
TECHNICAL MEMORANDUM

TO: Chris Berry
City of Santa Cruz Water Department

FROM: Jeff Hagar
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DATE: June 29, 2017

PROJECT: City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2017

Steelhead (*O. mykiss*) population abundance and life-history characteristics were assessed in Laguna Creek Lagoon and the San Lorenzo River Lagoon during the summer of 2017 by the City of Santa Cruz Water Department and Hagar Environmental Science (HES). Surveys are conducted annually with mark-recapture abundance surveys conducted in the early summer and again in the late summer using a large seine (46 meter (150 ft.) long by 2.4 meter (8 ft.) deep). Additional catch per effort surveys are conducted in the San Lorenzo Lagoon during July and August. Early summer and late summer mark-recapture abundance estimates for *O. mykiss* are completed using PIT tags. Fish are tagged one day and recaptured the next day in Laguna Creek. In the larger San Lorenzo River Lagoon, fish are captured and tagged on two consecutive days and recaptured during a subsequent two-day period (there are two days between the end of the mark period and the beginning of the recapture period). During July and August only catch per unit effort (CPUE) is assessed, no PIT tagging is implemented.

Laguna Creek lagoon was open intermittently through the end of July in 2017. Abundance of *O. mykiss* was relatively high both in the early summer and late summer and growth rates were good (average 0.66mm per day, range 0.17 to 0.89 mm/day, for thirteen fish).

The San Lorenzo Lagoon mouth was open for most of the summer and was open during all seining surveys. Water quality conditions reflected the open condition of the lagoon, tidal exchange, and a high rate of freshwater inflow. Lagoon temperatures were relatively cool (20°C or less) during most of the sampling periods. High salinity was present in deeper waters and oxygen was generally sufficient for salmonids, particularly in the upper layers of the water column. Abundance of juvenile steelhead was an order of magnitude higher than any past sampling events conducted by HES. Abundance was high on all sample dates. Seining effort had to be shortened in July, August and September due to limits imposed by our Federal endangered species take permit, even with increased take limits through coordination with

Santa Cruz County. Juvenile steelhead were most abundant near the trestle bridge but were captured at all regularly sampled stations from the beach to the bend upstream of Riverside Bridge. A number of fish tagged early in the summer were recaptured later in the summer (July, August, and September) indicating that at least a portion of the population was resident all summer.

As in 2016 NOAA Fisheries reported observations of lagoon tagged *O. mykiss* in the San Lorenzo River at the PIT tag antenna installed at Felton. A few fish moved during the summer but the majority of observations at Felton occurred in November.

Laguna Creek

Summary

The winter of 2016-2017 was very wet with flow peaks from precipitation events as late as mid-April. Flow in Laguna Creek just upstream of the lagoon was near 12 cfs on May 1 and declined to about 9 cfs at the time of initial seining in June (Figure 1). The relatively high inflow levels were associated with extended open lagoon conditions until the end of July when the lagoon closed for the rest of the season (Figure 1, lagoon depth). Brief periods of closure occurred beginning in late May but never lasted more than a few days until two longer closures (10 days and 7 days) preceding the final closure July 31.

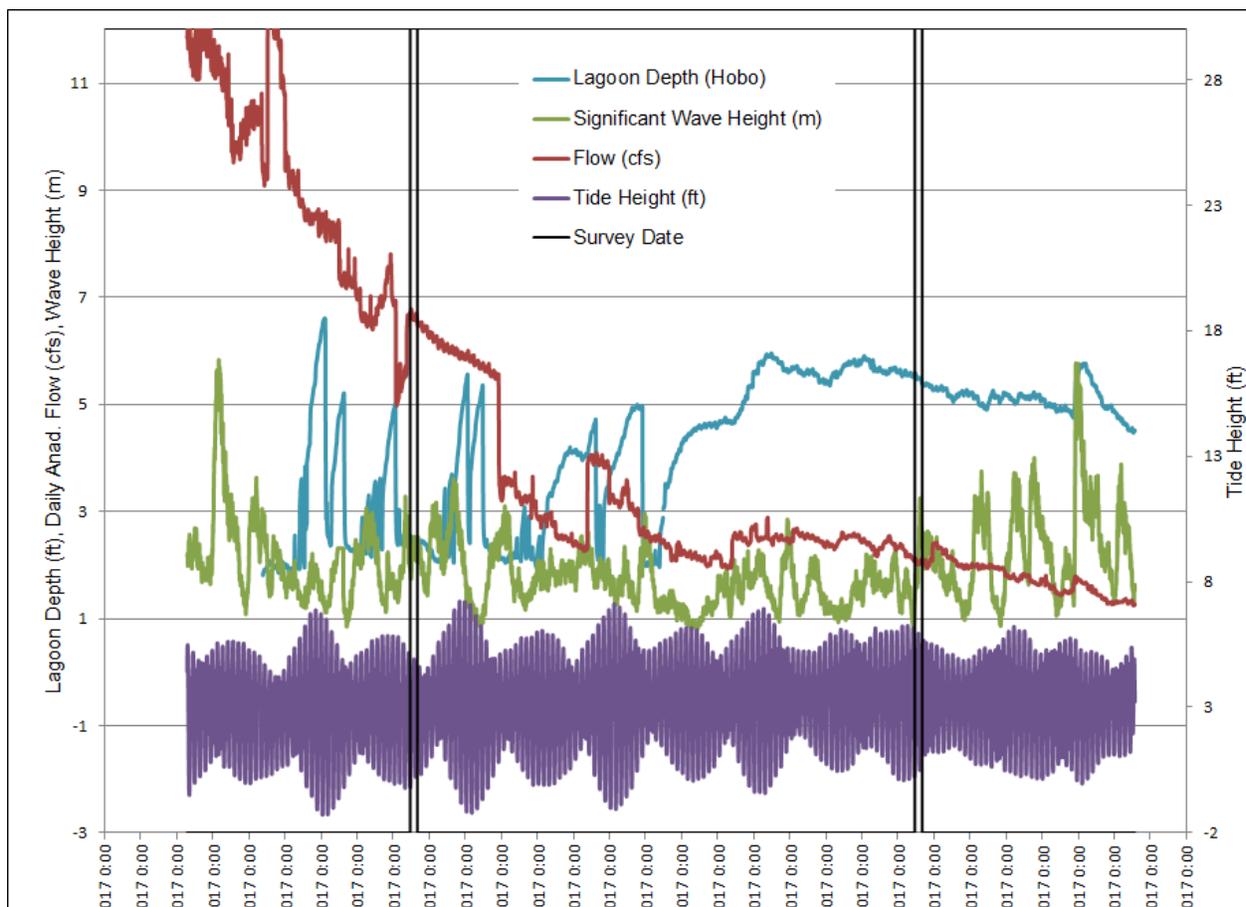


Figure 1. Laguna Creek Lagoon stage, streamflow, wave height, and tides 2017 (Source: lagoon depth from 2ND Nature and City of Santa Cruz, streamflow from Balance Hydrologics, wave and tide data from NOAA)

The wet winter of 2016-2017 and experimental diversion restrictions for habitat improvement resulted in relatively high inflows to the lagoon through the summer. Laguna Lagoon was intermittently open through the end of July. In June, habitat conditions were suitable in the upper 0.8 meters (2.6 ft.) of the water column with water deeper than 1.2 meters (3.9 ft.) not

supportive of *O. mykiss* due to high temperature and low dissolved oxygen. Catch per unit effort in June was the highest observed to date and the population estimate was the second highest. Large numbers of young-of-year (more than half the *O. mykiss* present in the lagoon) were present but were not counted in the population estimate as they were too small for tagging. In September, the mouth had been closed for a month and a half and water quality conditions were good for *O. mykiss* to a depth of at least 1.6 meters (5.2 ft.). Abundance of *O. mykiss* was down compared to June but still high relative to past surveys. The smaller size class was still well-represented but the larger size class was much reduced. Growth rates averaged 0.66 mm/day between the June and September sample dates, a good rate but lower than has been observed in some years. One *O. mykiss* tagged in Laguna Creek in June was recorded at the NOAA PIT tag antenna at Felton in November.

Early summer (June 13-14)

Early summer Site Conditions

- The mouth was open with a long, low gradient outlet channel extending the full length of the beach and opening along the rock shelf at the far north end of the beach (Figure 2). The lagoon appeared relatively full (Figure 3) and any tidal action was muted indicating that the outlet was perched above tidal influence (high tide of 1.5 meters (4.9 ft.) on June 14). Stage ranged from 2.5 the morning of June 13 to 2.3 the afternoon of June 13. The usual pockets of deep water were present along the rock bluff, the sand beach at the back of the mouth, and along the edge of the marsh inland. Maximum depth was about 1.7 meters (5.6 ft.).



Figure 2. Laguna Creek Lagoon outlet channel, June 14, 2017



Figure 3. Laguna Creek Lagoon, June 13, 2017

- Inflow from Laguna Creek ranged from 9.0 to 9.1 during the survey (almost 3 times the levels during the 2016 June survey).
- The lagoon was salinity, temperature, and oxygen stratified with relatively fresh cool and oxygenated water at the surface, a halocline/thermocline between 0.4 and 1.2 meters (1.3 and 3.9 ft.), and elevated salinity (>25 ppt) at 1.2 meters (3.9 ft.) and below (Figure 4, center panel). The lagoon was freshening between the 13th and the 14th in the middle of the water column (Figure 4).
- Temperature was reverse stratified (cooler at the surface and increasing with depth) (Figure 4, left panel). The surface 0.4 meters (1.3 ft.) was less than 16.0°C, with increases at depth to 28.0°C. Temperature was suitable for *O. mykiss* only in the upper meter (3.3 ft.).
- The upper water column was well oxygenated with dissolved oxygen generally 8 mg/L or higher but decreased to 6 mg/L or less at the bottom.
- The water column was clear with substrate visible at greatest depth surveyed (1.7 meters (5.6 ft.)).

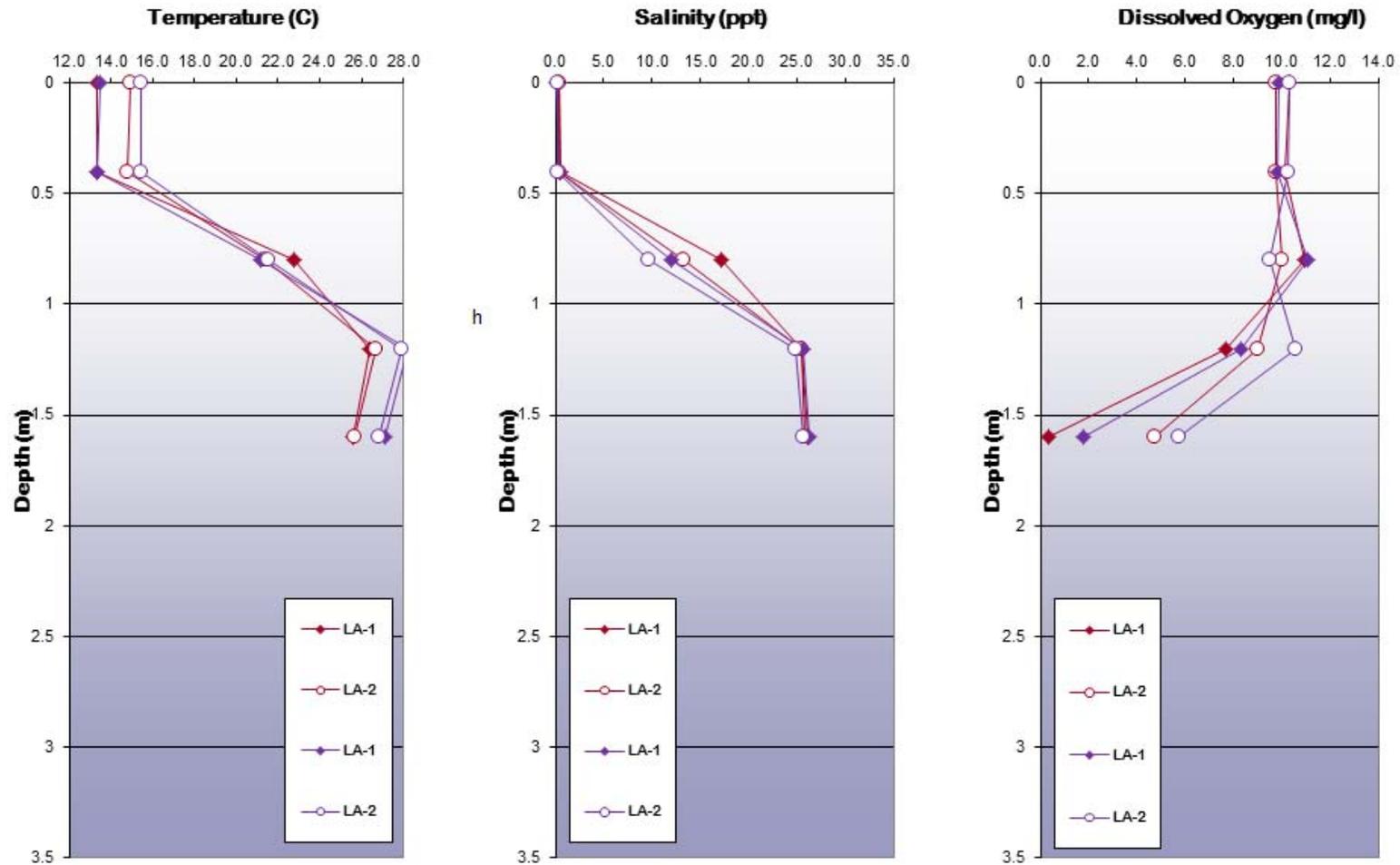


Figure 4. Depth profiles of water quality parameters in Laguna Creek Lagoon during June. Profiles plotted in red are June 13; profiles in blue are June 14.

Early summer Survey Results

- A total of 471 *O. mykiss* were captured in 11 hauls on June 13 and 14 between the beach and the water quality monitoring station (LA-3) (Table 1). Overall CPUE for *O. mykiss* was the highest recorded for all surveys to date at 42.8 per haul¹ (Table 2). The majority of fish (58% of the catch) were less than 80mm FL, probably all young-of-year.

Table 1. Fish catch in Laguna Creek Lagoon, June 2017

Species	LA-1	LA-1.5	LA-2	LA-3	Grand Total
	June 13-14				
<i># Hauls</i>	8	2	1	0	11
Steelhead	272	141	58		471
Threespine stickleback	1589	752	588		2929
Staghorn sculpin	6	26	10		42
Tidewater goby	10	34	5		49
<i>O. mykiss CPUE</i>	34.0	70.5	58.0		42.8

Note: See Figures at end of document for sample station locations.

