond, a 40-ft wide operable tide gate system known as the "armored notch" located in the south-east corner of the pond complex was constructed to allow for experimental testing of the effects of restoring tidal flows to the pond. The armored notch consists of eight, 5-foot wide gates each with 10 removable aluminum doors per tide gate allowing for flexible management of flows into and out of the pond (Figure 1).

Tidal flows were returned to the A8 complex over a period of years, experimentally opening additional gates and using bio-monitoring of sentinel species to inform management of potential additional mercury exposure to biota due increased tidal flows to the pond. Construction of the A8 armored notch began in September 2010, with the initial opening of a single gate in June 2011. Mercury concentrations in sediment, water, and biosentinel species - threespine stickleback, (*Gasterosteus aculeatus)* and Mississippi silversides (*Menidia beryllina*), lonjaw mudsucker (*Gillichthys mirabilis*) and eggs of Forster's Terns (*Sterna forsteri*) and American Avocets (*Recurvirostra americana*) was monitored during 5 monthly surveys (April, June, July August and October) beginning in 2010 during the construction phase and in 2011 before and immediately following the initial opening of the single gate (Ackerman et al. 2013) Elevated mercury concentrations were observed in biosentinel fish species in Alviso Slough and in Forster's Tern eggs in 2011 relative to reference sites, suggesting the increase in biosentinel species mercury concentrations was due to construction and opening of the armored notch (Ackerman et al. 2013). Subsequent surveys in 2012 and 2013 showed mercury concentrations in biosentinels had returned to pre-construction levels, however; mercury concentrations remained relatively high in fish and bird eggs with concentrations in Terns eggs remaining above the toxicity threshold of 0.90 µg/g) (Ackerman and Slotton unpublished data). Bio-monitoring of fish and bird egg mercury concentrations continued in in Alviso Marsh from 2014 to 2018, with support from the Santa Clara Valley Water District as additional gates were opened at the A8 notch. This study utilized these additional monitoring efforts to address additional uncertainties regarding restoration of the A8 complex.

The South Bay Salt Pond Restoration Project EIR outlined additional uncertainties of pond restoration on non-avian species and water quality following the restoration of tidal flows to the A8 complex (EDAW 2007). Pond management (*opening of additional tide gates*) and resulting water discharge to the sloughs has the potential to decrease slough water quality and affect aquatic species. Shallow water habitats in marshes, particularly those that are impounded by water control structures can experience dramatic fluctuations in dissolved oxygen (DO) due to the daily process of photosynthesis producing oxygen during daylight and consumption (respiration) of oxygen and night, a phenomenon known as diel-cyclic hypoxia (Diaz and Breitburg 2009). At times, respiration can far outstrip production causing prolonged periods of hypoxia. In addition, shallow impounded habitats can potentially increase water temperatures and water clarity in connected sloughs and change slough salinity through storage of low-salinity water from winter storm events or from evaporation during warm periods. These changes to slough water quality can have impacts on aquatic species abundance, diversity and community composition by reducing habitat suitability for sensitive species, promoting hardier species which are often invasive (non-native) species (Bowen and Valiela at al. 2001; Breitburg et al. 2002; 2009).

To determine if management of the A8 complex influences aquatic species inhabiting the Alviso Marsh, we conducted nekton surveys in the sloughs of Alviso Marsh (Alviso Slough, Guadalupe Slough and Artesian Slough (also referred to as Mallard Slough) to document changes in abundance of fish, invertebrates, diversity and community structure in Alviso Slough.

Site description

The Alviso Marsh Complex is the southernmost marsh located in Lower South Bay (LSB) and the location of the earliest restoration efforts performed by the SBSPRP (Figure 1). The marsh consists of two major tidal channels and four tributary sloughs. Alviso Slough is connected to the Guadalupe River at the uppermost end and is shallow (<4-m depth), relatively narrow (30- to 70-m wide), and bordered by a narrow band of cordgrass and pickleweed. Coyote Creek Slough is the major axis of the marsh, bifurcating into three smaller sloughs, Mud Slough, Artesian Slough, and Dump Slough, and is connected to the Coyote Creek watershed. The 1,280 acre A8-complex includes three internally breached ponds (A5, A7, and A8) and is connected to the upper reaches of Alviso Slough through an operable tide gate system (commonly knownly as the A8 notch) consisting of eight, 5-ft wide operable tide gates (Figure 1). Tidal flows enter the complex through this gate system located at the upper end of Alviso Slough, but overall volume of water exchanged on tides is small relative to the volume of the ponds and thus water elevation changes little. Water control structures are also located at the north ends of ponds A5 and A7; A5 exchanges water with Guadalupe Slough, while A7 with Alviso Slough. Gates were opened over several years (2011-2017); first opening a single tide gate in June 2011, three gates in June 2012, five gates in late September 2014, and all eight gates in June 2017 (Table 1).

Table 1. Schedule of operation for the armored notch on pond A8. The gates were not closed after March 2014.

Open	Closed	Gates
6/1/2011	12/1/2011	1
6/1/2012	12/1/2012	3
6/1/2013	12/1/2013	3
3/4/2014	NC	3
9/24/2014	NC	5
6/2/2017	NC	8

Figure 1. Map of the Alviso Marsh with the four slough sites in orange triangles.

Surveys for fish and macroinvertebrates were conducted at slough sites (Artesian Slough-*also referred to as Mallard Slough in prior mercury studies by D. Slotton*), upper Alviso Slough, lower Alviso Slough, and Guadalupe Slough) chosen for fish bio-sentinel monitoring for mercury contamination (Figure 1), (Ackerman et al. 2013). The lower Alviso Slough site was not included in the 2014 survey due to funding availability. Five surveys per year were conducted from February 2014 to February 2018, (April, May, June-July, September-October, and February) except for 2014 when only four survey periods were completed (Table 2). Small fish (20-mm to approximately 3-cm) and macroinvertebrates (>5-mm) were sampled using a 30-m beach seine, 1.5-m depth with 0.32-cm stretch mesh to assess species assemblage differences among restoration sites. Seine hauls were manually pulled along the shoreline sampling a rectangular area to a depth of approximately 1.5-m. Seine hauls swept an area of 81-m^2 ± 16-m 1-standard deviation. All sampling occurred during daytime hours from approximately between 8-am and 8-pm. Surveys were conducted before and after changes in gate operations at the A8 notch.

Table 2. Survey number, dates and gate operations at the A8 armored notch.

