



Fishery and Water Quality Monitoring of Pajaro River Lagoon/Lagoon, 2021
(Sampling for Tidewater Goby under USFWS Endangered Species Recovery Permit TE-793645-4)



Upper Pajaro Lagoon Adjacent Model Airport, looking south toward lower lagoon. (D. Alley) October 2021

Purpose of Sampling

The Santa Cruz County Flood Control and Water Conservation District Zone 7 is required to conduct annual fish sampling in the Pajaro Lagoon as a permit condition for lagoon breaching. Fish sampling documents the presence/absence, distribution and abundance of steelhead (*Oncorhynchus mykiss*), tidewater goby (*Eucyclogobius newberryi*), and other fish and wildlife. 2021 was the tenth year of annual sampling, which began in 2012.

Summary of 2021 Results

No steelhead or tidewater goby were captured in Pajaro River Lagoon in fall 2021. The catch in the lower lagoon was dominated by jack smelt (*Atherinopsis californiensis*) and top smelt (*Atherinops affinis*). Other captured native fish species included shiner perch (*Cymatogaster aggregata*), arrow goby (*Clevelandia ios*), threespine stickleback (*Gasterosteus aculeatus*), staghorn sculpin (*Leptocottus armatus*), diamond turbot (*Hypsopsetta guttulata*), California halibut (*Paralichthys californicus*) and Pacific herring (*Clupea pallasii*). A longjaw mudsucker (*Gillichthys mirabilis*) was captured at a site near the mouth of Watsonville Slough.

2021 Lagoon Conditions

During fish sampling in early October, a lagoon was present, having a closed sandbar. At the time of fish sampling, the lagoon was deeper than in previous years in which the sandbar was open with an estuary connection to the Monterey Bay and having tidal influence. The drought year of 2015 was the last previous year with a closed sandbar. The sandbar had been open earlier in 2021, as evidenced by moderate saline conditions at the time of fish sampling. The Santa Cruz County stage recorder indicated that the sandbar had been closed since late June 2021. In 2021, the lower lagoon remained cool and unstratified nearshore, with moderate salinity in late morning. In the upper lagoon down through the water column, temperature (20 to 24 C), salinity (2 to 23 ppt) and oxygen (33 to 0 mg/L) were stratified from surface to bottom. Under very murky conditions, light could not penetrate to the bottom in deeper areas of the upper lagoon greater than about 0.85 m from the surface. This led to anoxic or near anoxic conditions in the lower water column due to the absence of photosynthesis in this aphotic zone.

Methods

Pajaro Lagoon (closed sandbar) was sampled on October 5–7, 2021. Sampling locations included along the beach berm from the mouth of Watsonville Slough to the east, adjacent to the model airport (1.8 miles upstream of Watsonville Slough), at Thurwachter Bridge (2.1 miles upstream of Watsonville Slough) and behind the City of Watsonville wastewater treatment plant at the boat ramp (2.9 miles upstream of Watsonville Slough) (**Figure 1**).

On 5 October, the lower lagoon along the beach was sampled for steelhead with the 106-foot bag seine (8 successful seine hauls). On 6 October, the upper lagoon was sampled with the 106-foot bag seine (3/8-inch mesh), and water quality data were collected. Three seine hauls were made at the model airport, with 3 more at Thurwachter Bridge. Water quality was measured mid-channel at these 2 sites (water temperature (°C), salinity (parts per thousand), conductivity (umho = micro-siemens = 1 millionth of a siemens) and oxygen (mg/L = parts per million) measured through the water column at 0.25 meter intervals). Conductivity is a measure of water's capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. These conductive ions come from dissolved salts and inorganic materials such as alkalis, chlorides, sulfides and carbonate compounds and not just sodium chloride.

On 7 October, tidewater gobies were sampled for, using a 30-foot seine with 1/8-inch mesh.

Five seine hauls were made in the lagoon along the beach. Three seine hauls were made in the upper lagoon (model airport, Thurwachter Bridge and boat ramp). Water quality was measured at 6 stations. The 4 lower lagoon measurements were made nearshore by wading. The two upper lagoon measurements were made nearshore by wading near the model airport and the boat ramp. Water quality measurements taken on 6 and 7 October were sufficient to determine general water quality conditions at the time of fish sampling.

