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Mortality of Native and Non-native Fishes during Artificial Breaching of Coastal Lagoons in Southern and Central California

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Abstract.—Fishes of California coastal streams and associated coastal lagoons have adapted to the Mediterranean-style rainfall cycle. Winter rains open the lagoons to the ocean; subsequent lack of rain and seasonal changes in beach dynamics typically closes them for much of the year. Dry and wet season artificial breaching or opening of barrier sand berms has been suspected to disrupt fish populations and lead to mortality of many aquatic organisms including federally endangered species. Such breaches have been rarely observed and then only after at least a few days or more have passed. Artificial breachings of three lagoons have been observed during or within a few hours after breaching and provide documentation of extensive disruption and mortality of aquatic organisms. These observations, Aliso Creek, Orange County (1975), Santa Clara River, Ventura County (2010), and Corcoran Lagoon, Santa Cruz County (2014-2015), confirmed many changes and effects of these events, including mortality of the federally endangered northern and southern tidewater gobies and southern steelhead. Despite the many ostensibly beneficial and non-faunal related reasons for breaching, our observations confirm such actions can cause considerable mortality of threatened and endangered species and are probably more severe than natural wet season breachings. Many city, county, as well as state and federal laws provide regulation of lagoon breaching to protect habitat and minimize or mitigate for impact to sensitive species and these need to be maintained and strengthened.

Many small coastal California lagoons at the mouths of streams and rivers remain nearly or completely closed to the ocean for most of the dry season (~April to November), the typical pattern of Californian and Mediterranean climate-influenced coastal lagoons (Warme et al. 1977; Kjerfve 1994; Woodroffe 2002; Fong and Kennison 2010). The closed condition supports a small but distinctive native estuarine and brackish water aquatic fauna and flora rapidly disappearing due to human modifications to these habitats. Anecdotal observations of artificial breaching of these lagoons have suggested such events adversely affect populations of fishes and other aquatic organisms. Opportunities to observe and document the effects of three such breaching provides some qualitative and quantitative assessments of the effects of these events on both native and non-native fishes and other aquatic organisms.

The sites observed were: Aliso Creek, Orange County, where the southern tidewater goby, *Eucyclogobius kristinae,* was extensively studied [Goldberg 1977; Swift et al. 1989 as *E. newberryi* (Swift et al 2016)]; the mouth of the Santa Clara River, Ventura County,

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Fig. 1. a) Aliso Creek Lagoon, closed to the ocean photo, 2 December 1973 (Swift et al. 1989); b) Trench being dug at mouth of Aliso Creek Lagoon, 2 December 1973; c) Recently drained lagoon from upstream end, 2 December 1973, d) Surf naturally rebuilding barrier berm at Aliso Creek Lagoon, 2 December 1973. Photos by C.C. Swift.

a site extensively studied due to the presence of endangered species and water quality concerns about municipal and agricultural wastewater[1]; and Corcoran Lagoon (Rodeo Gulch), Santa Cruz County, with a much smaller freshwater drainage upstream than the former two. Breaching of the lagoons was observed directly at Aliso Creek and within hours before and/or after breaching at the Santa Clara River and Corcoran Lagoon.

Materials and Methods

Site descriptions

Aliso creek: On 2 December 1973 this long, narrow lagoon (Fig. 1a) was about 0.75 ha, and bordered by a narrow fringe of marsh vegetation between the open water and riprap reinforcing much of the borders. The lagoon was up to 1.5 m deep, 20-25 m wide and about 400 m long with a sandy bottom and a narrow 1-5 m fringe of marsh vegetation near shore. The water level was relatively high, within 30-40 cm vertically from the top of the barrier sand berm (Fig. 1a) and 1-1.5 m above the mean high tide. Low tide was 0.82 m (2.7 ft) at 08:33 and the high tide was only slightly higher at 1.09 m (3.6 ft) at 13:28. The breach started with a hand-excavated trench (Fig. 1b) at 10:00-12:00 hrs and in one to two hours reduced the lagoon by 80-85% with the remaining standing water centered on the

[1] https://www.cityofventura.ca.gov/1248/ArchiveSanta-Clara-River-Estuary-Special.