Survey	Dates	A8 Gate Operations
2014 Survey 1	Feb 16 to Feb 23 2014	No gates open
2014 Survey 2	May 14 to May 17 2014	3 gates open
2014 Survey 3	Jun 28 to Jun 30 2014	3 gates open
2014 Survey 4	Aug 16 to Aug 24 2014	3 gates open
2015 Survey 1	Apr 18 to Apr 30 2015	5 gates open
2015 Survey 2	May 16 to May 19 2015	5 gates open
2015 Survey 3	Jun 25 to Jun 30 2015	5 gates open
2015 Survey 4	Sep 26 to Sep 29 2015	5 gates open
2015 Survey 5	Feb 13 to Feb 17 2016	5 gates open
2016 Survey 1	Apr 16 to Apr 17 2016	5 gates open
2016 Survey 2	May 19 to May 22 2016	5 gates open
2016 Survey 3	Jul 9 to Jul 11 2016	5 gates open
2016 Survey 4	Oct 8 to Oct 10 2016	5 gates open
2016 Survey 5	Feb 4 to Feb 7 2017	5 gates open
2017 Survey 1	Apr 15 to Apr 17 2017	5 gates open
2017 Survey 2	May 19 to May 22 2017	5 gates open
2017 Survey 3	Jul 15 to Jul 17 2017	8 gates open
2017 Survey 4	Oct 14 to Oct 17 2017	8 gates open
2017 Survey 5	Feb 10 to Feb 12 2018	8 gates open

The primary objective for these surveys were to collect Mississippi silverside (*Menidia beryllina*) and threespine stickleback (*Gasterosteus aculeatus*) for fish mercury bio-monitoring (*fish mercury concentrations will be reported by D. Slotton in his report, not in this report*). The bio-monitoring protocols required sampling slough sites within a relatively small area and due to the low abundance of sentinel species, multiple seine hauls (10-50) were conducted at each site to collect the requisite number and size of fish. Unfortunately this protocol led to local sample depletion of the aquatic community, thus for abundance, diversity and assemblage assessment we typically only recorded catch data from the first seine haul of each day at each slough site. In this first seine haul, all fish were quantified and identified to species. Large invertebrates (clams, shrimps, snails) >10-mm were quantified and identified to species, while smaller invertebrates (amphipods, isopods, and mysid shrimp) <10-mm were given a rank abundance from 0 to 5 (0=absent, 1 = 1-3, 2 = 4-10, 3 = 11-50, 4 = 51-100 and 5 = >100 individuals).Water quality was recorded at each site prior to the first seine haul with a handheld YSI Pro Plus. Water quality parameters included temperature (°C), salinity (parts-per-thousand, ppt), conductivity (microsiemens, μm), dissolved oxygen concentration (mg/L and % saturation). Sampling depth (m) and turbidity (Secchi depth, cm) was measured with a meter stick with a white disk mounted to the bottom for Secchi depth. Area sampled was estimated using distance from shore and along shore for each seine haul.

Results

Between February 2014 and February 2018, we conducted a total of 19 surveys quantified all fish and macroinvertebrates in a total of 171 seine hauls, capturing 51,538 fish composed of 32 species and 8,750 individual invertebrates of nine field-identifiable species (Table 3). Non-native species dominated the overall catch composition, comprising 84% of total fish catch and 86% of invertebrate catch. The catch was dominated by only four fish species that made up >90% of the fish catch (Table 3). The non-native Mississippi Silverside (*Menidia beryllina*), one of the two sentinel fish species in this study, was the most abundant taxa collected (Table 2). Non-native Rainwater Killifish (*Lucania parva*) and Yellowfin Goby (*Acanthogobus flaviminus*) were the second and third most abundant fish species, followed by the native Topsmelt (*Atherinops affinis*) and Northern Anchovy (*Engraulis mordax*). Three-spine Stickleback (*Gasterosteus aculatus*), a native species, was the second sentinel species in this study and was the sixth most abundant fish species (Table 3). The Oriental shrimp (*Palaemon macrodactylis*), a non-native species, was the most abundant invertebrate species, followed by the non-native overbite clam (*Potamocorbula amurensis*). Native invertebrates were rare in our seine hauls, comprising less than 6% of the catch. The native yellow shore crab (*Hemigrapsus oregonensis*) was the third most numerous invertebrate, followed by the California bay shrimp (*Crangon fransiscorum*). A composite taxa of unidentified polycheate worm was the fourth most abundant taxa. The sixth most abundant invertebrate was the Siberian prawn (*Exopalaeomon modestus*).

Beach sein haul being retrieved at the lower Alviso Slough site by Emily Trites and Rachel Fichman on July 16th 2017

Table 3. Catch summary for surveys from February 2014 to February 2018

A.

Rank	Common Name	Genus species	Origin	W	Sp	Su	F	Total Catch	% Catch
1	Mississippi Silverside	Menidia audens	Non-native	2525	5763	14729	5204	28221	55%
2	Rainwater Killifish	Lucania parva	Non-native	83	1258	6406	963	8710	17%
3	Yellowfin Goby	Acanthogobius flavimanus	Non-native	13	5314	756	27	6110	12%
4	Topsmelt	Atherinops affinis	Native	110	2432	950	83	3575	7%
5	Northern Anchovy	Engraulis mordax	Native	1038	550	329	2	1919	4%
6	Threespine Stickleback	Gasterosteus aculeatus	Native	15	451	730	153	1349	3%
7	Longjaw Mudsucker	Gillichthys mirabilis	Native	0	322	58	2	382	1%
8	Pacific Staghorn Sculpin	Leptocottus armatus	Native	117	118	22	1	258	1%
9	Arrow Goby	Clevelandia ios	Native	0	183	32	3	218	0%
10	Largemouth Bass	Micropterus salmoides	Non-native	0	66	125	7	198	0%
11	Western Mosquitofish	Gambusia affinis	Non-native	15	42	75	5	137	0%
12	Pacific Herring	Clupea pallasii	Native	37	97	0	0	134	0%
13	Threadfin Shad	Dorosoma petenense	Non-native	16	0	60	3	79	0%
14	Starry Flounder	Platichthys stellatus	Native	0	3	51	0	54	0%
15	California Halibut	Paralichthys californicus	Native	1	12	9	8	30	0%
16	Shiner Perch	Cymatogaster aggregata	Native	0	28	1	0	29	0%
17	Striped Mullet	Mugil cephalus	Native	0	19	10	0	29	0%
18	Bay Pipefish	Syngnathus leptorhynchus	Native	4	7	11	3	25	0%
19	Shokihaze Goby	Tridentiger barbatus	Non-native	4	5	2	12	23	0%
20	Walleye Surfperch	Hyperprosopon argenteum	Native	0	15	0	0	15	0%
21	Sacramento Sucker	Catostomus occidentalis	Native	0	10	0	0	10	0%
22	Plainfin Midshipman	Porichthys notatus	Native	0	0	0	6	6	0%
23	Prickly Sculpin	Cottus asper	Native	0	1	3	1	5	0%
24	Shimofuri Goby	Tridentiger bifasciatus	Non-native	3	0	2	0	5	0%
25	American Shad	Alosa sapidissima	Non-native	3	1	0	1	5	0%
26	Bat Ray	Myliobatis californica	Native	0	0	0	3	3	0%
27	White Croaker	Genyonemus lineatus	Native	0	3	0	0	3	0%
28	Diamond Turbot	Pleuronichthys guttulatus	Native	1	1	0	0	2	0%
29	Tule Perch	Hysterocarpus traskii	Native	0	0	0	1	1	0%
30	Chameleon Goby	Tridentiger trigonocephalus	Non-native	0	1	0	0	1	0%
31	Striped Bass	Morone saxatilis	Non-native	0	0	1	0	1	0%
32	Common Carp	Cyprinus carpio	Non-native	0	0	1	0	1	0%
			Total	**3985**	**16702**	**24363**	**6488**	**51538**	

B.