Table 2. *O. mykiss* and coho salmon (*O. kisutch*) catch per seine haul in Laguna Creek Lagoon at consistently sampled stations (data from HES 2005, HES 2009, HES 2010, HES 2011, HES 2012, HES 2013, HES 2014, HES 2015, HES 2016, and HES 2017)

	<i>O. mykiss</i> Catch per Haul				Coho (<i>O. kisutch</i>) Catch per Haul			
	Jun	Jul	Sep	Oct	Jun	Jul	Sep	Oct
2004		2.4	0			0	0	
2008	11		6		0		0	
2009	7		19		0		0	
2010	13			1.7	0			0
2011	19.8			0.1	0			0
2012	11.3		10.3		0		0	
2013	28		8.6		0		0	
2014	20		33		0			
2015	0.1			11.4	0			0
2016	1.1		5.2		0		0	
2017	42.8		14.5		0		0	

¹ The mark-recapture population estimate was actually higher in fall 2014 however.

- The *O. mykiss* catch included fish in a smaller size group of 40mm to 89mm FL, and a group of larger individuals from 90mm to 230mm FL (Figure 5).
- The smaller *O. mykiss* and about two-thirds of the larger individuals were at parr stage. A third of the larger individuals, all greater than 120mm FL, were characterized as silvery parr. No smolts were observed.
- All *O. mykiss* had adipose fins present.
- Threespine stickleback were very abundant. Tidewater goby were also abundant but numbers were not reflected in the catch statistics since most were not retained in the relatively large mesh net.
- The over-wash pond was not sampled.

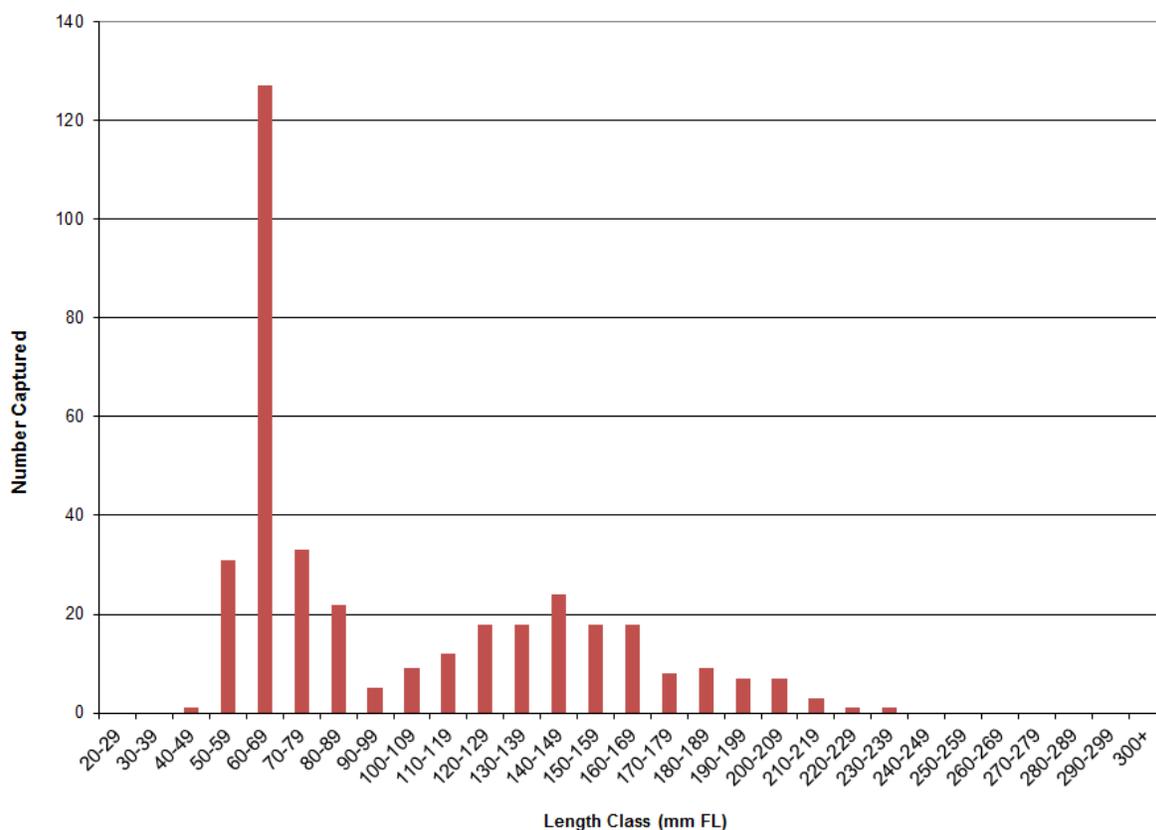


Figure 5. *O. mykiss* length classes in Laguna Creek Lagoon, June 2017

Early summer *O. mykiss* Population Estimate

- Only fish 80mm FL or greater were included in the population estimate.
- Two-hundred and thirty-two *O. mykiss* were captured during the marking period on June 13. One-hundred and forty-six were less than 80mm FL and were excluded from the population estimate (not counted as tagged fish). Five were recaptures of fish tagged during the tagging period. Therefore, there was a total of 81 tagged *O. mykiss* in the appropriate size classes released in the lagoon on June 13.
- On June 14, a total of 237 *O. mykiss* were captured. One-hundred and thirteen were below the minimum size range and were not included in the calculations. Out of the remaining 124, 15 had been tagged on June 13.
- The population estimate using the Petersen method (Ricker 1975) is 641 *O. mykiss* 80mm FL or larger in the lagoon in mid-June. The 95% confidence limits for this estimate are 398 and 1017. This is the second highest population estimate for all surveys (late summer 2014 was 828).
- The substantial number of *O. mykiss* less than 80mm FL can be estimated by assuming that the capture probability was the same as for the larger fish. Capture probability is estimated as the number of tags captured during the recapture period (15) divided by the number of tagged fish in the lagoon (81) or 0.185. Using this logic, if 113 *O. mykiss* less than 80mm were captured during the recapture period there were an estimated 611 *O. mykiss* in this size class present in the lagoon. The total population would have been 1251.
- CPUE was similar during the mark and recapture periods (46 and 40 respectively) and the size classes had similar distributions. These are indications that the population was closed during the survey period.
- Untagged fish 80mm FL or larger captured during the recapture period were tagged in order to collect over-summer information.

Late summer (September 19-20)

Late summer Site Conditions

- The mouth was closed and had been closed since July 31. Stage was stable during the seining at about 1.7 meters (5.6 ft.) (2nd Nature data) (Figure 1). The stage and configuration were similar to June (Figure 6 and Figure 7).
- The lagoon had closed four times since the June survey: June 21-24, June 24-27, July 9-19, and July 21-28.
- Inflow from Laguna Creek at the time of the survey was fluctuating around 2.1 cfs.
- Maximum depth to about 2.6 meters (8.5 ft.). The deepest water was available in a narrow band along the rock wall and in the corner of the marsh and rock wall at LA-1, and along the marsh at LA 1.5 and LA-2.
- The lagoon was fresh in the upper 1.6 meters (5.2 ft.) with a lens of increasing salinity below to near 18 ppt in the deepest water (Figure 8, center panel).
- Temperature profiles were nearly isothermal between 17.4°C and 17.7°C in the upper 1.2 meters (3.9 ft.) (Figure 8, left panel). Temperature increased in the halocline to a maximum of 27.3°C in the deepest water.
- Dissolved oxygen ranged from 8.6 mg/l to 10.0 mg/l in the upper 1.2 meters (3.9 ft.). At Station 1 oxygen increased in the halocline then declined in deeper water. At Station 1.5 there was little or no oxygen increase in the halocline and oxygen rapidly decreased to near zero at a depth of 2 meters (6.6 ft.) (Figure 8, right panel).
- The upper part of the water column was relatively clear but lack of clarity in the halocline resulted in secchi depths between 2.3 meters (7.5 ft.) near the mouth and 1.8 meters (5.9 ft.) upstream (Station 1.5)



Figure 6. Laguna Creek Lagoon, September 19, 2017.



Figure 7. Beginning the haul, Laguna Creek Lagoon, September 20, 2017

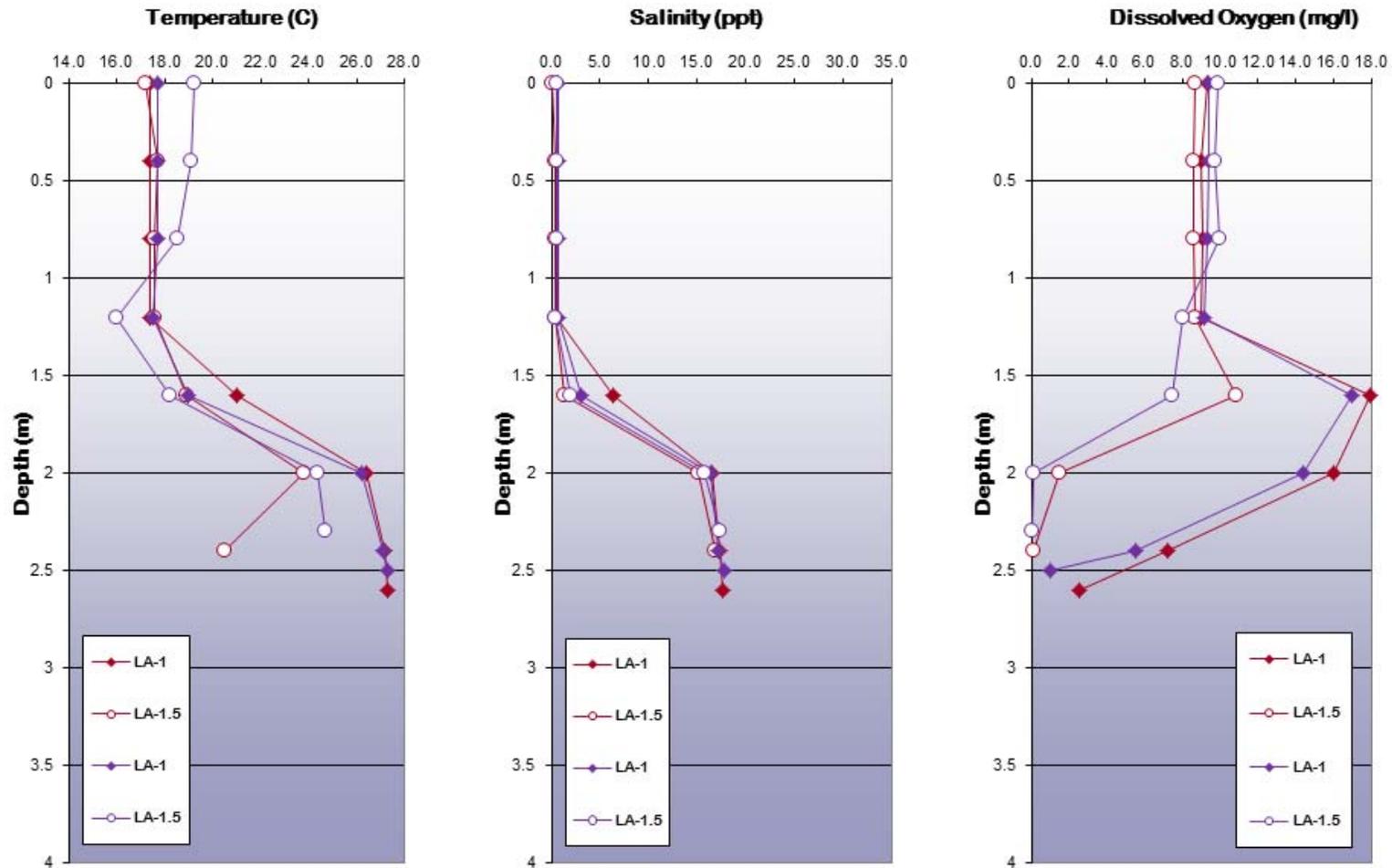


Figure 8. Depth profiles of water quality parameters in Laguna Creek Lagoon during September. Profiles plotted in red are September 19; profiles in blue are September 20.

Late summer Survey Results

- *O. mykiss* were captured and marked on September 19. On September 20 the lagoon was re-sampled and the proportion of re-captured fish was recorded.
- Six seine hauls were completed on September 19 and 8 hauls on September 20 between the beach (LA-1) and just downstream of the water quality monitoring station (Table 3).
- Overall abundance of *O. mykiss* based on number caught per seine haul (catch per unit effort or CPUE) at 14.5 per haul was at the higher end for Laguna Creek in previous late summer surveys with 8 years having lower CPUE and only 2 having higher (Table 2). However, abundance was substantially down from the 42.8 per haul in June.
- CPUE was higher during the mark period (September 19) at 18.5 per haul but dropped to 11.5 per haul on the 20th. The size class distribution was similar for both days.
- The majority of *O. mykiss* present in September were in the 110-160mm FL size class. Based on previously observed growth rates, these are likely fish that were in the abundant 50-90mm FL size class in June. The larger size class present in June (110-170mm FL in June), which would have grown by 65-70mm by September based on recaptures of tagged fish (Table 4), appeared to have largely disappeared from the lagoon in September (Figure 9). This is also evident when the length distribution in September is compared to the average for Laguna in the late summer from past surveys (Figure 10). Possible explanations for this unusual observation include: size selective predation favoring larger size classes (human or marine mammal), movement of this size class back upstream, or exit to the ocean during one of the periods when the lagoon was open in late June and July. The third theory has support in that one of the June tagged fish was recorded in the San Lorenzo River at Felton in November (see below).
- Thirteen *O. mykiss* tagged in June were recaptured in September. These fish grew at an average rate of 0.66mm per day (range 0.17 to 0.89 mm/day), or about 64 mm over the period (range 17-87 mm)(Table 4).
- One *O. mykiss* tagged in June was recorded at the NOAA PIT tag antenna at Felton on November 17. The fish was tagged June 14 at a size of 166 mm FL. It would have left the lagoon during one of the open periods before July 31.
- Seventy-nine percent of the *O. mykiss* catch were characterized as parr (sizes from 90-169 mm FL), 14% were characterized as silvery parr (lengths from 120-249 mm FL), and 7% had the appearance of adult or ocean migrants (lengths from 190-259 mm FL).
- No incidence of *O. mykiss* with black-spot disease or other external parasites, disease, or abnormalities was noted.
- All *O. mykiss* examined had an adipose fin intact.
- In addition to *O. mykiss*, large numbers of stickleback were captured. Tidewater goby appeared to be relatively abundant but were not captured in large numbers due to the relatively large mesh size of the net.
- The over-wash pond was not sampled.