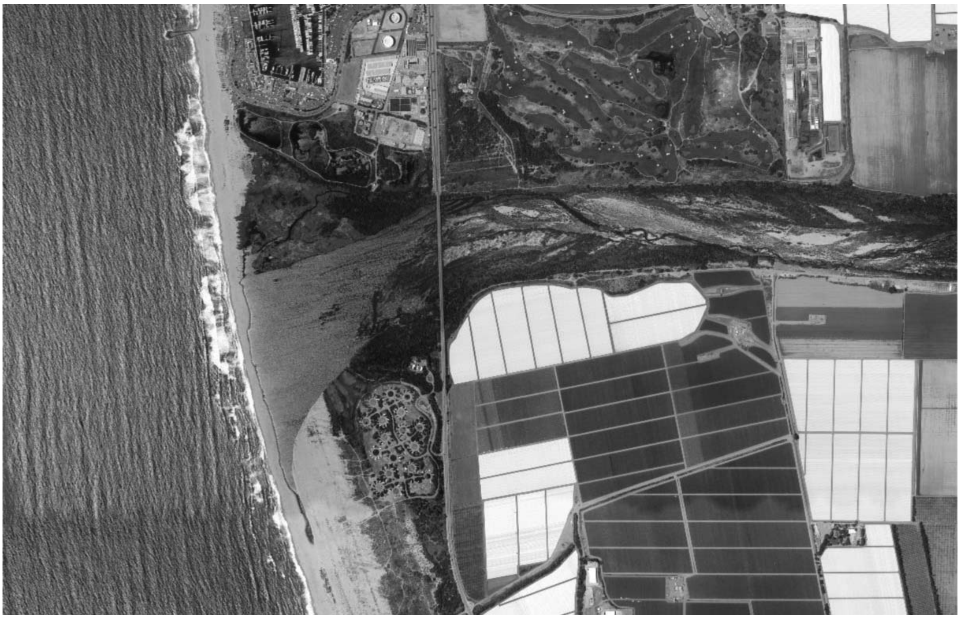

Fig. 2. Aerial view of the Santa Clara River lagoon; Harbor Boulevard bridge runs north-south, about 0.8 km upstream from the ocean.

Hwy 1 bridge (Fig. 1c). The barrier berm was partly rebuilt by the surf in about two hours (Fig. 1d) and the lagoon began to enlarge. The inflow of Aliso Creek (≤ 56 l/sec [2 cfs]) continued to flow over the upper half or so of the newly exposed sandy lagoon bottom. From the upstream to downstream ends the temperature and salinity went from 8.5-9.5°C and 4.8-7.2‰, respectively. No further physical observations were made but the lagoon was relatively high again by early June 1974 (Swift et al. 1989).

Santa Clara river: On 16 September 2010 after months of closure the lagoon level stood a meter or so above high tide behind the sand berm and gradually shallowed upstream to about 600 m above the Harbor Boulevard Bridge. The surface area was about 45 ha (Fig. 2). The lagoon was 700 m to 900 m wide along the beach with a narrow 0.5 km extension to the south. Upstream the lagoon narrowed, increasingly confined by artificial levees. The substrate was over 90% fine to coarse sand with small areas of gravel near the river channel and muddier substrates in some marginal areas. Most depths were ≤1.5 m with extensive marginal emergent aquatic vegetation widest toward the mouth at the beach and riparian forest near and above the Harbor Avenue Bridge. Marginal vegetation was bulrush (*Schoenoplectus* sp. or *Scirpus* sp.), cattails (*Typha* sp.), with willows (*Salix* sp.), and cottonwoods (*Populus fremontii*) beyond on emergent shores. The sandy seaward shore of the lagoon lacked vegetation.