Rank	Invertebrates	Genus species	Origin	W	Sp	Su	F	Catch	Catch %
1	Oriental shrimp	Paleomon macrodactylus	Non-native	437	4071	890	1185	6583	75%
2	overbite clam	Potamocorbula amurensis	Non-native	383	87	547	135	1152	13%
3	yellow shore crab	Hemigrapsus oregonensis	Native	1	24	201	21	247	3%
4	Unidentified Polychaete	NA	NA	214	2	0	5	220	3%
5	bay shrimp	Unk Crangonid spp.	Native	33	132	5	1	171	2%
6	Siberian prawn	Exopalaemon modestus	Non-native	34	4	119	0	157	2%
7	European mudsnail	Illyanasa obsoleta	Non-native	45	26	13	2	86	1%
8	unidentified clam	NA	NA	0	0	9	60	69	1%
9	Asian clam	Corbicula fluminea	Non-native	5	0	21	0	26	0%
10	comb jelly	Pleurobrachia bachei	Non-native	13	3	3	0	19	0%
11	softshell clam	Unk Macoma spp.	Native	10	1	5	0	16	0%
12	Asian mussel	Musculista senhousia	Non-native	0	2	0	2	4	0%
			Total	**1175**	**4352**	**1813**	**1411**	**8750**	

Abundance Trends

Abundance of fish and invertebrates varied by year, survey number and slough site (Figure 2A-D). Fish and invertebrate abundance tended to be lower during the winter surveys at all sites (Table 4) except for upper Alviso Slough. Strong seasonal variability in abundance is common in estuaries and was documented in the Alviso Marsh from 2010 to 2014 in our otter trawl surveys (Cook 2016). Fish abundance was higher at the upper Alviso Slough site than the lower Alviso Slough Site and higher than the Guadalupe Slough but was highest at the Artesian Slough site (Table 4). Invertebrate abundance was highest at the lower Alviso Slough site followed by upper Alviso Slough, Guadalupe Slough and Artesian Slough (Table 4).

Table 4 Summary of mean catch per seine haul by season and site.

	Upper Alviso		Lower Alviso		Guadalupe		Artesian	
	Fish	Inverts	Fish	Inverts	Fish	Inverts	Fish	Inverts
	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE	x̄ ± 1SE
Winter	224 ± 130	5 ± 3	42 ± 7	108 ± 28	89 ± 32	6 ± 3	121 ± 80	51 ± 27
Spring	204 ± 61	185 ± 82	61 ± 12	47 ± 12	109 ± 21	16 ± 7	609 ± 154	1 ± 1
Summer	493 ± 83	21 ± 7	383 ± 184	189 ± 103	276 ± 122	73 ± 48	1198 ± 609	2 ± 1
Fall	192 ± 158	6 ± 3	62 ± 18	223 ± 60	290 ± 81	8 ± 4	427 ± 197	0 ± 0
Survey mean	285 ± 48	86 ± 37	96 ± 27	105 ± 21	168 ± 33	26 ± 12	594 ± 164	14 ± 8

Did abundance of fish and invertebrates change in response to opening gates on the armored notch?

There was no clear change in abundance of fish or invertebrates in Alviso Slough following the opening of additional gates on the armored notch (Figure 2A-D). The first gate opening occurred between surveys 1 and 2 of 2014, unfortunately we did not have data at the Alviso Slough sites during survey 1, and thus we cannot assess abundance change when three gates were opened March 4th 2014 (Table 1). Abundance of fish declined and invertebrates increased between August of 2014 and April of 2015 (surveys 2014_4 and 2015_1) at the upper Alviso Slough site following the opening of two additional gates on September 24th 2014 (Figure 2A). Fish abundance also declined at the Guadalupe Slough and Artesian Slough sites between these surveys, thus the opening of two additional gates was not likely that cause for fish abundance decline. Sampling at the upper Alviso Slough site during survey 4 of 2014 did not occur thus we cannot assess abundance change at this site. Three additional gates were opened June 2nd of 2017 and abundance of fish and invertebrates at the Upper Alviso Slough site increased (Figure 2A). Unfortunately no data was recorded at the lower Alviso Slough site during survey 3 of 2017. Abundance also increased at the Guadalupe Slough site but decreased at the Artesian Slough site during this period (Figure 2C-D).