Figure 1. Pajaro Lagoon Fish and Water Quality Sampling Sites





Lower Pajaro Lagoon, looking west toward the levied upper lagoon. (T. Suttle) 5 October 2021



Lower Pajaro Lagoon, looking east along southern beachfront berm margin. (T. Suttle) 5 October 2021



Lower Pajaro Lagoon, east end of the lagoon with closed sandbar. (T. Suttle) 5 October 2021

Results – Fish Capture

Sampling of the lower lagoon along the beachfront with the larger bag seine yielded 10 native fish species (**Table 1**) compared to 4 in 2019 and 2020, 7 in 2018, 4 in 2017, 3 in 2016, 1 in 2015, 3 in 2014 and 10 in 2013. Smelt were again the most abundant species, with those being identified as jack and topsmelt. Other species, in declining abundance, included shiner perch, staghorn sculpin, arrow goby, diamond turbot, California halibut, Pacific herring and longjaw mudsucker (a goby). Yellowshore and Dungeness crabs were common. But no tidewater gobies or steelhead were detected in the lower lagoon.

Results of sampling for steelhead in the upper lagoon near the model airport and Thurwachter Bridge with the large seine yielded no fish, for the first time since sampling began in 2012. (**Table 2**).

Our tidewater goby sampling with the smaller, fine-meshed seine in the lower lagoon yielded no tidewater gobies or steelhead along the beachfront where 5 native species were captured, those consisting of jack and topsmelt, shiner perch, arrow goby and stickleback, all in very low numbers (**Table 3**). No tidewater gobies were captured in the upper lagoon in 2021 after being detected the previous year (**Table 4**). Species captured in the upper lagoon with the smaller seine included only 2 native species, those being shiner perch and threespine stickleback.



Longjaw mudsucker goby. (T. Suttle) 5 October 2021



Shiner Perch. (T. Suttle) 7 October 2021

Table 1. Fish capture* results from sampling lower Pajaro lagoon with the 106-foot bag seine (3/8-inch mesh), 5 October 2021.

Date	Location	Seine Haul	Steel-head	Tide-water Goby	Arrow goby	Longjaw mudsucker	Smelt (jack and top)	Staghorn Sculpin	Pacific Herring	California Halibut	Diamond Turbot	Shiner Perch
5 Oct 2021	East of Watsonville Slough #8	8				1	5					
	East of #1	1					829		1			8
	East of #2	2					961	1			1	3
	East of #3	3			1		97					
	East of #4	4					159					
	East of #5	5			2		908					
	East of #6	6			3		641	6		1		1
	East of #7	7					49					3
Total		8	0	0	6	1	3,648	7	1	1	1	15

*42 yellowshore crabs, 17 Dungeness crabs. 1 osprey, 200+ mostly brown and a few white pelicans, cormorants

Table 2. Fish capture* results from sampling upper Pajaro Lagoon with the 106-foot bag seine (3/8-inch mesh), 6 October 2021.

Date	Location	Seine Haul	Steel-head	Tide-water Goby	Northern Anchovy	Bay pipefish	Smelt	Staghorn Sculpin	Three-spine Stickle-back	Starry Flounder	Longjaw mudsucker goby
6 Oct 2021	Model Airport	1-3									
	Thurwacher Bridge	4-6									
Total			0	0	0	0	0	0	0	0	0

Table 3. Fish capture* results from sampling the periphery of lower Pajaro lagoon, lower Watsonville Slough and upper Pajaro Lagoon with the 30-foot seine (1/8-inch mesh), 7 October 2021.

Date	Location	Seine Haul	Steel-head	Tide-water Goby	Arrow goby	Three-spine Stickle-back	Bay pipe-fish	Smelt	Mosquito fish	Staghorn Sculpin	Shiner Perch	Longjaw mudsucker goby
7 Oct 2021	Approx. 100 m east of Pajaro Dunes	5			2			7				
	East of #5	4										
	East of #4	3						1			1	
	East of #3	2			1	1						
	East of #2	1										
	Airport- 0.3 miles down from Thurwacher Br	6				1						
	Thurwacher Br.- 2.1 miles up from Watsonville Slough	7										
	Boat Ramp- 0.8 miles upstream of Thurwacher Br.	8									4	
Total		8	0	0	3	2	0	8	0	0	5	0

* 3 yellowshore crabs.

Table 4. Annual Number of Tidewater Gobies Captured in Pajaro Lagoon/ Lagoon in Fall.