The lagoon was high late the previous afternoon (J. Mann, pers. comm., 17 September 2010) and opened and drained during the night before the survey (Fig. 3a). Earlier on Tuesday, 14 September 2010, C. Spahr and J. Wong, separately observed a trench approximately 1.25 m wide, 3 m long, and 1 m deep between the wetted edge of the lagoon and the upper extent of high tide. After the breach, the river flowed about 283 l/sec (10 cfs) meandering west southwest along the north side and the wastewater outflow channel

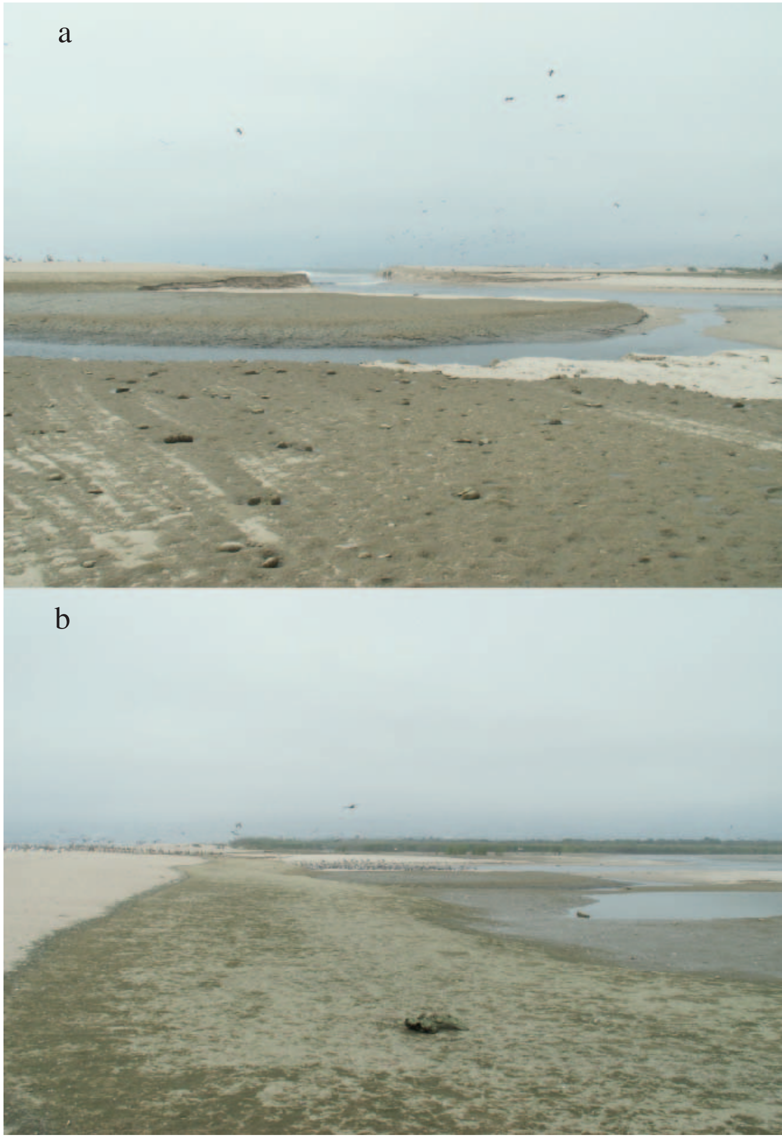

Fig. 3. a) View of lower Santa Clara River lagoon on the morning of observations, 17 September 2010, illustrating the shallow, formerly submerged sand flats with two men standing in the breach in the barrier sand berm for scale. Photo by C. Dellith. b) South side of drained Santa Clara River lagoon with small isolated ponds and seepage from the sand into the remnant watered area. Photo by Chris Dellith, 17 September 2010.