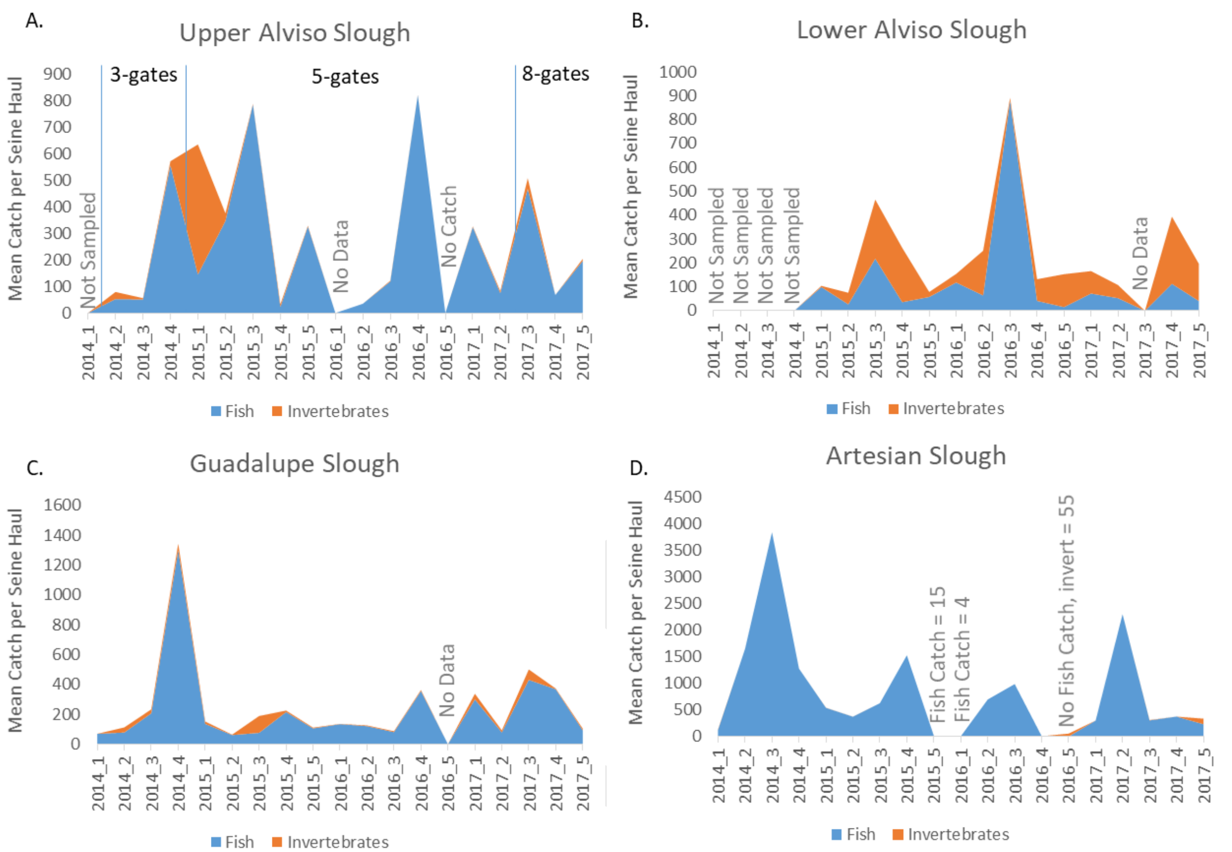

Figure 2. Mean catch per seine haul by survey year and number for all fish and invertebrates at A. upper Alviso Slough (ALV-2, B. lower Alviso Slough (ALV-3), C. Guadalupe Slough (GUA) and D. Artesian Slough (ART). Note y-axis are distinct for each figure. Armored notch gate openings occurred following 2014_1 when three gates were opened, between 2014-4 and 2015-1 when five gates were opened and between 2017_2 and 2017_3 when all eight gates were opened depicted in A. Note y-axis scales are unique for each plot.

Species Diversity Trends

The diversity of species captured in the study was summarized by averaging number of species (richness) per survey and site. Species richness varied by slough sites, ranging from a low of 4.2 species per seine haul at the Artesian Slough site to a high of 8.9 species at the lower Alviso Slough site and was generally higher for fishes (3.9 - 6.1) than invertebrates (0.3 – 2.8) (Table 5). The proportion of native species varied by site. For fishes the percent native species was similar between the Alviso Slough sites and Guadalupe Slough ranging 45-49% native, but Artesian Slough had much lower native species richness of only 28%. Invertebrate richness was also similar between Alviso Slough sites and Guadalupe Slough and much lower at Artesian Slough (6%) (Table 5).

Table 5. Summary statistics for species richness

	Fish Richness			Invertebrate Richness		
Upper Alviso	**Total**	**Native**	**Non-native**	**Total**	**Native**	**Non-native**
Mean	5.4	2.4	3.0	1.2	0.2	1.0
Total Species Richness			6.6			
Ratio native/Non-native			0.82			0.21
% Native Richness			45%			16%
Lower Alviso	**Total**	**Native**	**Non-native**	**Total**	**Native**	**Non-native**
Mean	6.1	3.0	3.1	2.8	0.5	1.9
Total Species Richness			8.9			
Ratio native/Non-native			0.95			0.28
% Native Richness			49%			18%
Guadalupe	**Total**	**Native**	**Non-native**	**Total**	**Native**	**Non-native**
Mean	5.4	2.4	3.0	1.6	0.3	1.1
Total Species Richness			7.1			
Ratio native/Non-native			0.81			0.30
% Native Richness			45%			21%
Artesian	**Total**	**Native**	**Non-native**	**Total**	**Native**	**Non-native**
Mean	3.9	1.1	2.8	0.3	0.0	0.2
Total Species Richness			4.2			
Ratio native/Non-native			0.38			0.07
% Native Richness			28%			6%

Species richness varied less seasonally than did abundance (Figure 5). This is due to the life history patterns of different species using the Alviso Marsh. For example, Northern Anchovy and Pacific Staghorn Sculpin were more abundant in the Winter and Spring when the fish come into the marsh to spawn, while many of the more abundant taxa had higher abundance in the Spring and Summer (Table 3).

Did richness of fish and invertebrates change in response to opening gates on the armored notch?

There was no change in diversity following the opening of additional gates on the armored notch in Alviso Slough (Figure 5A). At the upper Alviso Slough site total fish and invertebrate species richness increased slightly following the gate openings between August of 2014 and April of 2015 (surveys 2014_4 and 2015_1) and between April and July of 2017 (Survey 2017_2 and

2017_3). There was also no apparent change in the ratio of native to non-native species following the pond opening events.