Table 3. Fish catch in Laguna Creek Lagoon, September 2017

Species	LA-1	LA-1.5	LA-2	LA-3	Grand Total
	September 19 and 20				
<i># Hauls</i>	7	2	3	2	14
<i>O. mykiss</i>	140	7	43	13	203
Threespine stickleback	3023+	a	165	100	3288
Staghorn sculpin			1		1
Tidewater goby	P	a	A	p	a
<i>O. mykiss CPUE</i>	20.0	3.5	14.3	6.5	14.5

Note: See Figures at end of document for sample station locations.
a=abundant, p=present

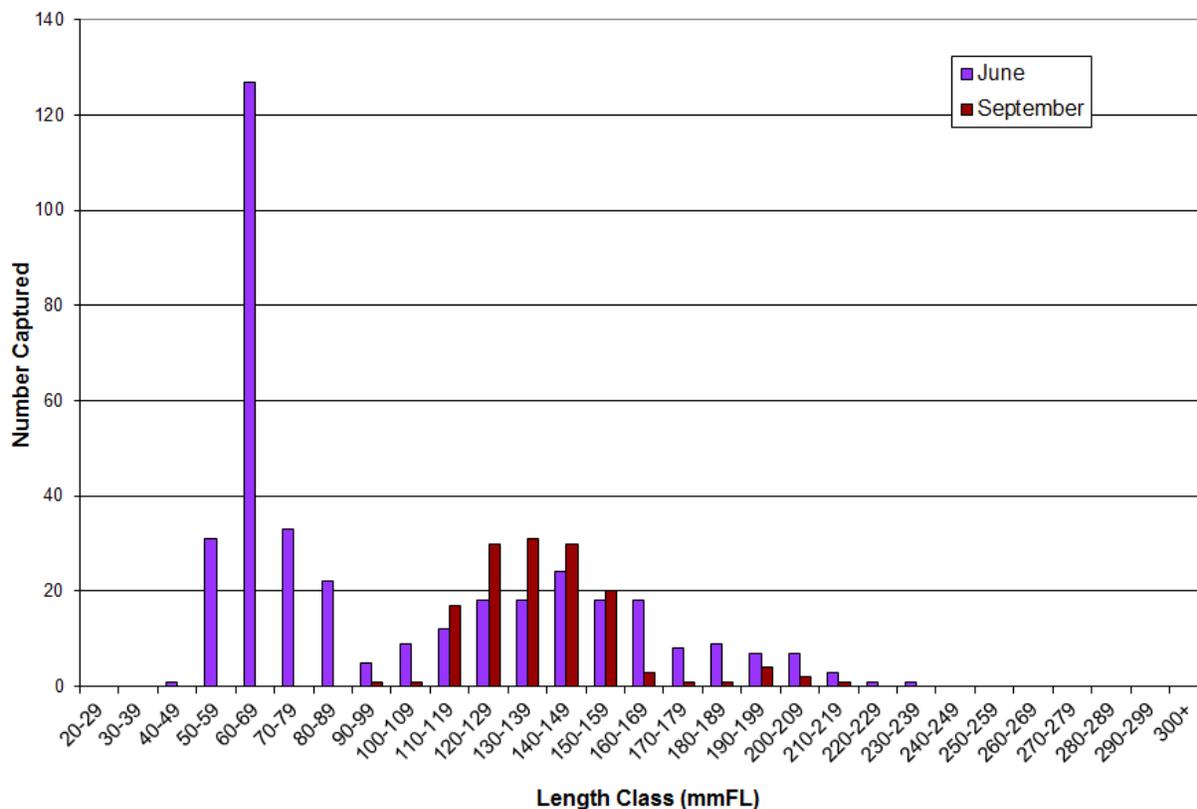


Figure 9. *O. mykiss* length classes in Laguna Creek Lagoon, late summer 2017

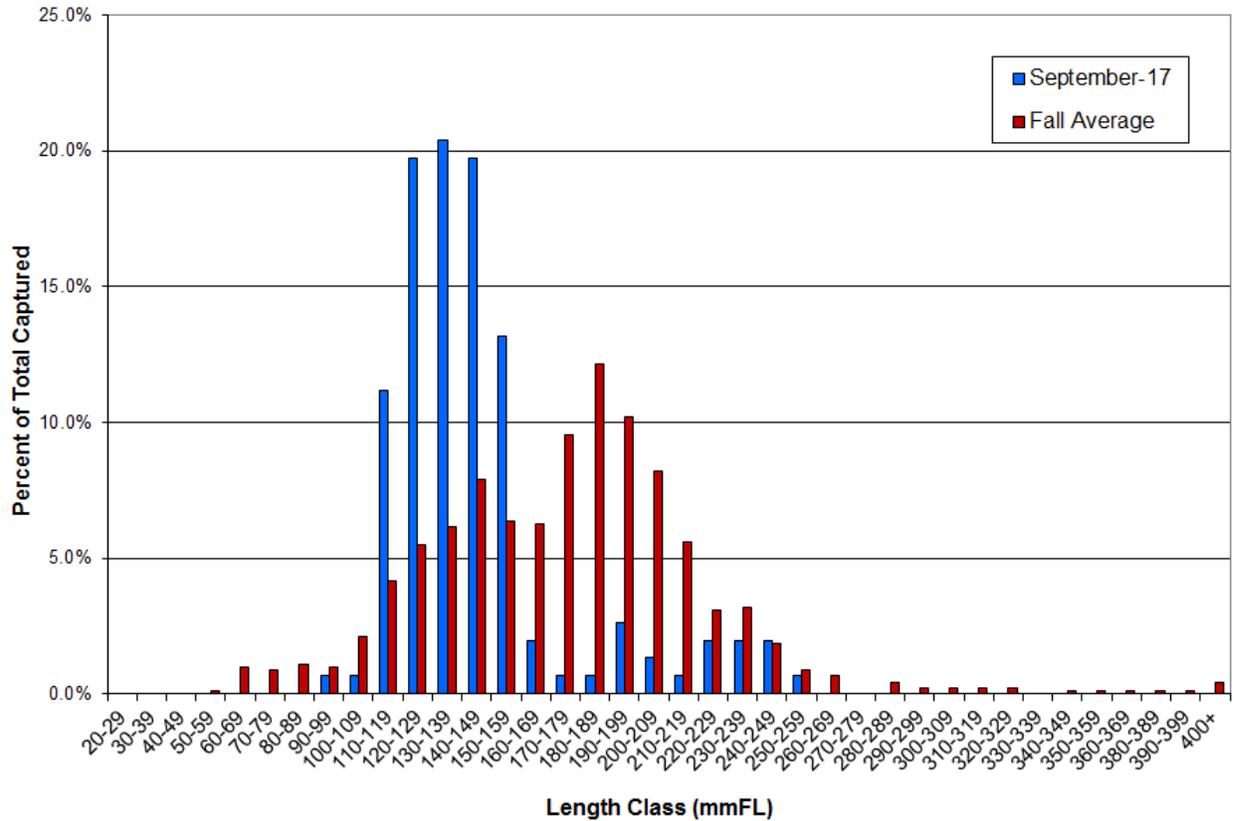


Figure 10. *O. mykiss* length classes in Laguna Creek Lagoon, late summer 2017 compared to average

Table 4. Laguna Creek Lagoon *O. mykiss* tagged in June and recaptured in September 2017.

Previous Capture Date	Recapture Date	Initial Length	Length at Recapture	Growth Rate (mm/day)	Growth (mm)
6/13/17	9/19/17	76	149	0.74	73
6/14/17	9/19/17	112	183	0.73	71
6/14/17	9/19/17	112	183	0.73	71
6/13/17	9/19/17	112	199	0.89	87
6/14/17	9/19/17	117	191	0.76	74
6/14/17	9/19/17	122	177	0.57	55
6/14/17	9/19/17	125	200	0.77	75
6/14/17	9/19/17	138	216	0.80	78
6/13/17	9/19/17	139	188	0.50	49
6/13/17	9/19/17	140	197	0.58	57
6/14/17	9/19/17	152	227	0.77	75
6/14/17	9/19/17	160	212	0.54	52
6/13/17	9/19/17	217	234	0.17	17
Average				0.66	64

Late summer *O. mykiss* Population Estimate

- A total of 111 *O. mykiss* were captured on September 19. Six of these were recaptures so 105 were marked on September 19 by insertion of a PIT tag in the abdominal cavity.
- On September 20, a total of 92 *O. mykiss* were captured, of which 17 had been tagged on September 19.
- The population estimate using the Petersen method (Ricker 1975) is 548 *O. mykiss* in the lagoon on September 20. The 95% confidence limits for this estimate are 349 and 850. This estimate is about 85% of the abundance estimate in June.
- As previously noted, catch per unit effort decreased from 18.5 per haul on September 19 to 11.5 per haul on the 20th indicating that fish may have left the lagoon between the mark and recapture periods, possibly violating the assumption of a closed population and confounding the population estimate.
- The relationship between population estimate and CPUE was updated with the 2017 data (Figure 11). The least squares regression r^2 is 0.66 (from 0.78 previously), and was statistically significant with $F=0.002$. The strength of the relationship was diminished by the late summer data point. Forcing the relationship through the origin improves the r^2 to 0.91.

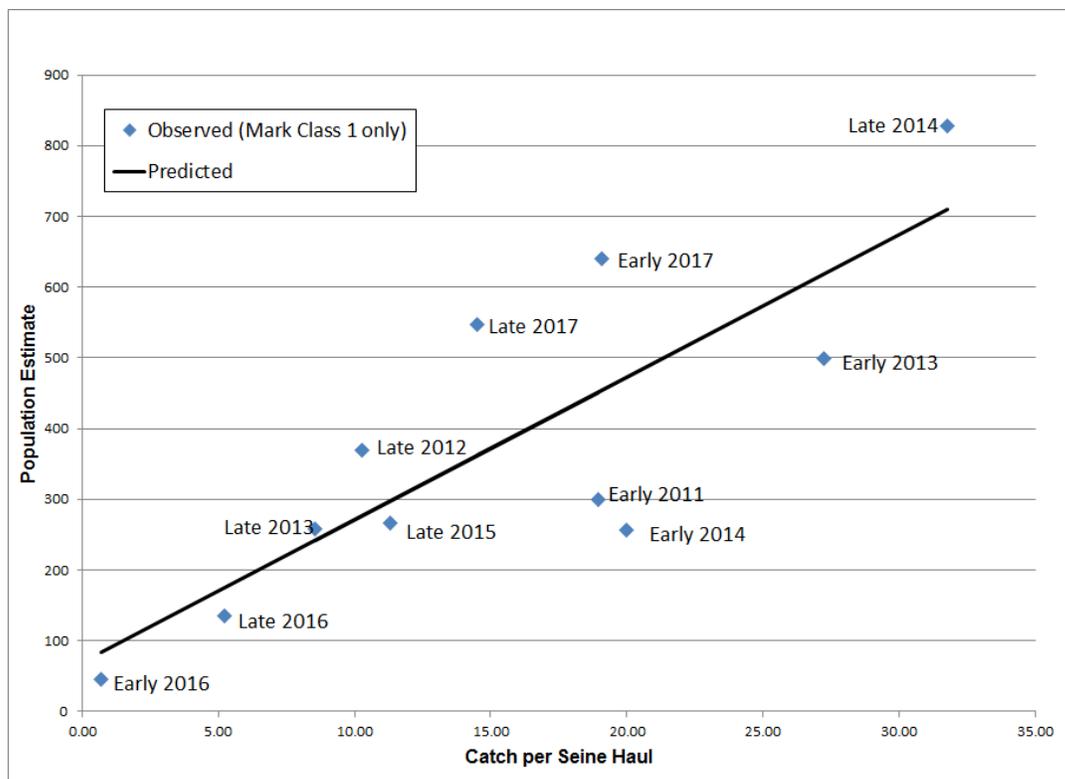


Figure 11. Relationship between *O. mykiss* population estimate and CPUE in Laguna Creek Lagoon²

² Population estimates not available in Late Summer 2011, Early Summer 2012, and Early Summer 2015 due to insufficient catch. In two cases (Late Summer 2011 and Early Summer 2012) the lagoon was open and in one case (2015) it had only recently closed.

San Lorenzo River

Summary

The winter of 2016-2017 was very wet with flow peaks from precipitation events as late as mid-April. Flow in the San Lorenzo River at Santa Cruz was 192 cfs on May 1 and gradually declined over the course of the summer to around 18 cfs in early November (Figure 12). High flows kept the lagoon mostly open through the summer. The lagoon first closed only briefly in mid-July and closed again briefly in late-July and mid-August. A more extended closure of 10 days occurred from October 6-16 (Figure 12, WSE). The lagoon outlet formed a sinuous outlet channel near San Lorenzo point early in the summer that migrated west onto main beach later in the summer.