(about 275 l/sec or 9.7 cfs) from the north ran southwest joining the river channel about 150 m upstream of the breach. Less flow emanated from a residual channel (≤ 15 l/sec or ≤ 0.5 cfs) from the south side of the lower lagoon to near the breach (Fig. 3b, background). The low tide was 0.148 m (+0.37 ft) at 01:06 and high tide was only 1.24 m (4.1 ft) at 07:51 the morning of the breach and low again at 0.82 m (2.7 ft) at 12:51. The lagoon was

Fig. 4. a) Full Corcoran lagoon before breach, 19 December 2015; b) Trench dug on beach at seaward end of Corcoran lagoon. 19 December 2015; c) Drained Corcoran lagoon about the same area as shown when lagoon full in Fig. 4a, 11 February 2014; d) Moribund northern tidewater gobies on substrate of Corcoran Lagoon coated with sand from struggling on the surface after sudden lowering of the lagoon. 11 February 2014. Photos by K. Kittleson.

reduced to about 10% of its aerial extent. A residual ponded area just inside the gap in the beach was roughly circular, about 50 m in diameter, and had been 3-4 m deep judging by the empty lagoon border (Fig. 3a). The remaining drained area was exposed moist sand with seepage and two remnant pools on the south side. The large gap in the barrier sand berm remained by 16:00 with a strong outflowing current. Water temperatures ranged from 17-20°C. and salinities from 1.0-2.5‰ measured at three locations: at Harbor Boulevard, just inside the break in the beach berm, and to the north in the wastewater outflow. The narrow range of water quality measurements over widely spaced sites indicates the lagoon was well mixed and very similar in temperature and salinity in the areas less than 2 m deep. The deep pool near the ocean may have been more saline at depth. Some wave surge carried into the lower lagoon during the first half of the day within 150 m of the breach. The water throughout the lagoon was yellowish to greenish, visibility limited to about 40-50 cm. At Harbor Boulevard Bridge, the water coming down the river was clearer but roiled by fish activity. The lagoon had not appreciably refilled by approximately 16:30 when the survey ended.

Corcoran lagoon: On 10-11 February 2014 the lagoon was high and rising during rains and flooded the coastal road near the beach, East Cliff Drive (Fig. 4a), and threatened Radio Station facilities on piers in the lagoon. The lagoon covered about 7-8 ha and was up to about 2.5 m deep under the East Cliff Drive bridge at the mouth of the lagoon. A trench was observed on the beach on the afternoon of 10 February 2014 but was not deep enough to initiate flow from the lagoon to the ocean. The lagoon breached the morning of 11 February 2014 reducing the lagoon to about 3 ha and a depth of about 30 cm at the bridge and it remained very low through 12 February 2014. The high tide was 1.52 m (5.0 ft) at 01:40, a low of 0.43 m (1.4 ft) at 07:45, and another high of 1.13 m (3.7 ft) at 13:44.

Preceding a 21 December 2015 breaching event East Cliff Drive again was flooded by water about 25 cm deep by 14 December 2015, was still high on 19 December 2015, and at mid-day a small trench had a small outgoing flow (Fig. 4b). This trench was filled in mid-afternoon. On the 20 December 2015 the lagoon was still high, more than 2 m deep. By 09:00 on 21 December 2015 the lagoon had breached and drained (Fig. 4c). The wetted surface area was reduced by 80-90%. The low tide late (19:29) on the 20 December 2015 was 0.06 m (0.2 ft) and on the 21 December 2015 a high of 1.28 m (4.2 ft) at 03:26, low of 1.04 m (3.4 ft) at 08:23, and high again of 1.28 m (4.2) at 12:56.

The events at Aliso Creek and Corcoran Lagoon were observed visually over most of each lagoon area with some dead specimens taken by hand and a few seine hauls with a 4.6 m × 1.8 m (15 × 6 ft) 3.2 mm (1/8th in) mesh seine at Aliso Creek. At Santa Clara River the lagoon was sampled with a seine (3.2 × 1.2 m, 3 mm mesh) at 28 stations on both sides of the remnant channels and pools from 50 meters above Harbor Boulevard to just inside the beach. Visual observations were conducted over 50-60% of the dewatered lagoon. Water quality was taken with a YSI water quality meter in the Santa Clara and with hand held thermometers and refractometers at Aliso Creek. Wastewater discharge was obtained by the City of Ventura Wastewater data and the river and small tributary flows were estimated on site. Tide levels were taken from National Oceanographic and Oceanic Administration (NOAA) websites. Fish numbers were often estimated and released to avoid additional stress. Voucher specimens of some moribund tidewater gobies and steelhead, and some other fish were kept for further study and deposited in the Natural History Museum of Los Angeles County and with the National Marine Fisheries Service (steelhead) and U.S. Fish and Wildlife Service (tidewater gobies).