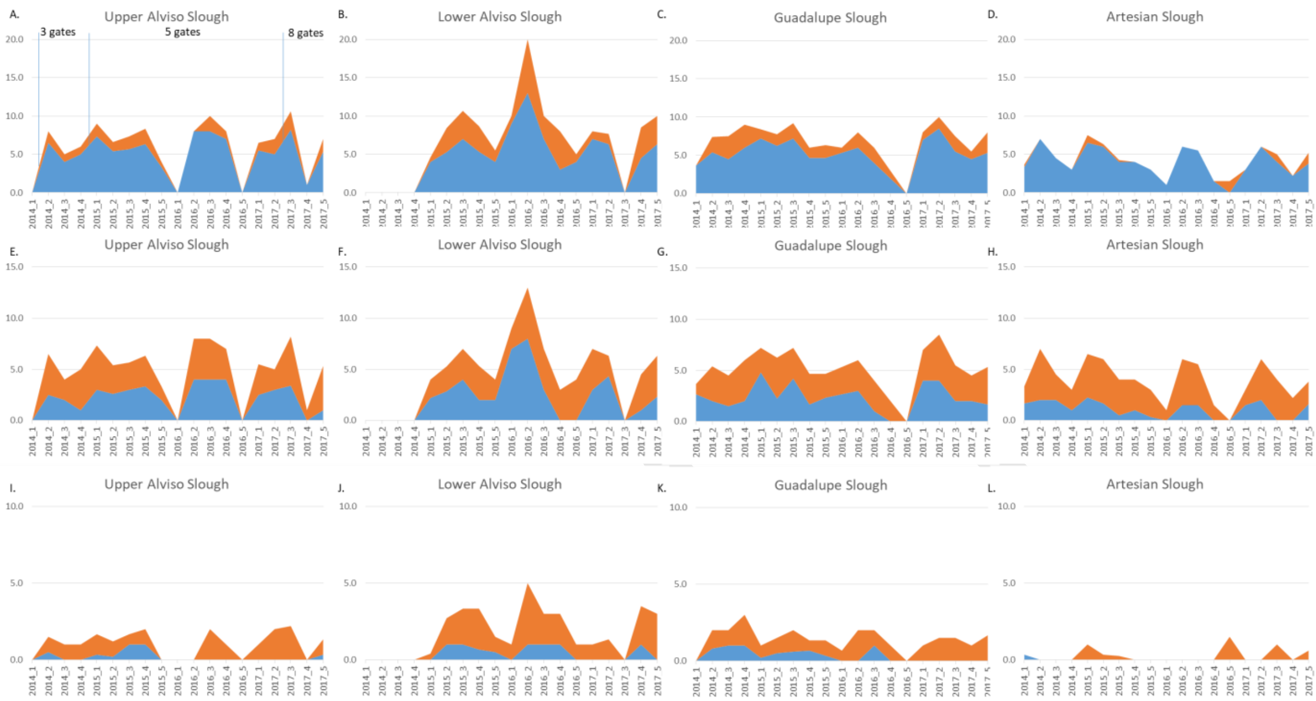

Figure 3 Mean species richness by survey year and number among the slough sampled in this study. A-D total fish (blue) and invertebrates (red) richness, E-H native fish (blue) non-native fish (red), I-L native invertebrates (blue) non-native invertebrates (red). Gate openings are depicted in A.

Water Quality

Water quality varied by year, survey and slough sites (Figure 3). Salinity was considerably lower at the Artesian Slough site, which is located near the San Jose-Santa Clara Wastewater Facility (Figure 1) and was higher at the lower Alviso Slough site than the upper Alviso Slough site (Figure 4A). Salinity was also much lower in 2017 which was one of the wettest years since the 1982-83 El-Nino. Temperature was consistently higher at the Artesian Slough site, while the other sites all were similar and varied seasonally (Figure 4B). Water clarity was much greater at the Artesian Slough site, and during a few survey was higher at the upper Alviso Slough site compared to the lower Alviso Slough site (Figure 4C). Dissolved oxygen concentration did not appear to be systematically different among the slough sites like the other water quality variables. DO was high in the Winter surveys and lower in the Summer and Fall (Figure 4D).

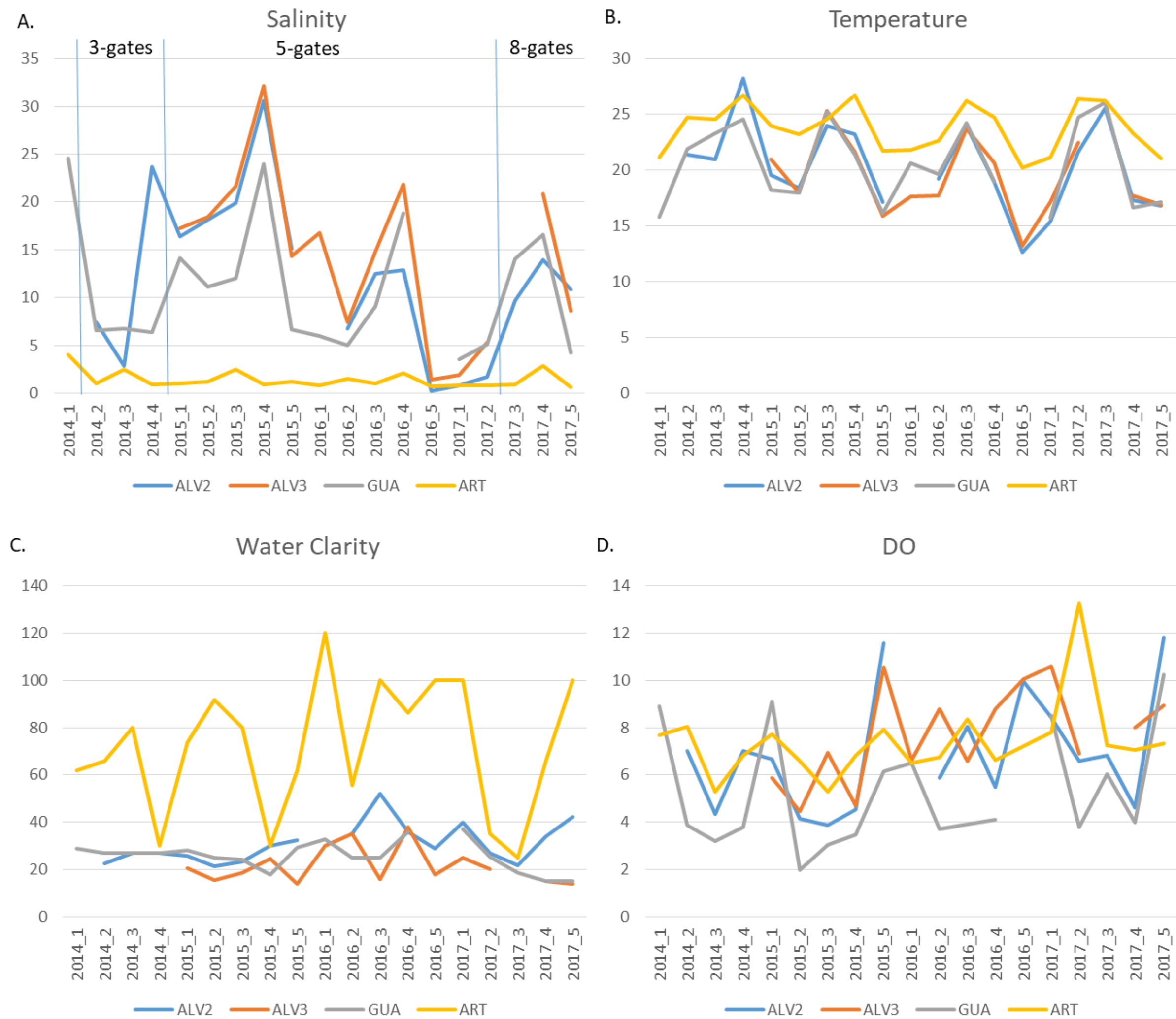

Figure 4 Water quality conditions during each survey and slough site. A. salinity in practical salinity units PSU B. Temperature in degrees Celsius, C. Water Clarity measures as Secchi depth in cm, and D. Dissolved oxygen concentration in mg/L

Did water quality change in response to opening gates on the armored notch?