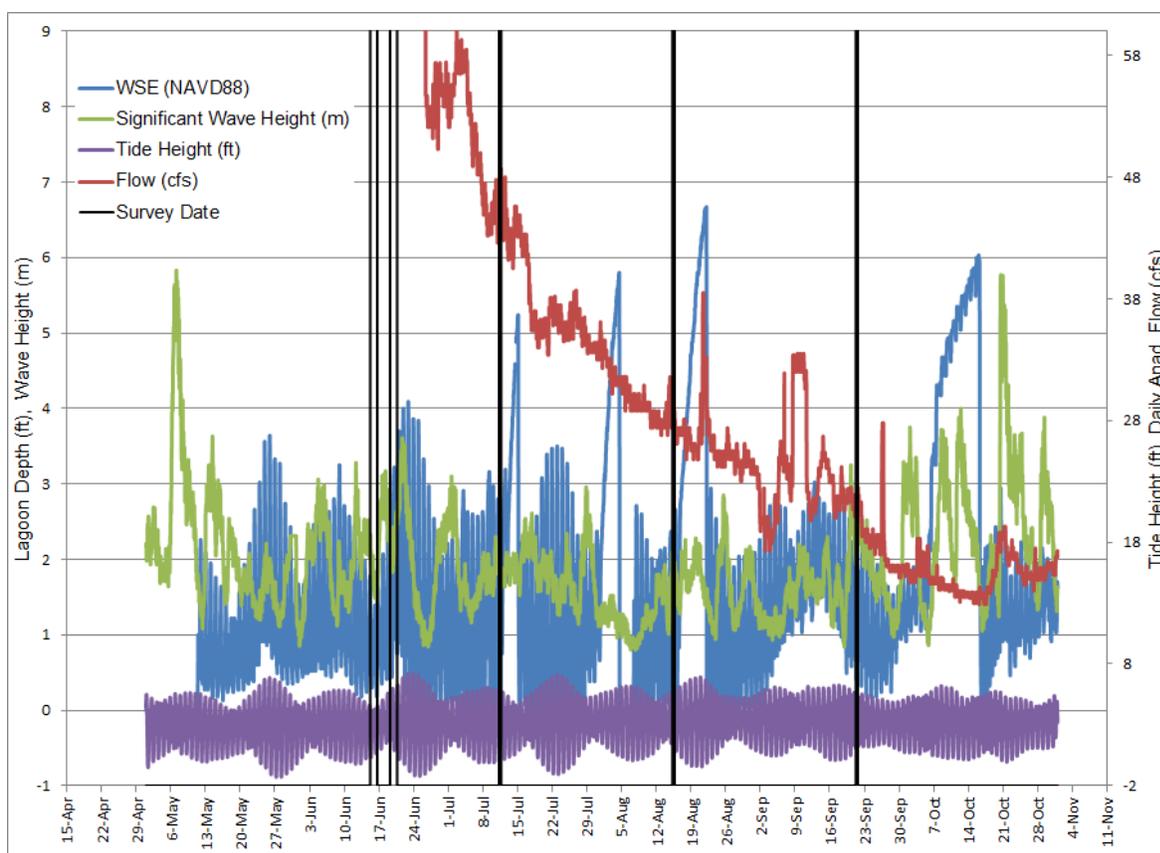


Figure 12. San Lorenzo Lagoon stage, streamflow, wave height, and tides 2017 (Source: lagoon stage from 2ND Nature, streamflow from USGS, wave and tide data from NOAA)

Abundance of *O. mykiss* in the lagoon was unprecedented. The San Lorenzo lagoon was sampled four times during the summer of 2017 (Table 5). The initial seining survey began on June 15 with an open lagoon. *O. mykiss* were captured and marked on June 15-16 and sites were resampled for recaptures on June 19-20. Mid-season surveys were completed on July 11 and August 15, and a final survey was conducted on September 21. So many *O. mykiss* were captured in June that the July, August, and September surveys had to be abbreviated due to NMFS permit limitations, despite an increase in the take limit through coordination with the Santa Cruz County steelhead monitoring project. Mark-recapture estimates were only completed during the June survey. CPUE data provided an indication of abundance during the July, August, and September surveys. The large numbers of *O. mykiss* captured also limited the number of hauls that could be made at each station and the number of stations that could be sampled.

Table 5. *O. mykiss* catch per haul for the San Lorenzo River Lagoon during 2017

Station	Location	<i>O. mykiss</i> Catch per Haul				
		15-20 Jun	July 11	Aug 15	Sept 21	Overall
2017						
SL-1	South of Trestle	5.5	466.0	265.0	643.0	231.8
SL-2	RR Trestle	100.9	424.0	279.0		168.8
SL-3	Near YSI Station					
SL-4	U/S YSI					
SL-5	Riverside Drive	566.7			13.0	428.3
SL-6	U/S Bank Restoration	76.6			15.0	66.3
	Overall	134.4	452.0	272.0	328.5	205.6

The June CPUE exceeded all previous estimates and the 2018 catch was an order of magnitude higher than observed in all surveys to date in the San Lorenzo Lagoon (Table 6). *O. mykiss* abundance remained high through the summer, possibly increasing after June, under open lagoon conditions. Only partial sampling was conducted after June to avoid exceeding the level of take authorized in the project’s incidental take permit.

Table 6. *O. mykiss* catch per haul for the San Lorenzo River Lagoon by month and year (data from HES 2009, HES 2010, HES 2011, HES 2012, HES 2013, HES 2014, HES 2015, HES 2016, and HES 2017).

Year	<i>O. mykiss</i> Catch per Haul				
	June	July	August	September	October
2008	2.6				0.1
2009	0.3			1.0	0.5
2010	8.3	21.5			28.25
2011	13				2.5
2012	1.7			14.4	
2013	2	8.4		4.7	
2014	1.2	1.1		0.0	
2015	2.6	0	0		0
2016	39.7	1.0	2.0	7.8	
2017	134.4	452.0	272.0	328.5	

Many of the *O. mykiss* present in June (more than two-thirds of the total catch) were a smaller size class, likely large young-of-year, and too small to be tagged and included in the population estimate. The population estimate of just the larger fish that were within the tagging range was 35% higher than the previous record in 2016 and more than five times any survey previous to 2016. The lagoon was open with only a few brief closures during the summer. Water level in the lagoon was tidally influenced but relatively stable between 0.6 and 1.2 meters (2 and 3.9 ft.)(NAVD88). Sufficient deep water areas around the trestle and upstream of Riverside Bridge to support the unusual abundance of *O. mykiss* in the lagoon. Temperature was variable depending on the mix of fresh and salt water but was much cooler than previous years with substantial periods of lagoon closure. Salinity was often elevated due to the large tidal exchange but did not appear to deter the abundant *O. mykiss* present.

Eleven percent of *O. mykiss* tagged in the lagoon during the summer were later recorded at Felton, mostly in November but small numbers from December through April as well. Growth rates were variable in 2017 but somewhat lower on average than seen in previous years, possibly a result of the high density present in the lagoon throughout the summer.

Early summer (June 15-16, 19-20)

Early summer Site Conditions

- The lagoon was open during the sampling period (Figure 12 and Figure 13). Daily average flow at Santa Cruz gage ranged from 79 cfs on the June 15 sample date to 63 cfs on June 19 (historical discharge, USGS site 11161000 San Lorenzo River at Santa Cruz California).
- Lagoon stage was tidally influenced and ranged from 0.18 to 1.73 (NAVD88). The shoreline was conducive to sampling for sufficient area at all regularly surveyed sites.
- The lagoon was salinity stratified with salinity close to seawater at depths of 1.2 meters (3.9 ft.) or more (Figure 14, center panel). Salinity was near zero at the surface and increased slightly with depth down to the halocline, depending on tidal influx.
- Temperature was highly variable, depending on tidal influx and air temperature. At some times and locations there was thermal stratification with colder seawater underlying warmer fresh water. Maximum recorded temperature during the sampling period was 22.9°C (Figure 14, left panel), recorded at the surface on June 19 during an afternoon ebb tide.
- Dissolved oxygen levels were generally above 6.5 mg/L above the halocline but declined to levels as low as 3.7 mg/L below the halocline (Figure 14, right panel).
- Water clarity was high with secchi disk visible at or near the substrate at all stations (up to 2.2 meters (7.2 ft.) deep).



Figure 13. San Lorenzo Lagoon mouth June 16, 2017

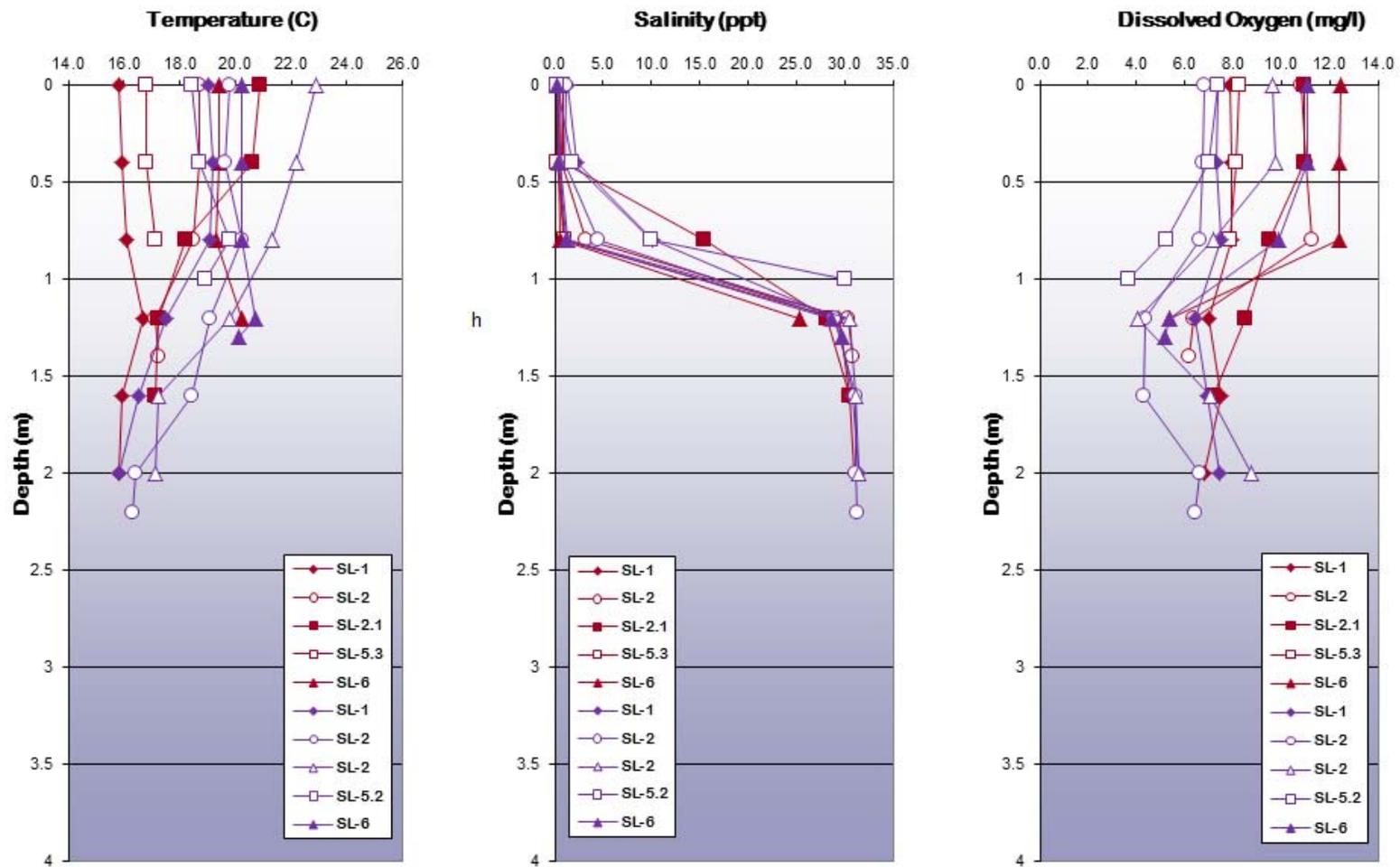


Figure 14. Depth profiles of water quality parameters in the San Lorenzo Lagoon during June. Profiles plotted in red are June 15-16; profiles in blue are June 19-20

Early summer Survey Results

- *O. mykiss* were captured and marked on June 15 and 16 and the lagoon was resampled on June 19 and 20. Untagged *O. mykiss* captured on June 19 and 20 were also tagged for over-summer information.
- Twenty-one seine hauls were completed at regularly sampled stations between the beach and the bend upstream of Riverside Bridge.
- *O. mykiss* abundance was the highest observed in annual surveys to date (134.4 per haul) and were most abundant at the trestle and downstream to the outlet (Tables 6 and 7).
- Two size classes of *O. mykiss* were present: smaller fish from 50mm to 110mm FL and a group of larger fish from 110mm to 250mm FL (Figure 15).
- The smaller size group was characterized primarily as parr (98%) with a few silvery parr (2%). The larger size class was parr (56%), silvery parr (39%), and a few smolts (4%).
- All *O. mykiss* examined (560) had an adipose fin, indicating they were not of hatchery origin.
- Twenty-six percent of *O. mykiss* examined had black-spot disease (BSD) lesions.
- The overall fish catch was dominated by very abundant topsmelt and steelhead (Table 7). Eight other fish species were captured with shiner surfperch, staghorn sculpin, and striped bass the most common.

Table 7. Fish catch in San Lorenzo River Lagoon, June 2017

Species	South of Trestle (1)	Around Trestle (2)	Upstream of Riverside Bridge (5)	Bend downstream of Laurel Ave. (6)	Grand Total
<i># Hauls</i>	6	7	3	5	21
<i>O. mykiss</i>	33	706	1700	383	2822
Pacific herring		9	1		10
Sacramento sucker			1	1	2
Topsmelt	2661	5968	2826	216	11671
Threespine stickleback		3		1	4
Rockfish (gopher?)	1				1
Staghorn sculpin	6	142	6	9	163
Striped bass	71		2	1	74
Shiner surfperch	33	149		34	216
Starry flounder	1	1	1	2	5
Shrimp		1			1
<i>O. mykiss CPUE</i>	5.5	101	566.7	76.6	134.4