Results

Aliso creek: Ten to twenty gulls were actively feeding on the newly exposed flats of the drained lagoon presumably on southern tidewater gobies and mosquitofish the only common fishes in the lagoon. Seining in the remnant lagoon took a few hundred southern tidewater gobies but only about 7-10 mosquitofish. Seine hauls took the gobies almost exclusively in the upper half of the lagoon, both in the full lagoon and after breaching in the much smaller residual lagoon that remained.

Santa Clara river: Live native fish species captured in seine hauls included northern tidewater goby (~1855), staghorn sculpin (*Leptocottus armatus*) (2), threespine stickleback (*Gasterosteus aculeatus*) (10 adult), and California killifish (*Fundulus parvipinnis*) (1 adult). Live non-native fishes captured were mosquitofish (*Gambusia affinis*) (51), arroyo chub (*Gila orcutti*) (15), fathead minnow (*Pimephales promelas*) (102), Mississippi silverside (*Menidia audens*) (15), carp, *Cyprinus carpio* (97), prickly sculpin (*Cottus asper*) (63), and green sunfish (*Lepomis cyanellus*) (114). In addition, one African clawed frog larvae (tadpole) (*Xenopus laevis*), and approximately 10 red swamp crayfish (*Procambarus clarki*), were taken.

Additional native fishes observed moribund included at least 2000 northern tidewater gobies (dead on the exposed lagoon bottom, approximately 3-5/m^2 in many areas), staghorn Sculpin (4-5 dead on sand bar), striped mullet (*Mugil cephalus*) (1), and southern steelhead (7 dead in the flowing river channel from about 100 m above to 400 m below Harbor Boulevard Bridge). Moribund non-native species observed included several hundred to a few thousand each of fathead minnows, juvenile green sunfish, and carp. A few hundred each of prickly sculpin, suckers (*Catostomus santaanae, C. fumeiventris,* and their hybrids), mosquitofish, and one large black bullhead (*Ameiurus melas*), were observed mostly in the upper half of the lagoon. Ten to 15 dead Mississippi Silversides were seen also. At least 200 or more adult carp were observed in the main river channel from above Harbor Boulevard Bridge to within 100 m of the ocean and were acting distressed or expiring in increasing numbers through the day.

Carp, fathead minnows, and northern tidewater gobies were represented by all sizes from small juveniles to large adults. The threespine stickleback and California killifish were all adults from an isolated backwater pool on the lagoon bottom south of the breach to the ocean. The staghorn sculpin were captured in the lower one third of the lagoon and were large juveniles. The mosquitofish were captured mostly in the upper half of the lagoon and wastewater channel. The Mississippi silversides were adults widely scattered in the lagoon and usually freshly dead. The green sunfish were captured throughout the lagoon and were overwhelmingly juveniles less than approximately 70 mm.

About half the expanse of bare sand and mud was carefully examined and dead northern tidewater gobies, green sunfish, and fathead minnows were stranded and coated with sand. Far fewer suckers, prickly sculpin, or carp were stranded probably because they were more oriented to the stream channels where flow prevailed and not widely distributed in the lagoon. Most of them were in the upper half of the river channel and showing signs of stress gasping at the water surface or lying unresponsively at the water's edge; probably due to low oxygen conditions that likely lead to the mortality of the southern steelhead.

The outer ocean beach was examined for ~0.80 km north of the breach during the early afternoon. In the fresh wrack line along the upper reach of the waves, freshly dead northern tidewater gobies, juvenile green sunfish, fathead minnows, and a single striped mullet were noted. These small species (excluding the mullet) were estimated 5-10 indiv/m of beach (thus 4000-8000 total fish). Some of the tidewater gobies were alive and returned to the water but many were dead. The green sunfish and fathead minnow probably died due to intolerance of high salinity.