Year	# of Tidewater Gobies Captured in Pajaro Lagoon/Estuary	# of Seine Hauls at Approximately Similar Locations with 30-foot Seine (1/8-inch mesh)
2012	111	8
2013	436	8
2014	414	8
2015	42	8
2016	29	8
2017	0 (1 with 3/8-inch mesh seine adjacent model airport)	8
2018	0	8
2019	0	8
2020	11	8
2021	0	8



California Halibut (T. Suttle) 5 October 2021



Diamond Turbot (T. Suttle) 5 October 2021



Pacific herring. (Photo by T. Suttle) 28 September 2020



Staghorn Sculpin. (T. Suttle) 5 October 2021

Water Quality

Stress to freshwater acclimatized steelhead would probably not occur until conductivity levels reach 12,000 to 15,000 micro-mhos, associated with sudden increases in salinity to 10 – 12 parts per thousand (ppt) (**J. Cech, personal communication**). However, steelhead acclimatized to lagoon conditions with fluctuating salinity and associated stratification can survive where salinity increases with depth and may range from 8 to 20 ppt at depths of 0.75 m and deeper, with salinity in the upper 0.5 m less than 1 ppt. These were lagoon conditions in Aptos lagoon in 2018 with steelhead present (**Alley 2019**). Similar conditions existed in Aptos Lagoon in 2019 and 2020 with steelhead present (**Alley 2020a; 2021a**). Water temperatures above 22° C (72° F) and oxygen levels below 5 parts per million (mg/L) are thought to stress steelhead. After 15 years of water quality monitoring and steelhead/tidewater goby sampling of Santa Rosa Creek Lagoon near Cambria, CA, and 30 years at Soquel Creek Lagoon in Capitola, CA, the following were recommendations to insure steelhead habitation. These recommendations would be difficult to attain at Pajaro Lagoon because of the absence of/ or extremely limited summer stream inflow.

- *The 7-day rolling average water temperature within 0.25 m of the bottom should be 19°C or less.*
- *Maintain the daily maximum water temperature below 25°C (77°F).*
- *If the maximum daily water temperature should reach 26.5°C (79.5°F), it should be considered the lethal limit.*
- *Water temperature at dawn near the bottom for at least one monitoring station should be 16.5°C (61.7°F) or less on sunny days without morning fog or overcast **and** 18.5°C (65.3°F) or less on days with morning fog or overcast.*
- *Maintain the daily dissolved oxygen concentration near the bottom at 5 milligrams/liter or greater, though it does not become critically low and potentially lethal until it is less than 2 mg/l throughout the water column for several hours, with the daily minimum occurring near dawn or soon after.*

Coastal lagoons are very food-rich environments where steelhead growth rates are very high, despite warmer water temperatures. A study completed by **Farrel et al. (2015)** indicated that the thermal range over which a Tuolumne River *O. mykiss* population could maintain 95% of peak aerobic capacity was 17.8°C to 24.6°C. Furthermore, up to a temperature of 23°C, all individual fish could maintain a factorial aerobic scope (FAS) value >2.0 (FAS = Maximum metabolic rate (MMR) / Routine metabolic rate (RMR)), one that is predicted to provide sufficient aerobic capacity for the fish to properly digest a meal.

Tidewater gobies can physiologically tolerate the warmest, most saline, and lowest oxygen conditions that may be found in lagoon/estuary conditions, so long as some oxygen is present on the bottom. However, they typically build their nests in sand on the bottom under freshwater conditions or low salinity. Therefore, they need freshwater conditions, or nearly so, and oxygen along the bottom to reproduce. This condition may only exist at the upper end of a lagoon where

freshwater inflow exists. If the sandbar closes and a freshwater lagoon develops from sufficient freshwater inflow in the summer, spawning conditions may be extensive. Artificial summer and fall sandbar breaching unassociated with stormflow, especially after freshwater conversion of the lagoon, would negatively impact tidewater gobies. Tidewater gobies are poor swimmers and require overwintering backwater habitat protected from water velocity to avoid being flushed out of the wet-season estuary during stormflow.