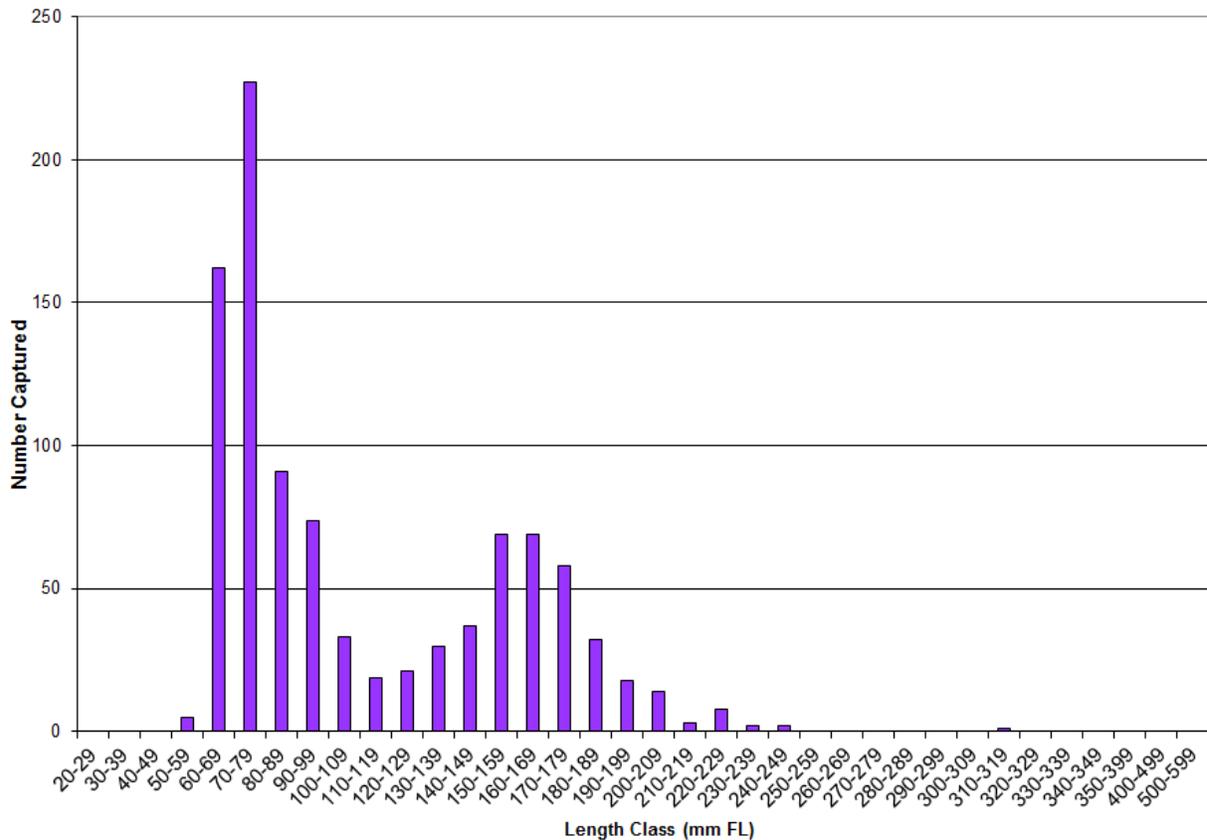


Figure 15. *O. mykiss* length classes in San Lorenzo Lagoon, June 2017

Early summer *O. mykiss* Population Estimate

- Due to very large numbers of fish in some seine hauls, not all captured fish could be tagged. Of the 1709 *O. mykiss* captured during the mark period, 903 were released without tagging. The tag supplier (Biomark) recommends that body cavity tagging should only be done down to a length of 65 mm but six fish in the 80-89 mm size class died after tagging so only fish 90 mm FL or larger were tagged. The 903 releases included an estimated 579 less than 90mm FL and 324 that were 90mm FL or larger. There were 331 *O. mykiss* not released that were 90mm FL or larger available for tagging. Of these 27 were recaptures of previously tagged fish. One fish was not tagged and one died after tagging, leaving a total of 302 tagged *O. mykiss* at the end of the mark period.
- A total of 1114 *O. mykiss* were captured during the recapture period but only 479 were 90 mm FL or greater. Thirty-nine of these had been tagged during the marking period.
- Population estimate using the Petersen method (Ricker 1975) is 3636 *O. mykiss* in the lagoon in June. The 95% confidence limits for this estimate are 2678 and 4926.
- CPUE was 171 per haul during the mark period and 101 per haul during the recapture period. This, and the fact that the lagoon was open initially, indicates the potential for an

unstable population in the lagoon. The proportion of young-of-year and older *O. mykiss* in the population was similar during the mark and recapture periods.

July Survey (July 11)

The July survey was abbreviated due to high abundance of *O. mykiss* and the potential for exceeding the incidental take limit for the project. Sampling was completed on a single day with 2 hauls at Station 1 and one haul at Station 2. No population estimate was made and CPUE data only reflects abundance in the lower lagoon.

July Site Conditions

- The lagoon was open at the time of sampling and had not yet been closed (Figure 12). Inflow from the San Lorenzo River was still relatively high at about 48 cfs (Figure 12).
- The lagoon stage was tidally influenced and ranged from -0.12 to 0.5 meters (-0.4 and 1.6 ft.) during the survey period (City of Santa Cruz data). Limited areas of beach were present to finish seine hauls at the back side of the beach and around the trestle.
- The limited data collected indicated salinity stratification with high salinity below 0.8 meters (2.6 ft.) depth (Figure 16, center panel) in the areas where seining was conducted.
- Water temperature was relatively cool with maximum temperature recorded at 21.5 at the surface during the afternoon near the trestle (Figure 16, left panel).
- Dissolved oxygen was low during the early morning low tide, particularly at a depth of 0.8 meter (2.6 ft.) and greater. During the afternoon, as the tide came in, water temperature cooled and dissolved oxygen increased (Figure 16, right panel).
- The influence of tidal inflows can be seen with cooler temperatures, higher salinity, and higher dissolved oxygen during the afternoon high tide at Station 2 (Figure 16).
- The water column was relatively clear with secchi disk visible at the bottom at both stations. Water depth was relatively shallow at 1.3 meters (4.3 ft.) at Station 1 and 2 meters (6.6 ft.) at Station 2.

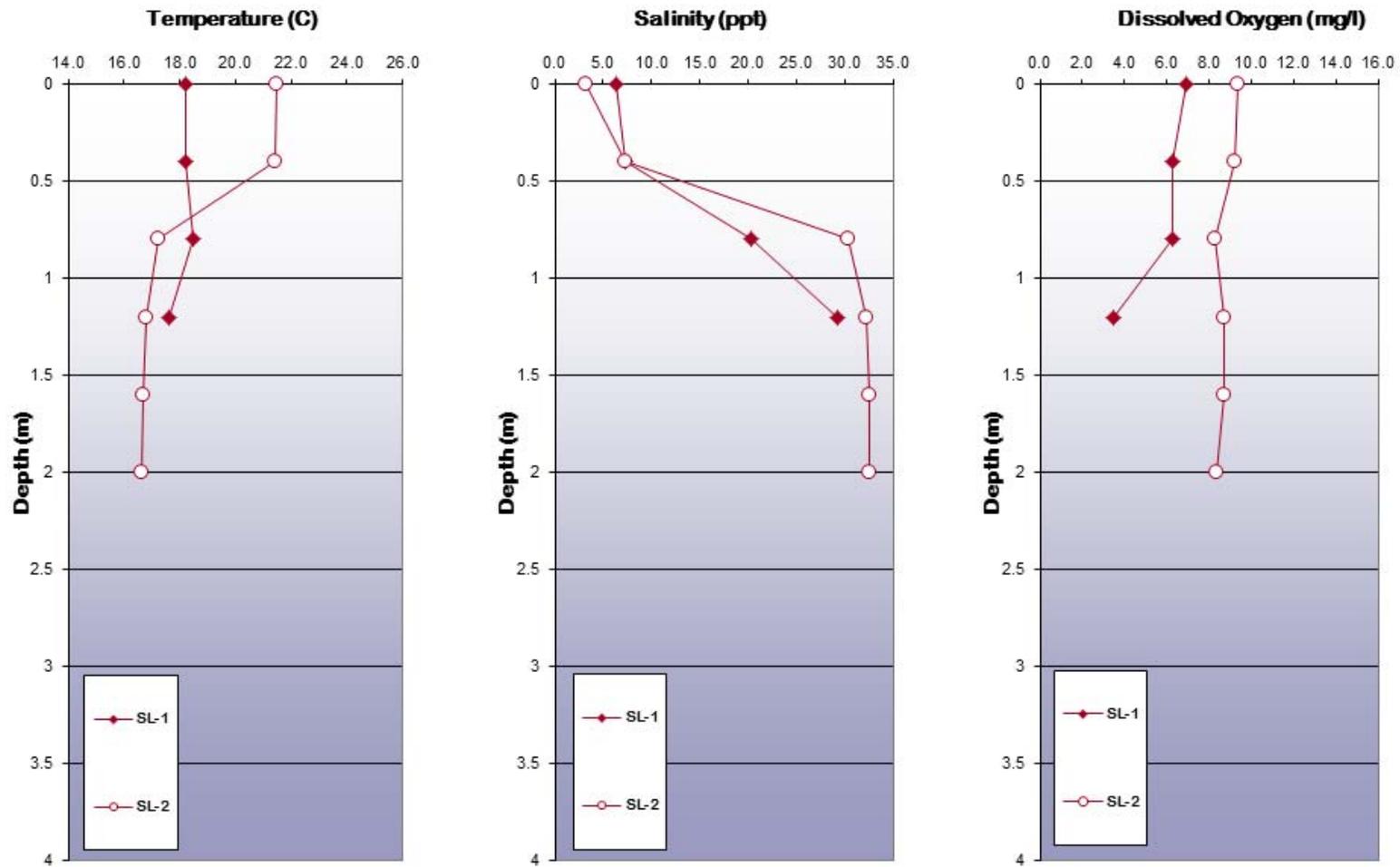


Figure 16. Depth profiles of water quality parameters in the San Lorenzo Lagoon during July Survey (July 11)

July Survey Results

- Only three seine hauls were completed on a single day and only two stations were sampled (1 and 2). Sampling was abbreviated due to large numbers of *O. mykiss* captured in relation to limits imposed by the projects incidental take permit.
- *O. mykiss* and topsmelt dominated the catch (Table 8). CPUE at the two stations sampled was much greater than in June, indicating that overall abundance of *O. mykiss* in the lagoon may have been greater than in June (Table 7). CPUE for topsmelt was also higher than in June.
- Striped bass were still present in the lagoon though less abundant than in June and Pacific herring were no longer present.
- The smaller *O. mykiss* size class present in June had shifted 20-30mm larger in July, consistent with potential growth in the intervening period (Figure 17). Oddly, the larger mode of the size distribution appeared not to have changed.
- Thirty-five *O. mykiss* captured in July had been tagged in June. These fish grew at an average rate of 0.78 mm/day (range 0.42 to 1.16 mm/day). They ranged in size from 87 mm to 230 mm in June and 108 mm to 249 mm in July.
- Two new species, black perch (*Embiotoca jacksoni*) (Figure 18) and lingcod (*Ophiodon elongatus*) (Figure 19) were captured for the first time.

Table 8. Fish catch in San Lorenzo River Lagoon, July 2017

Species	South of Trestle (1)	Around Trestle (2)	Grand Total
<i># Hauls</i>	2	1	3
<i>O. mykiss</i>	932	424	1356
Topsmelt	2819	466	3285
Lingcod	1		1
Staghorn sculpin	4	1	5
Striped bass	14		14
Black surfperch	1		1
Starry flounder	4		4
<i>O. mykiss CPUE</i>	466	424	452

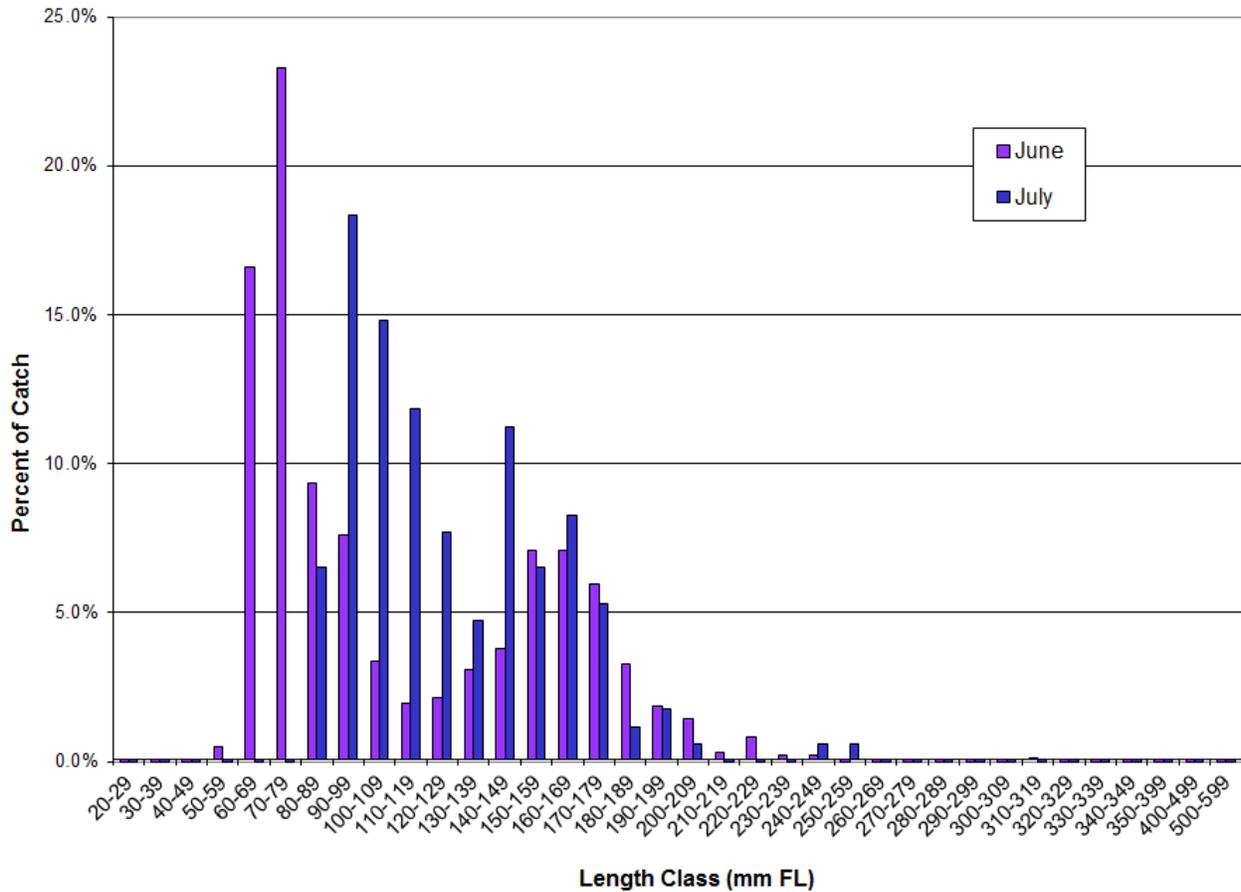


Figure 17. *O. mykiss* length classes in San Lorenzo Lagoon during June and July 2017



Figure 18. Black perch (*Embiotoca jacksoni*) captured in the San Lorenzo River lagoon July 11, 2017



Figure 19. Juvenile lingcod (*Ophiodon elongatus*) captured in the San Lorenzo River lagoon July 11, 2017

August Survey (August 15)

The August survey, as in July, was a single-day relative abundance survey. Sampling was conducted only at Stations 1 (downstream of the trestle) and 2 (around the trestle). Due to the large numbers of *O. mykiss* captured many were released without measuring or tagging. All previously tagged fish were measured.