Live juvenile and adult African clawed frogs were abundant and concentrated in the pooled deeper water just inside the breach to the ocean. Many were rising to the surface as if feeding but probably air breathing. Clearly hundreds, if not a few thousand, were present. Seaward and north of the breach at least 20 struggled out of the ocean surf to be preyed upon by Heermann's gulls (*Larus heermannii*), and beach visitors related witnessing this all day before our survey at 13:30. At least 15 dead clawed frogs were on the dune sand apparently expiring while attempting to cross the dry sand directly back to the lagoon.

Corcoran lagoon: In the afternoon of 11 February 2014 about 1000 northern tidewater gobies were rescued by being placed back in the remaining water. Between 1000 and 2000 were dead on the sand, similar to those seen at the Santa Clara (Fig. 4d). A small number of threespine stickleback (≤10), and at least one arrow goby, *Clevelandia ios*, died also. On the following day at about 13:00 hrs most of the dead gobies were gone and a few live ones were observed in shallow water in the lagoon still much reduced size.

After the draining that began on 21 December 2015 and continued on the 22 December 2015, 21 dead northern tidewater gobies were found on the mudflat upstream of the East Cliff Drive bridge and 10 others were still alive and rescued. About 30 dead threespine stickleback and one non-native tench, *Tinca tinca*, were also noted and 20 or more snowy egrets, *Egretta thula*, were actively feeding around the shallow remaining pools.

Discussion

Mild to extensive mortality of many kinds of both native and exotic fish species occurred during the dewatering events observed here. Most conspicuous and numerous were the native northern and southern tidewater gobies in the Santa Clara and Corcoran lagoons. Fathead minnows and green sunfish were also abundant among the moribund fish in the Santa Clara. At Aliso and Corcoran lagoons few other fishes were impacted, namely mosquitofish in the former and threespine stickleback in the latter. In addition to stranding, in the Santa Clara many fish (except tidewater gobies) and clawed frogs seemed stressed and unresponsive, probably due to the low oxygen. Hundreds of the aquatic invasive African clawed frogs known to prey on tidewater gobies (Lafferty and Page 1997) were also concentrated. Such concentration of predators can lead to extensive predation on smaller prey species adding to mortality.

Despite this mortality the species typically survive these events but may become more vulnerable to other impacts. Several extirpations of northern and southern tidewater gobies came after exceptionally high winter flows that apparently flushed the whole local population out of systems already channelized such that lateral marsh refuges were absent (Swift et al. 1989; 2018: USFWS 2005). The more extreme artificial breachings are more likely to dewater the marginal refuge areas at seasons when inflows are minimal or non-existent to rewater them fast enough to allow fish to survive.

Seven freshly moribund steelhead were found in the Santa Clara and no live individuals were seen. In the earlier spring and summer biologists with the United Water Conservation District transferred 64 smolts to the lagoon from the Freeman Diversion (16 km upstream); 34 when the lagoon was still open and 30 after it had closed (S. Howard, pers. comm., 22 September 2010). Additional smolts may have passed the diversion during high spring passage flows. Some preliminary studies indicate that smolts released in an open Santa Clara River lagoon leave for the ocean in a few days[2] (Kelley 2008). The fish found may have been among those transferred after the lagoon had closed. The relatively large size (227-310 mm SL; 267-365 mm TL) and robust condition of these fish indicated they were doing relatively well in the lagoon or river near the lagoon and that adequate conditions existed for them in at least part of the local habitat. The river was intermittently dry upstream and they were not recent arrivals to the lagoon area.

In contrast to other fish species noted, northern and southern tidewater gobies remaining in the Santa Clara and Aliso, respectively, appeared in relatively good condition. They were lively and not observed coming to the surface to take advantage of aerial oxygen although they have been observed to do so elsewhere (C. Swift, pers. Obs.). They seem to be able to survive relatively low oxygen levels as long as they remain in the water. The many dead tidewater gobies succumbed to stranding in the dewatered areas of the lagoon.