On 6 October, during steelhead sampling in the upper lagoon, air temperature was moderate (range of 16.5–19.6°C). Water temperature was warm and stratified (range of 20.2°C at the surface at the model airport to 22.9 °C at the bottom at Thurwachter Bridge by early afternoon) and would likely have been stressful for steelhead by early afternoon (**Table 5**). Salinity was stratified with depth at both sites. It was a minimum of 3.5 ppt at the surface at the model airport and a maximum of 23.1 ppt at the bottom there. These saline conditions probably would not be stressful to acclimated steelhead because of low salinity water nearer the surface. Oxygen levels were above 5 mg/l in the upper 0.75 m the water column where steelhead could inhabit. However, oxygen was less than 0.6 mg/ L below that, even at midday. Therefore, the water column below 0.75 m was likely uninhabitable to steelhead and even tidewater goby in the upper lagoon. Algae and other aquatic vegetation do not photosynthesize at night to produce oxygen. At night they only respire like other living things, consuming oxygen and producing carbon dioxide. After a night of plant respiration, oxygen levels are lowest near dawn and normally begin to increase as sunlight penetrates the water column and plants begin to photosynthesize. However, the water column was very turbid, with a secchi depth of only 0.85 m, making the lower water column dark.

On 7 October during tidewater goby sampling in the lower and upper lagoon, no stratification was found for water temperature or salinity in the lower lagoon in the morning with cool air temperature (16.2°C at 1004 hr) (**Table 6**). In the lower lagoon, water temperature was uniformly cool with slight cooling with depth below 0.75 m; salinity was uniformly moderate without stratification. Oxygen was only slightly reduced with depth at the 3 eastern sites in the lower lagoon, but was stratified at the western site, closest to Watsonville Slough by 1300 hr. Secchi depth was to the bottom nearshore in the lower lagoon, and oxygen levels were sufficient for steelhead and tidewater gobies to inhabit these areas in late morning and early afternoon.

Water quality measurements nearshore in the upper lagoon indicated that temperature and salinity were only slightly stratified at the model airport but were further upstream at the boat ramp. Water temperature was warm at both sites and especially stressful below 0.25 m at the boat ramp. Oxygen was stratified at both upper lagoon sites nearshore, with oxygen nearly absent (0.23 mg/L at 0.75 m) near the bottom at the boat ramp. Thus, conditions near the bottom at the boat ramp were likely uninhabitable for steelhead (high water temperature and little oxygen) and tidewater goby (little oxygen). Steelhead could inhabit the upper 0.5 m of the water column but

would be vulnerable to predation there and would prefer to be near the bottom in deeper water offshore if oxygen was available there, which it was not.

Table 5. Water quality measurements in the upper Pajaro lagoon during fish sampling for steelhead, 6 October 2021.

6-Oct-2021									
	Model Airport (mid-channel) Air temp. 19.6°C				1122 hr	Thurwachter Bridge (mid-channel) Air temp. 16.5°C			1345 hr
Depth	Temp	Salin	Oxygen (%sat.)	Cond	Temp	Salin	Oxygen (%sat.)	Cond	
(m)	(C)	(ppt)	(mg/l)	micro-mhos	(C)	(ppt)	(mg/l)	micro-mhos	
0	20.2	3.5	33.25	5862	21.3	7.9	27.93	12749	
0.25	20.5	8.2	29.91	12929	21.3	8.0	26.31	12822	
0.5	20.3	8.5	26.35	13275	20.9	8.1	24.23	12851	
0.75	20.4	8.5	20.52	13375	21.4	8.9	5.56	14164	
1.0	21.5	10.5	0.54	16594	22.0	10.4	0.55	16606	
1.25	21.7	10.8	0.45	17016	22.7	11.5	0.43	18522	
1.37b					22.9	12.3	0.30	19705	
1.50	22.5	12.4	0.00	19553					
1.75	22.6	21.9	0.00	33247					
2.00	22.6	23.1	0.00	34777					
2.15b	22.5	23.9	0.00	35643					

* “bot” indicates the lagoon bottom where measurements were taken through the water column.

Table 6. Water quality measurements in the lower Pajaro lagoon (Seine Hauls 1, 3 and 5 nearshore along beach) and 2 upper lagoon sites during fish sampling for tidewater goby, 7 October 2021.