August Site Conditions

- The lagoon was open at the time of sampling. It had closed briefly on two occasions since the July survey (July 12-15 and July 31-Aug 4) (Figure 12).
- The lagoon stage was tidally influenced and fell from 0.83 in the morning to 0.35 mid-afternoon before rising to 1.59 in late afternoon (City of Santa Cruz data). This was comparable to lagoon stage during the July survey. Limited areas of beach were present to finish seine hauls at the back side of the beach and around the trestle.
- The limited data collected indicated salinity stratification with high salinity below 0.8 meters (2.6 ft.) depth (Figure 20, center panel) in the areas where seining was conducted.
- Water temperature was relatively cool with maximum temperature recorded at 19.5 at the surface during the afternoon near the trestle (Figure 20, left panel).
- Dissolved oxygen was generally above 6 mg/l throughout the water column though some DO depression developed in the halocline in the afternoon at ebb tide (Figure 20, right panel).
- Water quality parameters were undoubtedly dynamic with the influence of tidal inflows and outflows.
- The water column was relatively clear with secchi disk visible at the bottom at both stations. Water depth was relatively shallow at 2.0 meters (6.6 ft.) at Station 1 and 1.8 meters (5.9 ft.) at Station 2.

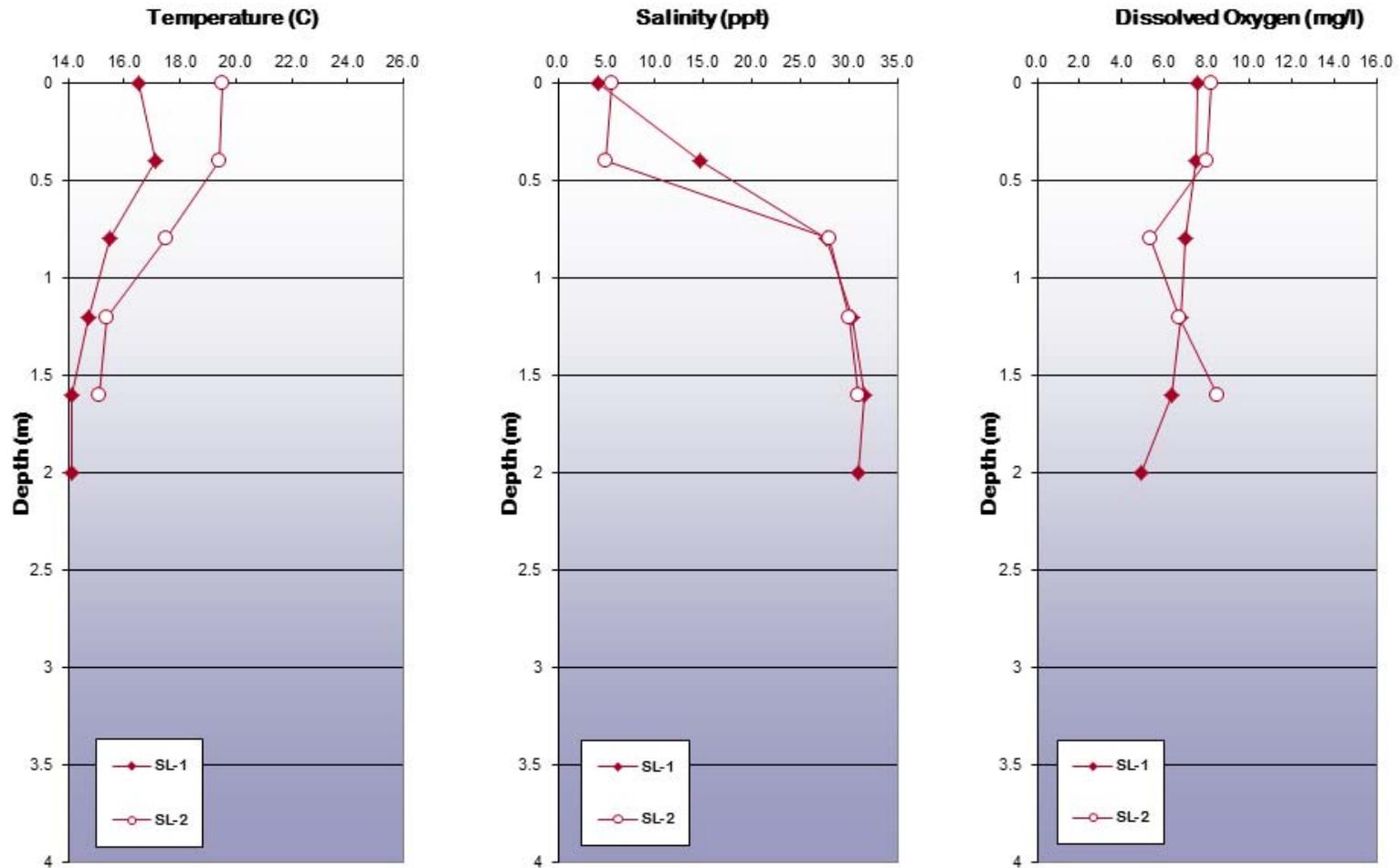


Figure 20. Depth profiles of water quality parameters in the San Lorenzo Lagoon during August Survey (August 15)

August Survey Results

- Four seine hauls were completed on a single day and only two stations were sampled (1 and 2). Sampling was abbreviated due to large numbers of *O. mykiss* captured in relation to limits imposed by the projects incidental take permit.
- As in July, *O. mykiss* and topsmelt dominated the catch (Table 9). CPUE at the two stations sampled was down about 40% from July for *O. mykiss* (Table 7) but still double the June levels. CPUE for topsmelt was only about 25% of the July level and 40% of the June level.
- Striped bass were still present in the lagoon.
- The smaller *O. mykiss* size class present in June and July had shifted another 30mm or so larger than in July, consistent with potential growth in the intervening period (Figure 21). The larger mode of the size distribution appeared to have shifted slightly larger from July as well.
- Twenty-five *O. mykiss* captured in August had been tagged in June and 18 had been tagged in July. These fish grew at an average rate of 0.61 and 0.62 mm/day, respectively. The range was 0.33 to 0.99 mm/day for June tagged fish and 0.34 to 1.00 for July tagged fish.

Table 9. Fish catch in San Lorenzo River Lagoon, August 2017

Species	South of Trestle (1)	Around Trestle (2)	Grand Total
<i># Hauls</i>	2	2	4
<i>O. mykiss</i>	530	558	1088
Northern anchovy		1	1
Topsmelt	661	478	1139
Staghorn sculpin	1	5	6
Striped bass	30	1	31
Shiner surfperch		13	13
<i>O. mykiss CPUE</i>	265	279	272

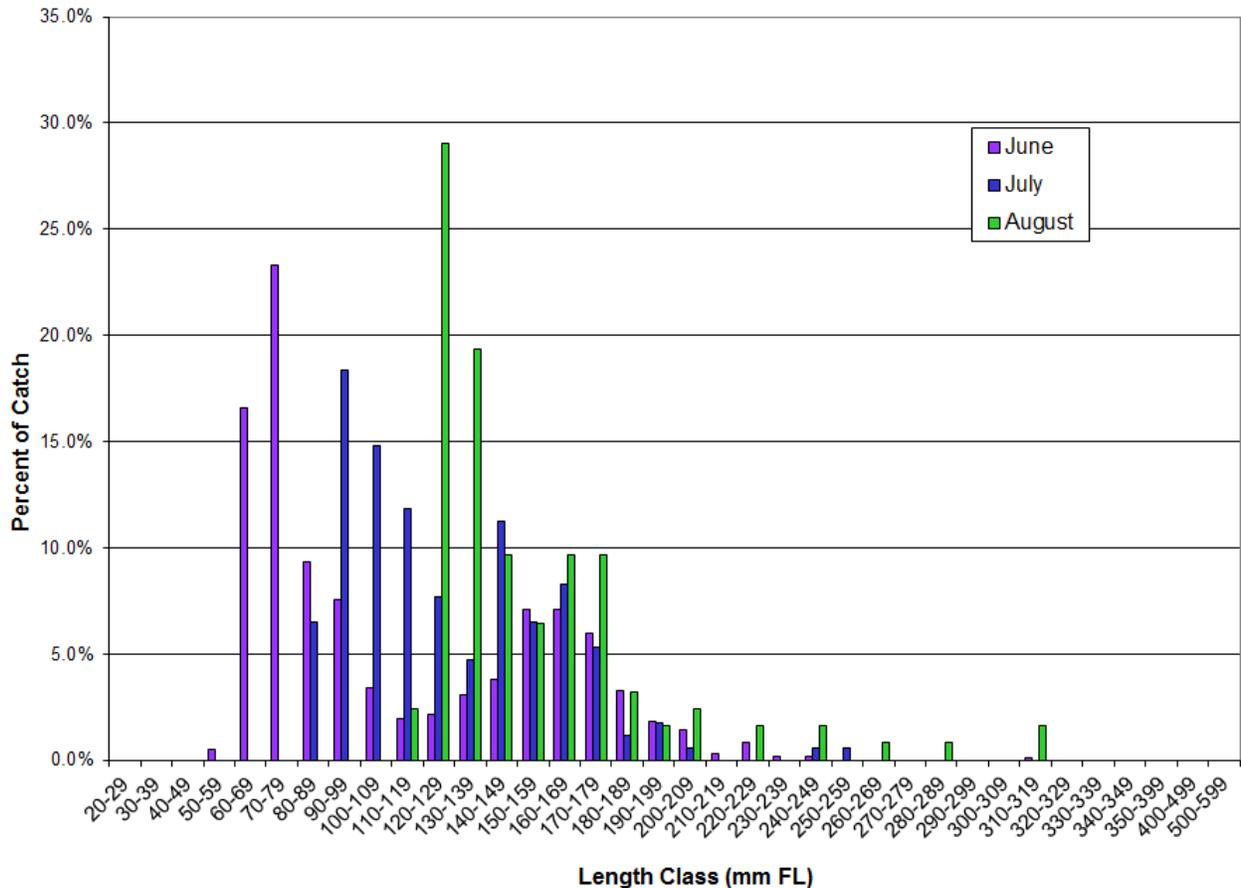


Figure 21. *O. mykiss* length classes in San Lorenzo Lagoon during June, July, and August 2017

Late summer (September 21)

The September survey was abbreviated to a single-day relative abundance survey due to incidental take permit limitations. Sampling was conducted at each of the regularly sampled Stations (1, 2, 5, and 6) but only one seine haul was completed at each station. Due to the large numbers of *O. mykiss* captured many were released without measuring or tagging. All previously tagged fish were measured.

Late summer Site Conditions

- The lagoon was open at the time of sampling. It had closed briefly on two occasions since the July survey (July 12-15 and July 31-Aug 4) (Figure 12). The outlet had migrated more to the west, further out on main beach (Figure 22). The outlet elevation appears to have been quite stable all summer keeping the lagoon at a moderate elevation without significant fluctuation or breaching. Although stage was only moderate (between 0.6 and 0.9 meters (2 and 3 ft.) NAVD88 during open periods), there was plenty of deep habitat along the east bluff in the lower lagoon and along the west bank upstream of Riverside Bridge and it supported high numbers of *O. mykiss* through the summer.

- The lagoon stage was tidally influenced and fell from 0.89 to 0.41 mid-morning before rising to 2.15 in early afternoon and dropping to about 1.45 for the final haul at 15:15 (City of Santa Cruz data). This was comparable to lagoon stage during the July and August surveys. Limited areas of beach were present to finish seine hauls at the back side of the beach and around the trestle.
- The limited data collected indicated that the lower lagoon was dominated by seawater from tidal inflows with a very shallow, cool freshwater lens in the morning, likely resulting from nocturnal cooling of surface inflows.
- Salinity was higher than 26 ppt at both Station 1 and Station 5 except for the shallow freshwater lens at Station 1 in the early morning at the end of the ebb tide (Figure 23, center panel).
- Water temperature was relatively cool with maximum temperature recorded at 19.9 at the surface during the afternoon upstream from Riverside Bridge (Figure 23, left panel).
- Dissolved oxygen was above 6 mg/l throughout the water column at both sites except at the very bottom at Station 1 at the end of the ebb tide (Figure 23, right panel).
- Temperature and dissolved oxygen conditions were in the suitable range for *O. mykiss*. Although salinity was elevated close to seawater, this did not seem to be a problem for the abundant *O. mykiss* present.
- The water column was relatively clear with secchi disk visible near the bottom in 2 meters (6.6 ft.) depth at Station 2.