No data was recorded during the first gate opening in March 2014 for Alviso Slough. Salinity and Temperature decreased, Water Clarity increased and little change occurred in DO at the upper Alviso Slough site between August of 2014 and April of 2015 (surveys 2014_4 and 2015_1) at the upper Alviso Slough site following the opening of two additional gates on September 24th 2014 (Figure 4A-D). These changes can largely be attributed to seasonal effects.

Assemblages

To determine if species assemblages varied by slough sites, seasons and years we included the top six fish and invertebrate species (Table 6), in a Non-metric Multidimensional Scaling plot which uses Bray-Curtis sample dissimilarity to construct a 2-D simplistic representation of assemblage structure.

Table 6. Abundant species used in species assemblage ordinations.

Rank	Fish	Origin	Total Catch	% Catch	Cumulative %
1	**Mississippi Silverside**	Non-native	28221	55%	55%
2	Rainwater Killifish	Non-native	8710	17%	72%
3	Yellowfin Goby	Non-native	6110	12%	84%
4	Topsmelt	Native	3575	7%	90%
5	Northern Anchovy	Native	1919	4%	94%
6	**Threespine Stickleback**	Native	1349	3%	97%

Rank	Invertebrates	Origin	Total Catch	% Catch	Cumulative %
1	Oriental Shrimp	Non-native	6583	75%	75%
2	Overbite Clam	Non-native	1152	13%	88%
3	Yellow Shore Crab	Native	247	3%	91%
4	Unidentified Polychaete	NA	220	3%	94%
5	Bay Shrimp	Native	171	2%	96%
6	Siberian Prawn	Non-native	157	2%	97%

There were distinct patterns among slough sites, seasons, and years (Figure 5A-C). Species assemblages found at Artesian Slough were the most distinct among the sloughs sampled, with the abundance of Mississippi Silverside, Rainwater Killifish, polycheate worms driving the assemblage dissimilarity (Figure 5A). The assemblage differences at the Artisian Slough can be explained by the large differences in water quality at this site (Figure 4). There was also strong seasonal patterning in the assemblage data. Winter and Spring assemblages appeared to be the most dissimilar while Summer and Fall were more similar to each other and located between Winter and Spring (Figure 5B). Seasonal patterns were driven by the lack of abundance of all species in the Winter and by grass shrimp and Yellowfin Goby in the Summer and the strong seasonal patterns in water quality (Figure 5C). There were also distinct patterns by year; the drought years of 2014-2016 were more similar to each other than the high flow year of 2017 and the following year of 2018. These single factors were statistically significant using PERMANOVA, however; the Season-Site interaction term was not significant and the Year-

Season-Site interaction was marginally significant (Table 7), thus sites generally changed similarly.

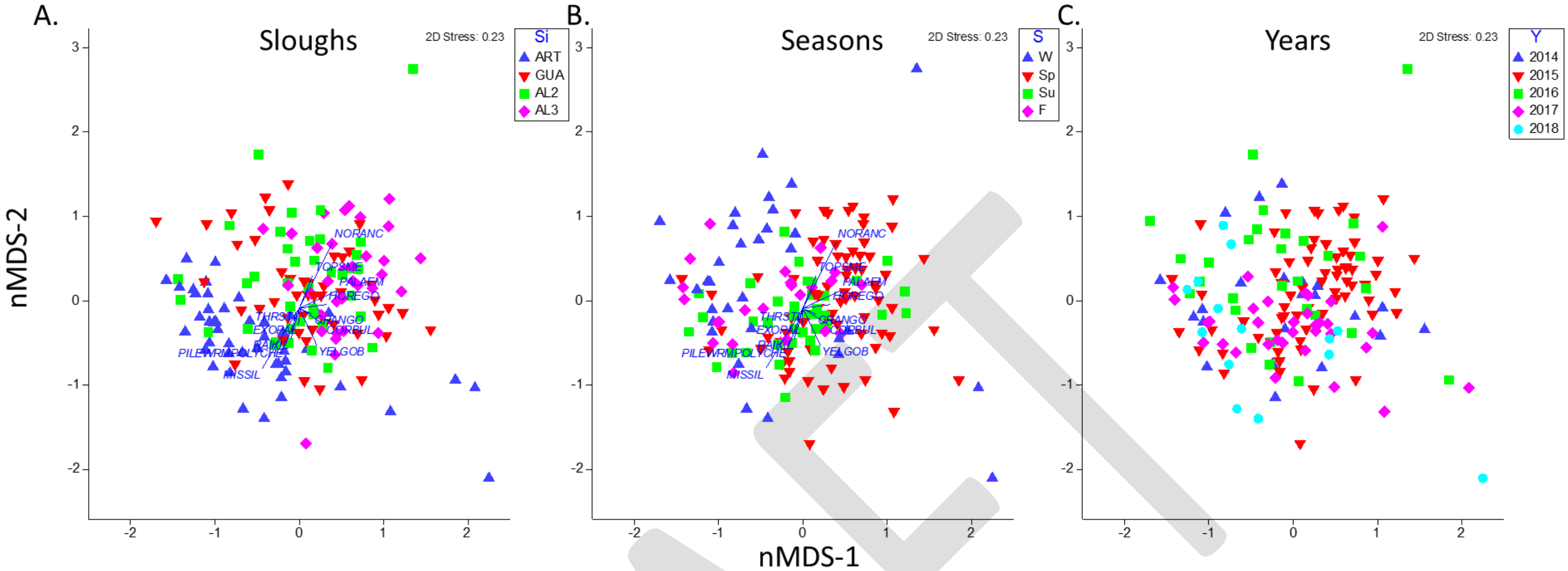

Figure 5. Non-metric multi-dimensional scaling plot of species assemblage. Labels are for slough sites, Artesian Slough (ART), Guadalupe Slough (GUA), upper Alviso Slough (AL2), and lower Alviso Slough (AL3). Vectors of taxa Spearmen rank correlations with sample dissimilarity overlayed on A. Slough sites and B. Seasons.

Table 7. PERMANOVA results table for species assemblage comparisons between years, seasons and sites.

PERMANOVA table of results

Source	df	SS	MS	Pseudo-F	P(perm)	Unique Perms
Year	4	18205	4551.3	4.5284	0.001	999
Season	3	28462	9487.3	9.4395	0.001	997
Site	3	23049	7683.1	7.6443	0.001	999
Year x Season	7	13262	1894.6	1.8851	0.009	998
Year x Site	11	21927	1993.3	1.9833	0.002	998
Season x Site	9	11730	1303.4	1.2968	0.125	999
Year X Season x Site	14	20686	1477.5	1.4701	0.025	997
Res	115	1.16E+05	1005.1			
Total	166	3.06E+05				

Did assemblages structure change in response to opening gates on the armored notch?