7-Oct-2021									
	Seine Haul 1 (l. lagoon) air temp 16.2°C			1004 hr		Seine Haul 3 (lower lagoon)			1053 hr
Depth	Temp	Salin	Oxygen	Cond	Temp	Salin	Oxygen	Cond	
(m)	(C)	(ppt)	(mg/l)	micro- mhos	(C)	(ppt)	(mg/l)	Micro- mhos	
0	16.2	11.0	8.29	15420	15.9	10.8	5.62	15027	
0.25	16.2	10.9	7.93	15254	15.9	10.7	5.17	14874	
0.5bot	16.2	10.9	8.10	15263	15.9	10.7	5.05 (55%)	14893	
0.67					15.8	10.7	4.82	14868	
0.75bot	16.2	10.9	8.01	15275					
1.0									
1.25									
	Seine Haul 5 (lower lagoon)			1132 hr	Seine Haul 6 (upper lagoon nearshore) Model Airport			1144 hr	
Depth	Temp	Salin	Oxygen	Cond	Temp	Salin	Oxygen	Cond	
(m)	(C)	(ppt)	(mg/l)	micro- mhos	(C)	(ppt)	(mg/l)	micro- mhos	
0	17.5	10.7	6.83	15545	20.5	8.1	27.07	12847	
0.25	17.7	10.7	6.49	15492	20.7	8.5	25.34	13427	
0.5	17.5	10.7	6.37	15460	20.7	8.8	23.31	13775	
0.75	17.4	10.7	6.18 (69%)	15444	20.9	9.2	7.80 (94%)	14485	
0.85bot	17.0	10.7	5.36	15305					
0.87bot					21.1	9.6	6.22	15106	

* “bot” indicates the lagoon bottom where measurements were taken through the water column.

Table 6 (continued). Water quality measurements in the lower Pajaro lagoon.(Seine Hauls 1, 3 and 5 nearshore along beach) and 2 upper lagoon sites during fish sampling for tidewater goby, 7 October 2021.

7-Oct-2021							
Seine Haul 8- Boat Launch Ramp (upper lagoon nearshore) (Adjacent Wastewater Plant)			1414 hr				
Depth	Temp	Salin	Oxygen	Cond			
(m)	(C)	(ppt)	(mg/l)	micro-mhos			
0	20.3	2.3	15.77	3865			
0.25	20.5	2.8	1896	4825			
0.5	22.5	7.4	16.89	12250			
0.75	24.2	9.4	0.23	15820			
0.95bot	24.7	10.8	0.16	17971			
1.0							
1.25							

* “bot” indicates the lagoon bottom where measurements were taken through the water column.

Conclusions

No steelhead or tidewater gobies were detected in the Pajaro Lagoon in fall 2021. The sandbar was closed at the time of sampling, creating deeper conditions than occurred in years when the sandbar was open. Insufficient freshwater inflow had prevented the lagoon from converting to freshwater, with unstratified, cool, moderately saline conditions nearshore in the lower lagoon. Under murky conditions, the upper lagoon possessed an aphotic, anoxic zone in deeper areas where water temperature, salinity and oxygen were stratified. The lower water column there was hot, saline and devoid of oxygen, or nearly so, in deep areas and nearshore. With steelhead seeking deeper water to inhabit, the upper lagoon was likely uninhabitable for steelhead except near the surface, which they typically avoid to prevent predation.

Mild winter stormflows allow better overwinter survival of tidewater gobies than in wetter years. Tidewater goby was detected in 2020, but was not in 2021 despite the mild winter having only 1 significant stormflow. With a leveed channel, protected backwaters with tules are limited for overwintering cover for tidewater goby during high stormflow events. The mild winter was associated with relative abundance of tidewater gobies in Aptos and Soquel Lagoons in 2021 (Alley 2022a; 2022b). However, this was not the case in Pajaro Lagoon. With tidewater goby being a bottom dweller, the upper Pajaro Lagoon provided no spawning habitat at sampling sites for tidewater goby due to anoxic conditions. The lower lagoon may have provided marginal tidewater goby spawning conditions with moderate salinity and oxygen present nearshore.

However, tidewater gobies prefer to nest along the margins in freshwater conditions, which were absent at Pajaro Lagoon sampling sites in 2021. Freshwater along the lagoon bottom may have existed in late spring or early summer when sufficient freshwater inflow may have entered at the most upstream extent of the lagoon. However, the Pajaro River typically goes dry upstream of the lagoon in all but the wettest years.



Tidewater gobies captured in Soquel Lagoon. (Photo by I.M. Laursen) 4 October 2020

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