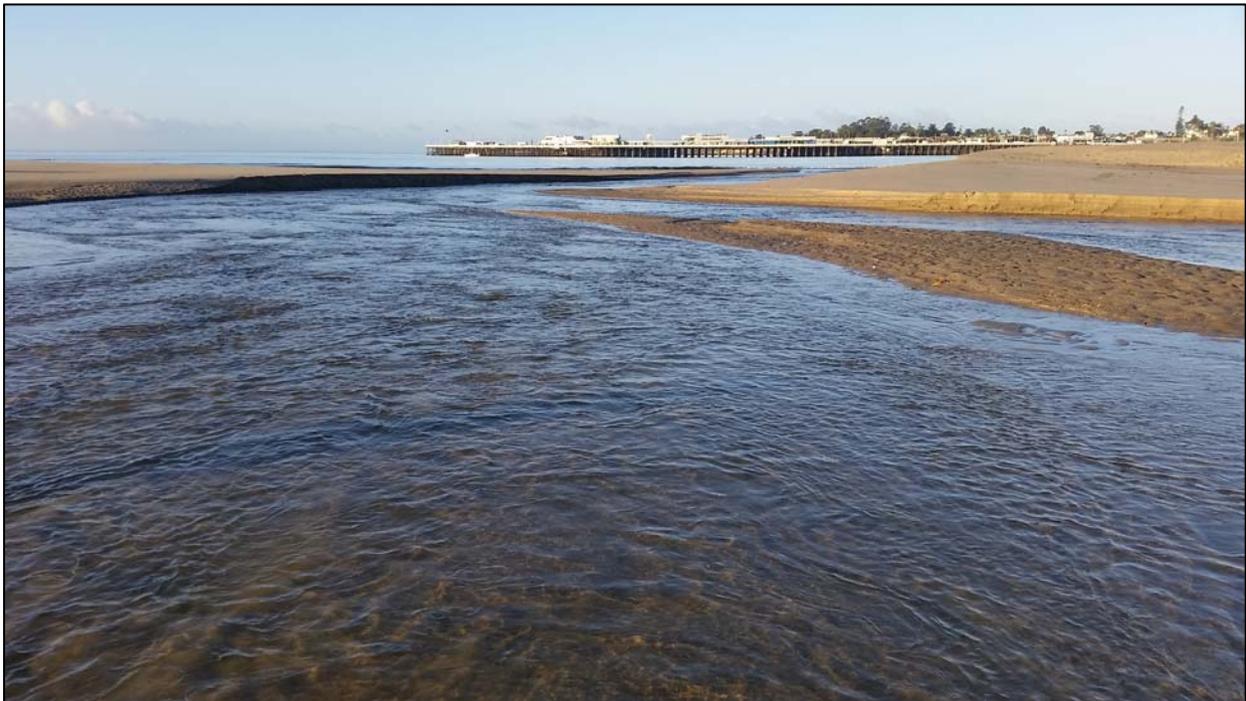


Figure 22. San Lorenzo Lagoon outlet channel during September survey (September 21)

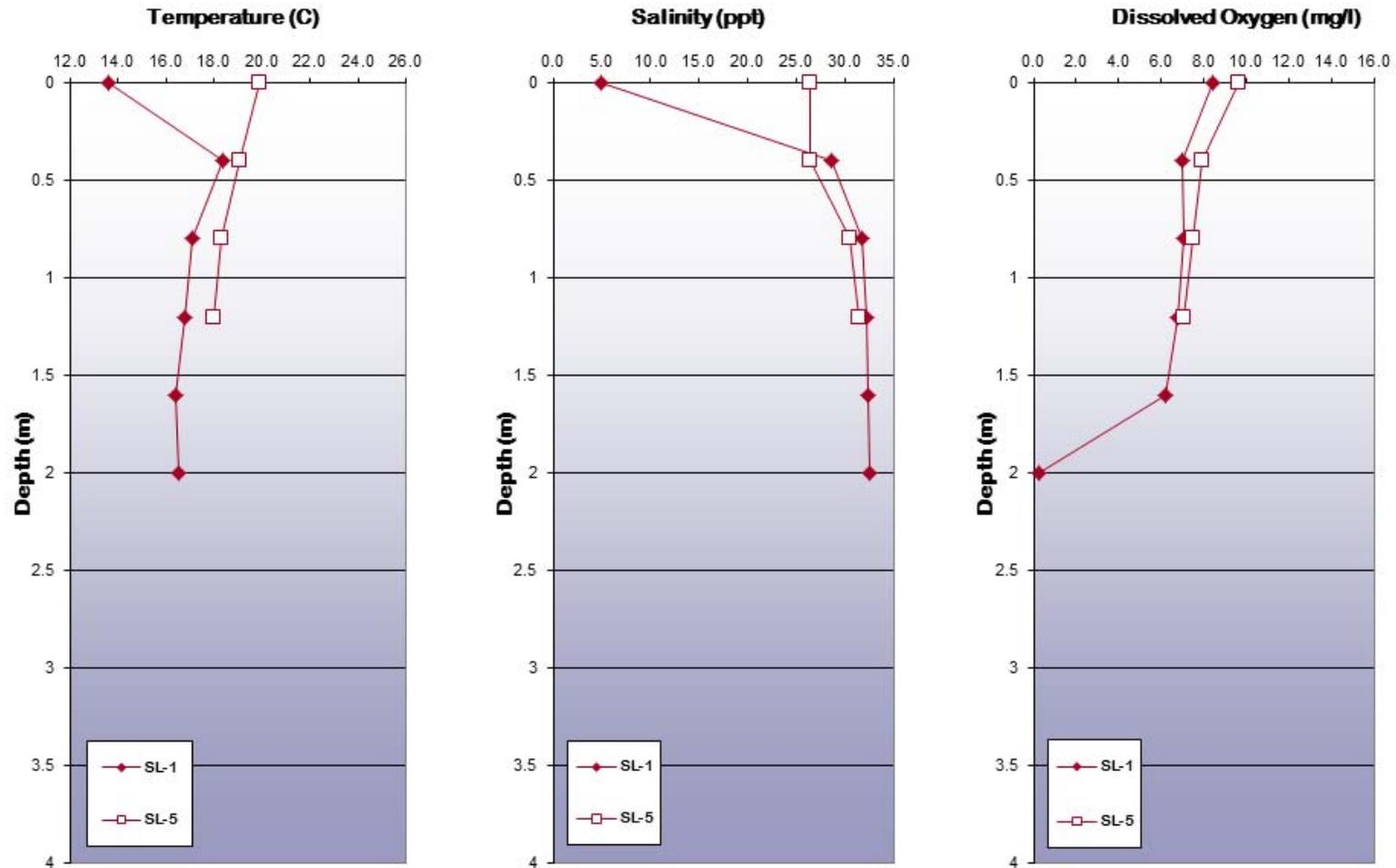


Figure 23. Depth profiles of water quality parameters in the San Lorenzo Lagoon during survey on September 21

Late summer Survey Results

- Four seine hauls were completed on a single day with a single haul at each of the regularly sampled Stations (1, 2, 5, and 6). Sampling was abbreviated due to large numbers of *O. mykiss* captured in relation to limits imposed by the projects incidental take permit.
- As in the previous 2017 surveys, *O. mykiss* and topsmelt dominated the catch (Table 10). CPUE for *O. mykiss* was down slightly from August at Station 1 but 4 times as high at Station 2 (Table 10). CPUE for *O. mykiss* was much higher at the lower lagoon Stations than upstream of Riverside Bridge despite similar water quality conditions. CPUE for topsmelt was back at a level comparable with June.
- No striped bass were captured.
- The most abundant mode in the *O. mykiss* size distribution had shifted about 20 mm larger and was possibly augmented by slightly smaller and slightly larger individuals or merged somewhat with the larger size class (Figure 24).
- Sixty-two *O. mykiss* captured in September had been tagged earlier in the summer, 40 in June, 7 in July, and 15 in August. Growth rates were highly variable between individuals with fish tagged in June growing at 0.02 mm/day to 0.86 mm/day. There may have been density dependent growth effects in 2017 due to the unusually large numbers of *O. mykiss* present (Table 11). The lowest individual growth rates were observed in 2017 when abundance was highest. Although the average growth rate was better than in 2013 when abundance was very low, only two fish were recaptured in 2013. Habitat conditions no doubt play a role as well.
- Twenty-nine percent of the catch was characterized as parr, 68% as silvery parr, and 3% as adult/ocean.
- All 165 *O. mykiss* examined had an adipose fin, indicating they were not of hatchery origin.
- Thirty out of 165 (18%) *O. mykiss* examined had black-spot disease (BSD) lesions.

Table 10. Fish catch in San Lorenzo River Lagoon, September 2017

Species	South of Trestle (1)	Around Trestle (2)	Upstream of Riverside Bridge (5)	Bend near Laurel Ave. (6)	Grand Total
<i># Hauls</i>	1	1	1	1	4
<i>O. mykiss</i>	172	1114	13	15	1314
Northern anchovy				26	26
Pacific herring				10	10
Topsmelt	301	339	684	737	2061
Threespine stickleback			1		1
Shiner surfperch		6			6
Squid	1				1
<i>O. mykiss CPUE</i>	172	1114	13	150	328

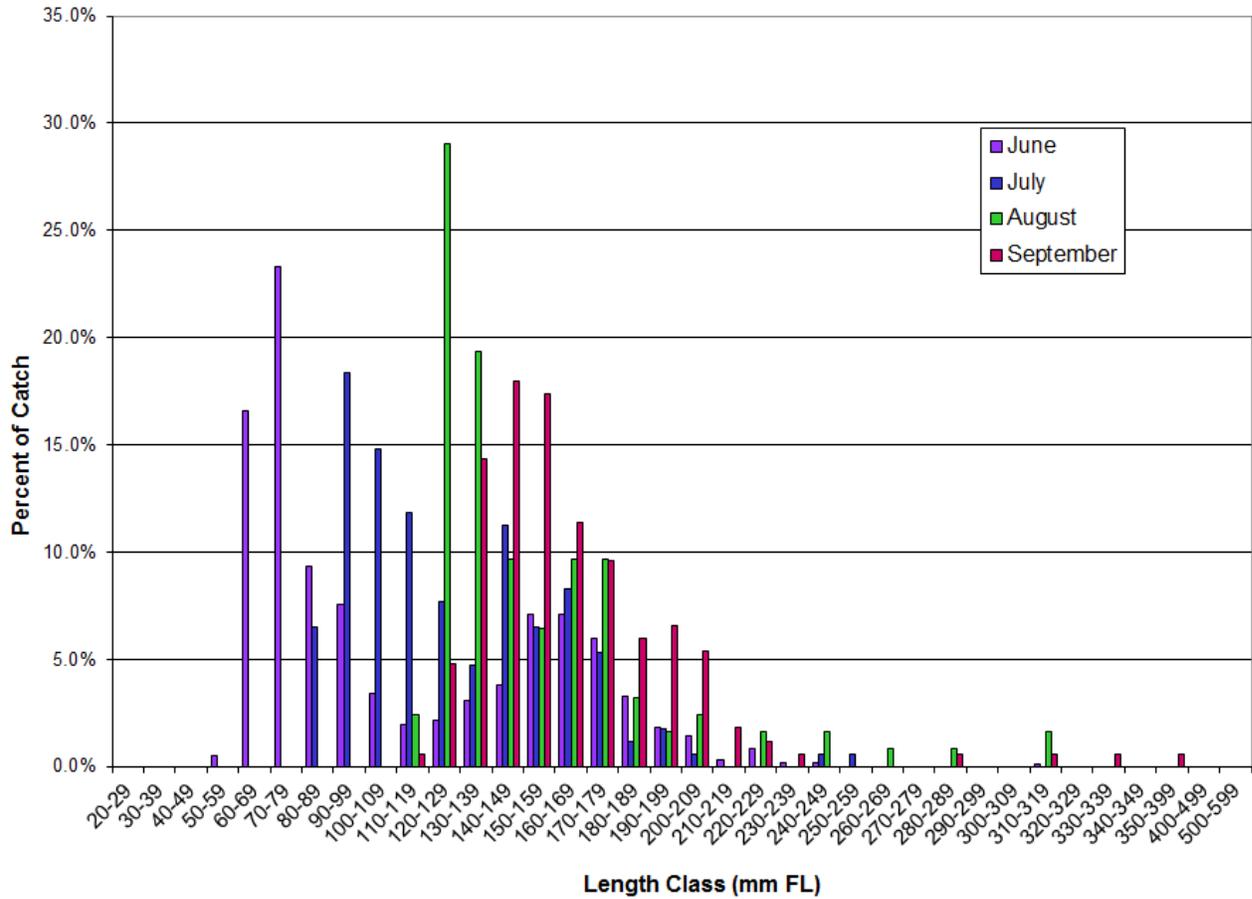


Figure 24. *O. mykiss* length classes in San Lorenzo Lagoon during different sample periods in 2017

Table 11. *O. mykiss* Growth Rates for Years Available

Year	N	Average June-Sept Growth (mm/day)	Range June-Sept Growth (mm/day)	September CPUE
2012	5	0.72	0.58-0.84	14.4
2013	2	0.34	0.27-0.41	4.7
2014	None captured			
2015	None captured			
2016	21	0.90	0.45-1.14	7.8
2017	40	0.46	0.02-0.86	328

Table 12. *O.mykiss* catch per haul for the San Lorenzo River Lagoon during recent sampling events (data from H.T. Harvey and Associates 2003, 2NDNATURE 2006, Ellen Freund (NOAA Fisheries), HES 2005, HES 2009, HES 2010, HES 2011, HES 2012, HES 2013, HES 2014, HES 2015, HES 2016, and HES 2017)

Station	Location	<i>O. mykiss</i> Catch per Haul					
2002						1 Oct	20 Nov
SL-2	RR Trestle						0.0
SL-3	Near YSI Station					5.5	
SL-4	Below Riverside						
SL-5	Riverside Drive						9.0
SL-7	Laurel St.						1.0
SL-8	Soquel Ave.					20.0	0.3
2004			6 July		21 Sep	29 Sep	
SL-1	Near Mouth				0.0	0.0	
SL-2	RR Trestle		24.5			0.5	
SL-3	Near YSI Station		20.0				
SL-4	Below Riverside		0.0				
SL-5	Riverside Drive		62.0		0.0	0.0	
SL-6	U/S Bank Restoration		3.0			0.0	
SL-7	Laurel St.		3.0				
SL-8	Soquel Ave.				0.0	0.0	
2005		14 Jun	14 Jul	16 Aug		5 Oct	
SL-1	Near Mouth	0.0	0.0	1.7		0.0	
SL-2	RR Trestle	28.0	5.3	179.5		0.0	
SL-5	Riverside Drive	0.0	12.3	10.7		62.7	
SL-8	Soquel Ave.	7.7	1.0	0.0		0.0	
2008		8, 19 Jun				7-8 Oct	
SL-1	Near Mouth	0				0	
SL-2	RR Trestle	9				0.25	
SL-3	Near YSI Station	0				0	
SL-5	Riverside Drive	0				0	
SL-6	U/S Bank Restoration	0				0	
SL-8	Soquel Ave.	0				0	
	Overall	2.6				0.1	
2009		10-11 Jun			16 Sep	21 Oct	
SL-2	RR Trestle	0.75			1.0	0.25	
SL-3	Near YSI Station	0.25					
SL-5	Riverside Drive	0				0	
SL-6	U/S Bank Restoration	0				1.5	
	Overall	0.3			1.0	0.5	
2010		22-23 Jun	17 Jul			Oct	
SL-1	Near Mouth	0.0				0	
SL-2	RR Trestle	11.7	0.5			31.3	
SL-3	Near YSI Station		42.5			0	
SL-5	Riverside Drive	0.0				9.0	
SL-6	U/S Bank Restoration	9.0				80.0	
	Overall	8.3	21.5			28.25	
2011		9-14 Jun				Oct	
SL-2	RR Trestle	11.7				1.7	
SL-3	Near YSI Station	7.8				5.7	
SL-4	Near Marsh Outlet	16.0				1.0	
SL-5	Riverside Drive	48.5				2.2	
SL-6	U/S Bank Restoration	0.5				0.3	
	Overall	13				2.5	

Table 12 (continued)