One common way to explore species assemblage data for signatures of anthropogenic impacts is through visualization of seriation (sequential ordering) of samples in nMDS ordination plots (Clarke et al. 2014). This technique displays the ordered spatial or temporal sequence of Bray-Curtis dissimilarities in nMDS ordinations (Figure 6). Sample are often spaced across impact sites or across time (before and after a disturbance). If distinct changes in species assemblage occur, samples taken in space or time closer to the impact site or disturbance will show distinct disruption or breaks in the assemblage patterns. We subset the data for only the upper Alviso Slough site assuming this location would most likely show changes in species assemblage due to opening gates to the armored notch and some consistent dissimilarity occurred between the upper and lower Alviso Slough sites in the full data set that is not likely the result of pond management (Figure 5A).

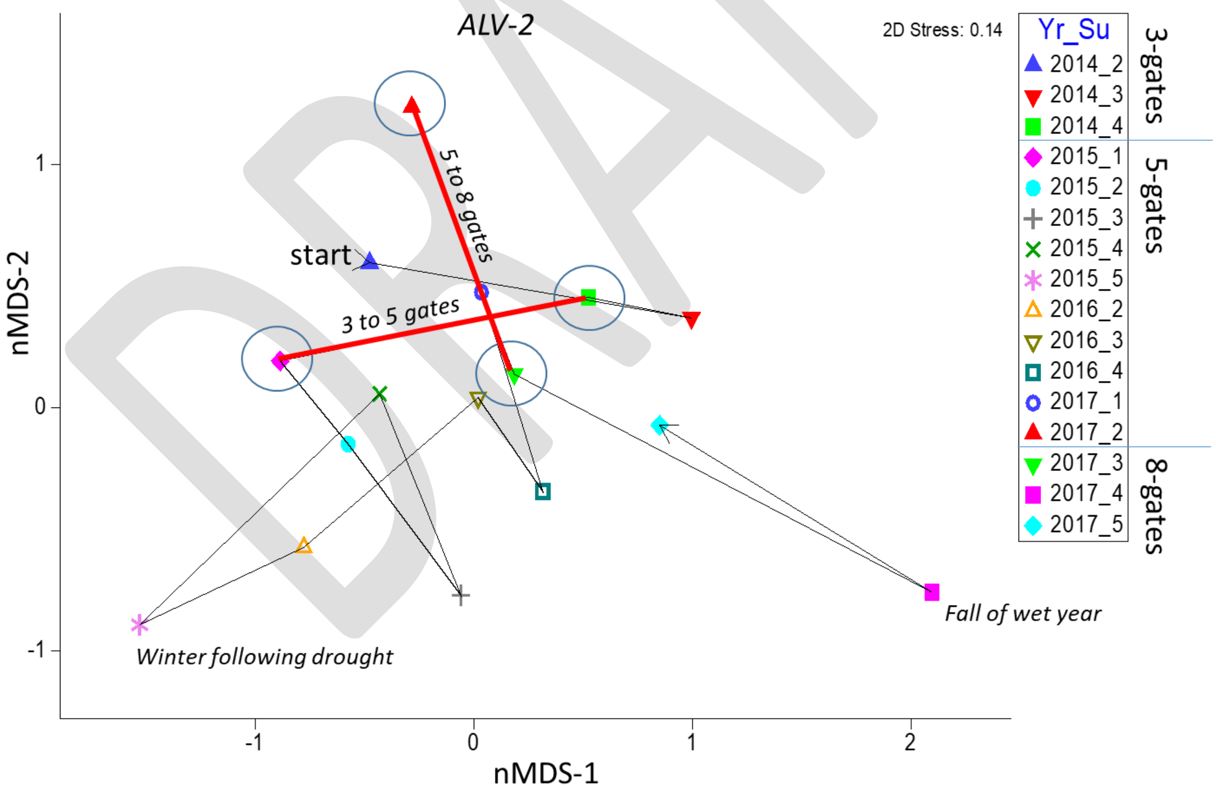

Figure 6 Seriation plot of species assemblage dissimilarity for upper Alviso Slough, with each year and survey number labelled and arrowed line depicting the temporal sequence of assemblage dissimilarity. If species assemblages changed following the opening of the armored notch distinct changes in the sequence would occur.

Species assemblages did not appear to change appreciably following the opening of gates on the armored notch (Figure 6). Distances between points before and after gates openings were similar in ordination length to other sample distances. The largest changes in species assemblage occurred between survey 4 and 5 of 2015 survey year, which represented the transition from prolonged drought to a wet period in February 2016, and between survey 3 and 4 of 2017 representing the transition from summer to fall of the extreme wet year.

Summary

From February of 2014 to February of 2018, we monitored the abundance, diversity and species assemblage of fish and invertebrates utilizing the shallow margins of sloughs in the Alviso Marsh to gain a better understanding of how salt pond restoration may benefit aquatic species. Seasonal variability was the most common pattern observed in abundance and species assemblage among the four slough sites sampled in this study. Species abundance was much lower in the Winter months and assemblage composition was different in Winter than in other seasonal surveys. During the course of this study, several gates were opened on the armored notch in pond A8 to increase tidal flows between upper Alviso Slough and the pond. We did not detect a strong effect of pond management actions on aquatic species abundance, diversity or assemblage with our survey data. However, our surveys were not conducted to directly test the effects of gate openings on aquatic species in Alviso Slough, rather our sampling schedule was dictated by protocols established for mercury contaminant monitoring. To more accurately determine the effects of pond management on aquatic species in Alviso Slough, surveys could have been organized more closely to dates when additional gates were opened on the armored notch. Any adverse impact to the species inhabiting upper Alviso Slough following pond gate openings likely would have occurred within the first few days. Moreover, sampling within pond A8 could have determined whether species abundance, diversity of assemblage occurred there in response to opening additional gates. Lastly, given the natural seasonal variability in the Alviso Marsh, gate openings could have occurred in the same season, once assemblage composition reached its most stable point within the season. Future studies could use mark-recapture or telemetry techniques to determine how the armored notch influences species movements and fish passage in Alviso Slough.