Station	Location	<i>O. mykiss</i> Catch per Haul					
2012		7-12 Jun			Sep 13-18		
SL-2	RR Trestle	5.2			21.3		
SL-3	Near YSI Station	0.8			17.5		
SL-4	Near Marsh Outlet	0					
SL-5	Riverside Drive	0			3.5		
SL-6	U/S Bank Restoration	0.1			5.0		
	Overall	1.7			14.4		
2013		6-11 Jun	17 July		Sep 12-17		
SL-1	South of Trestle	0.6			13		
SL-2	RR Trestle	0.8	2.2		1.6		
SL-3	Near YSI Station	6	24		1		
SL-4	Near Marsh Outlet	3			2		
SL-5	Riverside Drive	3			5.8		
SL-6	U/S Bank Restoration	0.3			6		
	Overall	2	8.4		4.7		
2014		5-10 Jun	17 July		Sep 11-15		
SL-1	South of Trestle	3.2	0		0		
SL-2	RR Trestle	0.9	3.5		0		
SL-3	Near YSI Station	1.0	0.5		0		
SL-5	Riverside Drive	0.5	0		0		
SL-6	U/S Bank Restoration	0.8	1		0		
SL-8	Water Street				1.1		
	Overall³	1.2	1.1		0.0		
2015		4-9 Jun	July 28-29	Aug 18-19		Oct 8-9	
SL-1	South of Trestle	0.8	0	0		0	
SL-2	RR Trestle	1.4	0	0		0	
SL-3	Near YSI Station	0.4	0	0		0	
SL-5	Riverside Drive	8.8	0	0		0	
SL-6	U/S Bank Restoration	2	0	0		0	
SL-10	Water Street	0					
	Overall⁴	2.6	0	0		0	
2016		9-14 Jun	July 13-14	Aug 16-17	Sept 22-27		
SL-1	South of Trestle	38.0	2.8	1.8	13.1		
SL-2	RR Trestle	138.5	0.5	2.8	4.4		
SL-3	Near YSI Station	2.0	1.0	0.3	17.0		
SL-4	Near Marsh Outlet		0.0				
SL-5	Riverside Drive	0.7	0.0	2.5	3.3		
SL-6	U/S Bank Restoration	22.0	0.0	2.4	8.0		
	Overall	39.7	1.0	2.0	7.8		
2017		15-20 Jun	July 11	Aug 15	Sept 21		
SL-1	South of Trestle	5.5	466.0	265.0	643.0		
SL-2	RR Trestle	100.9	424.0	279.0			
SL-5	Riverside Drive	566.7			13.0		
SL-6	U/S Bank Restoration	76.6			15.0		
	Overall	134.4	452.0	272.0	328.5		

³ Standard sites only (SL1-SL6)

- Forty *O. mykiss* that were tagged in June were captured in September. If recapture rates were the same for these fish as for marked fish in June (39/302 or 0.129), there would have been 310 June tagged *O. mykiss* in the lagoon in September. There were 302 *O. mykiss* tagged during the mark period in the lagoon in June, and an additional 177 tagged during the recap period for a total of 479 tagged fish in June. By these estimates, 65% of the *O. mykiss* present in June were in the lagoon in September.
- The NOAA PIT tag antenna at Felton detected 5 *O. mykiss* tagged in the lagoon between June and September including 4 tagged in June and 1 tagged in July (Table 13). An unknown number may have moved from the lagoon into the river downstream of Felton.
- As of April 29, 2018 a total of 105 *O. mykiss* tagged in the lagoon between June and September had been recorded at Felton. This represents 11.4% of *O. mykiss* tagged in the lagoon during the summer (Table 13).
- The relationship between population estimate and CPUE was updated with the early summer 2017 data, the only date in 2017 when a population estimate was possible (Figure 25). Least squares regression gives a highly significant relationship ($F=0.0001$) with an r^2 value = 0.93.

Late summer *O. mykiss* Population Estimate

No population estimate was completed in 2017 because sampling had to be abbreviated to a single day to avoid exceeding incidental take permit limits due to unusually large numbers of *O. mykiss* captured.

Table 13. Lagoon tagged *O.mykiss* recorded at Felton NOAA Fisheries PIT tag antenna 2017-2018

First Record at Felton	Tagged in June	Tagged in July	Tagged in August	Tagged in September	Total
2017 Jun					
Jul					
Aug	2	1			3
Sep	2				2
Oct					
Nov	40	13	8	14	75
Dec			1		1
2018 Jan	10	1	1		12
Feb				1	1
Mar	5			3	8
Apr	3				3
Total as of April 30, 2017	62	15	10	18	105
Total Tagged	479	157	121	164	921
Percent of Total Tagged	12.9	9.5	8.3	11.0	11.4

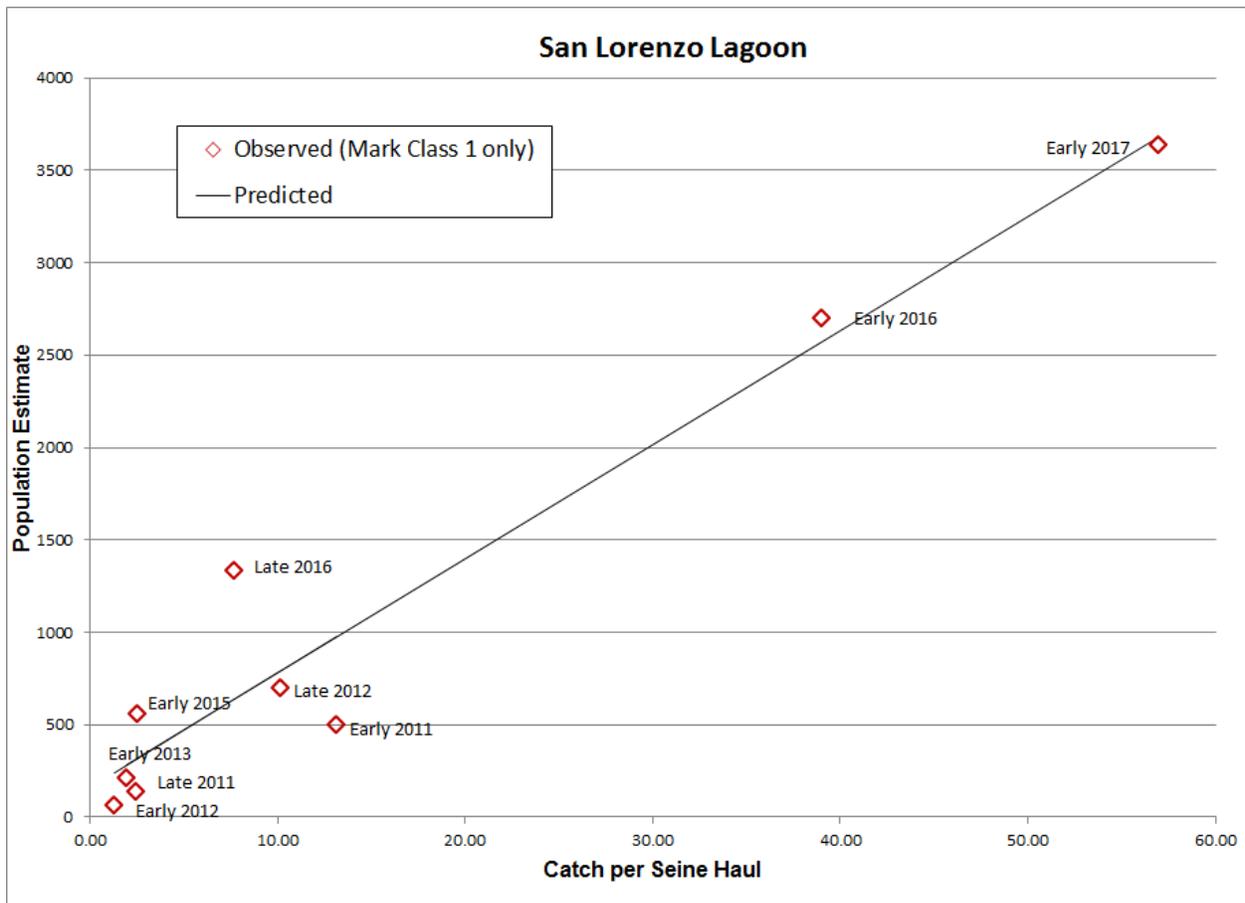


Figure 25. Relationship between *O. mykiss* population estimate and CPUE in the San Lorenzo River Lagoon⁴

⁴ The Early Summer 2013 and Early Summer 2015 estimates are likely biased due to the small number of marked fish and small number of recaptures. Population estimates are not available for Late Summer 2013 and Early Summer 2014 due to low recapture rates and indications that the assumption of closed population was violated (2013) or lack of recaptures (2014). No *O. mykiss* were captured in Late Summer 2014 and Late Summer 2015 so CPUE was zero and populations were assumed to be near zero also. CPUE values adjusted to reflect portion of population in tagging size range only.



Figure A-1. Laguna Creek Lagoon sampling stations

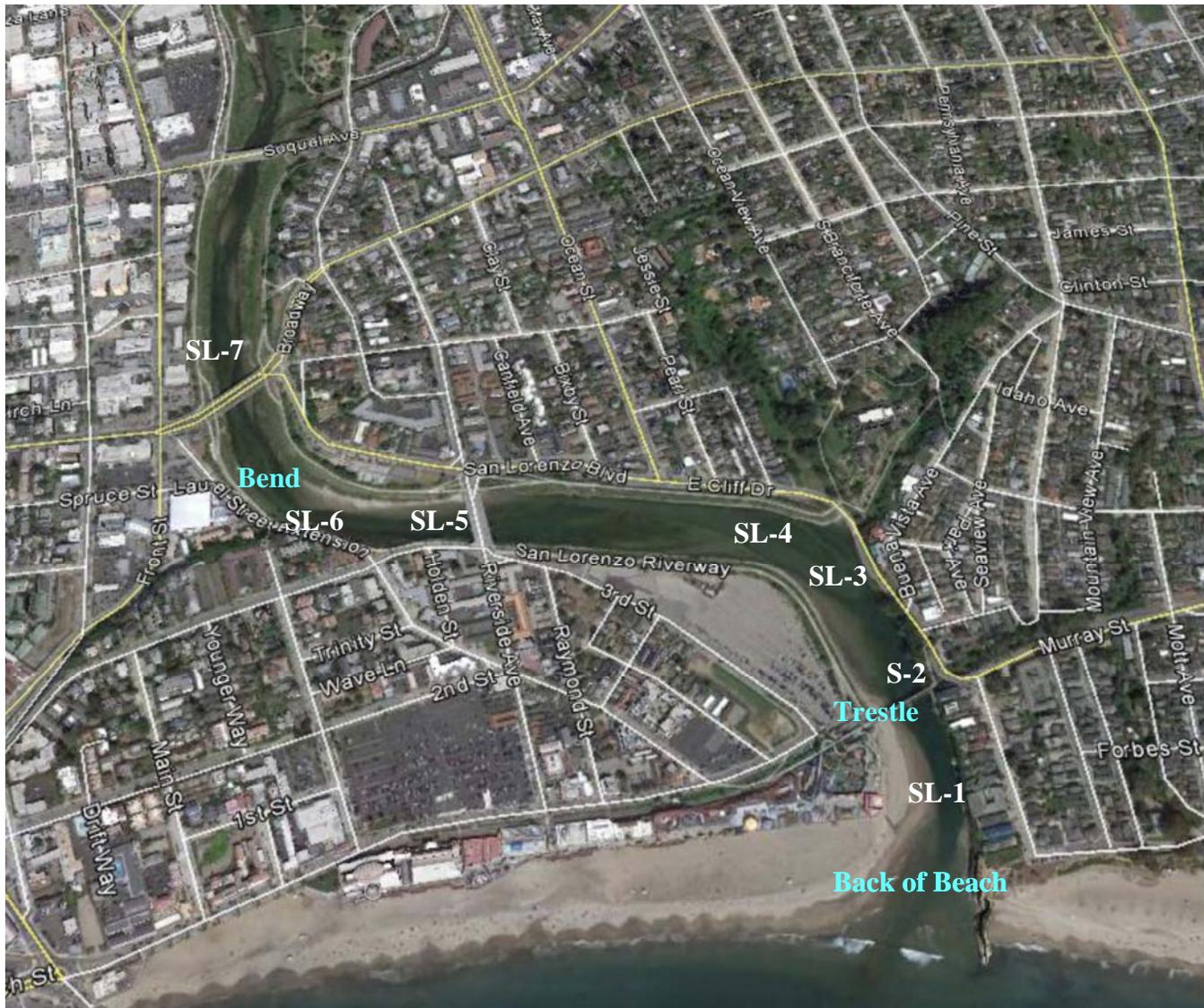


Figure A-2. San Lorenzo River Lagoon sampling stations

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Project Management:

Chris Berry
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Literature Citations

- 2NDNATURE. 2006. Comparative Lagoon Ecological Assessment Project (CLEAP) Santa Cruz County, California. Client: Santa Cruz County Resource Conservation District. Funder: California Coastal Conservancy. October 2006. Draft Final Report.
- H.T. Harvey & Associates. 2003. San Lorenzo Lagoon Steelhead Monitoring Feasibility Study. Prepared by H.T. Harvey & Associates and Scott Cressey. Prepared for: City of Santa Cruz. February 18, 2003.
- HES. 2005. DRAFT CLEAP Fish Sampling in San Lorenzo and Laguna Creek Lagoons 2004. Prepared for: California Coastal Conservancy and Santa Cruz County. February 9, 2005.
- HES. 2009. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling. Technical Memorandum, January 5, 2009.
- HES. 2010. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling. Technical Memorandum, January 15, 2010.
- HES. 2011. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2010. Technical Memorandum, September 30, 2011.
- HES. 2012. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2011. Technical Memorandum, December 11, 2012.
- HES. 2013. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2012. Technical Memorandum, November 15, 2013.
- HES. 2014. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2013. Technical Memorandum, June 24, 2014.
- HES. 2015. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2014. Technical Memorandum, June 25, 2015.
- HES. 2016. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2015. Technical Memorandum, June 28, 2016.
- HES. 2017. City of Santa Cruz Habitat Conservation Plan, Lagoon Fish Population Sampling 2016. Technical Memorandum, June 30, 2017.
- Ricker, W.E. 1975. Computation and Interpretation of Biological Statistics of fish Populations. Bulletin of the Fisheries Research Board of Canada. Bulletin 191. Department of the Environment, Fisheries and Marine Service. Ottawa, Canada 1975.