There were distinct differences in abundance, diversity and assemblage composition between slough sites; Artesian Slough being the most different. Mean fish abundance over all surveys was 2 to 6 time higher at the Artesian Slough site, averaging nearly 600 individuals per seine haul while invertebrate abundance and species richness was lowest. These patterns in part, can be attributed to the influx of freshwater from the Santa Clara-San Jose Wastewater Facility which discharges up to 80-million gallons of tertiary treated effluent into Artesian Slough daily. Salinity at the Artesian Slough site was consistently much lower than other sites ($\bar{x}$ = 1.4 psu vs. 10.8 to 14.5 psu at other sites) and many of the taxa captured at this site are known to prefer lower salinity habitats. These species tend to be non-native taxa including Rainwater Killifish (*Lucania parva*), Largemouth Bass (*Micropterus salmoides*), Western Mosquito Fish (*Gambusia affinis*), the Asian clam (*Corbicula fluminea*) and Striped Bass (*Morone saxatilis*) (Table 8). This not surprising as the freshwater regions of the San Francisco Estuary are known to be dominated by non-native species (). There were also many species (20 of 44 total identifiable taxa) that were not encountered at the Artesian Slough site during our surveys (Table 8). Some of these species are less tolerant of freshwater conditions including, Bay Rays (*Myliobatis californica*), Plainfin Midshipmen (*Porichthys notatus*), Shiner Perch (*Cymatogaster aggregate*), Walleye Surfperch (*Hyperprosopon argenteum*), White Croaker (*Genyonemus lineatus*), which are considered more stenohaline marine taxa (Allen et al.2006) . Other species not encountered at the Artesian Slough site in this study but captured during our otter trawl surveys include, Common Carp (*Cyprinus carpio*), Shimofuri Goby (*Tridentiger bifasciatus*), Starry Flounder (*Platichthys stellatus*), Siberian Prawn (*Exopalaemon modestus*) and Pacific Herring (*Clupea pallasii*)().

While, wastewater effluent contains many chemicals that are toxic to aquatic species and excess nutrients from wastewater discharge can lead to eutrophication, this effluent is the primary source of freshwater to the Alviso Marsh and most species utilizing this habitat are estuarine species needing low to moderate salinity conditions. We modelled habitat suitability for the dominant taxa in the marsh using our 6+ years of otter trawl surveys and found many native species were more abundant in freshwater and estuarine habitats with salinity up to 10 psu, including the Threespine Stickleback (*Gasterosteus aculeatus*) Pacific Staghorn Sculpin (*Leptocottus armatus*), and Pacific Herring (*Clupea pallasii*) (Lewis and Hobbs 2018), all important forage fish for the San Francisco Bay foodweb. Future flood control and restoration plans for the Alviso Marsh include reuse of wastewater effluent from this facility, which will lead to discharge of high salinity brine into Artesian Slough and increased salinity throughout the marsh. According to our models, this will have a profound impact on the aquatic species that use this region of the estuary. In addition our research in other marshes (Napa, Sonoma and Petaluma) shows that fish and invertebrate abundance is much greater in the Alviso Marsh (Barros et al. 2018) and is critical habitat for a threatened species (state-ESA) the Longfin Smelt (*Spirinchus thalichthys*) (Parker et al. 2017) and in 2017 we documented for the first time, successful reproduction occurring in the Alviso Marsh (Lewis et al. 2018). If wastewater effluent is to be removed from the Alviso Marsh, increased flows from the Guadalupe River and Coyote Creek may be required to offset the loss of freshwater flows to the estuary.

Micah Bisson pulling a beach seine at Guadalupe Slough October 15th 2017

Table 8 Catch summary table sorted for Artesian Slough catch

Common Name	Genus species	Upper Alviso	Lower Alviso	Guadalupe	Artesian	Total	% Catch Art
Mississippi Silverside	Menidia audens	4933	1238	4675	17375	28221	62%
Rainwater Killifish	Lucania parva	669	331	137	7573	8710	87%
Yellowfin Goby	Acanthogobius flavimanus	692	290	1400	3728	6110	61%
Threespine Stickleback	Gasterosteus aculeatus	578	166	295	310	1349	23%
Longjaw Mudsucker	Gillichthys mirabilis	69	18	85	210	382	55%
Unidentified Polychaete	NA	0	7	14	200	221	90%
Largemouth Bass	Micropterus salmoides	0	0	5	193	198	97%
overbite clam	Potamocorbula amurensis	92	349	523	188	1152	16%
Western Mosquitofish	Gambusia affinis	4	1	8	124	137	91%
Arrow Goby	Clevelandia ios	56	5	78	79	218	36%
Pacific Staghorn Sculpin	Leptocottus armatus	83	37	68	70	258	27%
European mudsnail	Illyanasa obsoleta	5	36	0	45	86	52%
Striped Mullet	Mugil cephalus	0	0	0	29	29	100%
Asian clam	Corbicula fluminea	0	0	0	26	26	100%
bay shrimp	Unk Crangonid spp.	3	1	143	24	171	14%
Topsmelt	Atherinops affinis	2519	450	590	16	3575	0%
Oriental shrimp	Paleomon macrodactylus	3184	2908	476	15	6583	0%
Threadfin Shad	Dorosoma petenense	51	0	23	5	79	6%
Northern Anchovy	Engraulis mordax	1155	641	120	3	1919	0%
Bay Pipefish	Syngnathus leptorhynchus	5	9	9	2	25	8%
California Halibut	Paralichthys californicus	10	6	13	1	30	3%
Shokihaze Goby	Tridentiger barbatus	1	19	2	1	23	4%
Diamond Turbot	Pleuronichthys guttulatus	0	0	1	1	2	50%
Striped Bass	Morone saxatilis	0	0	0	1	1	100%
yellow shore crab	Hemigrapsus oregonensis	17	181	49	0	247	0%
Siberian prawn	Exopalaemon modestus	129	17	11	0	157	0%
Pacific Herring	Clupea pallasii	20	2	112	0	134	0%
unidentified clam	NA	0	60	9	0	69	0%
Starry Flounder	Platichthys stellatus	45	0	9	0	54	0%
Shiner Perch	Cymatogaster aggregata	2	26	1	0	29	0%
comb jelly	Pleurobrachia bachei	11	6	2	0	19	0%
softshell clam	Unk Macoma spp.	4	10	2	0	16	0%
Walleye Surfperch	Hyperprosopon argenteum	0	0	15	0	15	0%
Sacramento Sucker	Catostomus occidentalis	9	1	0	0	10	0%
Plainfin Midshipman	Porichthys notatus	0	6	0	0	6	0%
Prickly Sculpin	Cottus asper	4	0	1	0	5	0%
Shimofuri Goby	Tridentiger bifasciatus	2	3	0	0	5	0%
American Shad	Alosa sapidissima	3	1	1	0	5	0%
Asian mussel	Musculista senhousia	0	4	0	0	4	0%
Bat Ray	Myliobatis californica	2	1	0	0	3	0%
White Croaker	Genyonemus lineatus	0	0	3	0	3	0%
Tule Perch	Hysterocarpus traskii	1	0	0	0	1	0%
Chameleon Goby	Tridentiger trigonocephalus	1	0	0	0	1	0%
Common Carp	Cyprinus carpio	1	0	0	0	1	0%

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