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[2] Kelley, E. 2008. Steelhead trout smolt survival: Santa Clara and Santa Ynez estuaries. Report for California Department of Fish and Game Fisheries Restoration Program, University of California, Santa Barbara, Santa Barbara, CA. 61 pp.

Possibly breeding burrows became uninhabitable with the withdrawal of water also causing the loss of egg clutches still unhatched. Some of the northern tidewater goby found dead on the outer ocean beach were probably intolerant of the churning surf, high salinity or both. Southern tidewater gobies can tolerate marine salinities but only with time for acclimation (Swift et al. 1989).

Tidewater gobies are often one of the most abundant native species in California coastal lagoons (Swift et al. 1989; 2018; Swenson 1999; USFWS 2005). During the Santa Clara event the other native species were rare, namely partially-armored threespine stickleback, California killifish, striped mullet, and staghorn sculpin. Their rarity was surprising since the lowered lagoon was very accessible to sampling during this survey and the fish had just been concentrated. Possibly they have a greater tendency to be carried out or actively leave the lagoon during such events. During previous lagoon surveys small juveniles of topsmelt (*Atherinops affinis*) and starry flounder (*Platichthys stellatus*) have been captured. A few other native estuarine species potentially present but not detected during this survey are diamond turbot (*Pleuronichthyes guttulatus*), shiner perch (*Cymatogaster aggregata*), yellowfin croaker (*Umbrina roncador*), arrow goby (*Clevelandia ios*), longjaw mudsucker (*Gillichthys miribalis*), and California halibut (*Paralichthys californicus*). They are usually rare in closed estuarine systems and could have gone undetected, or been carried out of the lagoon.

In the Santa Clara non-native arroyo chub and Mississippi silversides were also rare, while the green sunfish and fathead minnows were abundant. Mosquitofish were moderately abundant and tended to occur in the upper half to one third of the lagoon as did the suckers and prickly sculpin. Mississippi silversides, introduced in northern California in the 1960s, came down the California aqueduct into coastal southern California by the early 1990s, becoming widespread in freshwater and estuarine habitats of southern California (Swift et al. 2015). Ecologically similar to topsmelt, interactions between the two species are not well understood but the Mississippi Silversides appear to becoming more common while topsmelt numbers decline in the Santa Clara lagoon. Topsmelt juveniles provide food for the federally endangered California least tern and Mississippi silversides may fill this role. California least tern are known to forage in the Santa Clara River estuary; however, they are a migratory species and had likely departed for their wintering grounds by the time the breach had occurred. Mississippi silversides are smaller (≤100 mm SL) than topsmelt (≤200 mm SL in estuaries) but reach sizes that are targeted by California least terns. Mississippi silversides may not be large enough to be optimal for the larger species like Forster's tern (*Sterna forsteri*), Caspian tern (*Sterna caspia*), and elegant tern (*Sterna elegans*), that also breed and forage along the southern California coastline.

At all three sites artificially dug trenches facilitated the draining of lagoons and coincided with lower than average low tides and weak high tides allowing at or near maximum draining of lagoons over a few hours or less. The digging of the trench and emptying of the lagoon was directly observed at Aliso Creek. The trenches observed shortly before the breaches at the Santa Clara and Corcoran likely precipitated those. Once water begins to flow outward it rapidly erodes down through the unconsolidated beach sand emptying the lagoon in an hour or two in the case of Aliso and Corcoran. Natural breaches typically occur during high inflows when lagoons are large and the outflows exit over shallower sills in the beach displaced laterally along the coast muting the extent of draining. The lagoons become much shallower but often do not diminish appreciably in wetted surface area. At many sites today, coastal lagoons are constrained from expanding laterally along the coast forcing breaches more directly across the barrier beach in line with their tributary channel. Thus, even natural breaches can become more extreme in the extent of dewatering of lagoon habitat.

Closure is often artificially disrupted in California coastal lagoons for benefits considered desirable for a variety of local conditions. Some in the surfing community believe the new nearshore sediment profile produced by the rush of outgoing water improves the break of the surf and thus the surfing experience. Rising lagoon waters threaten to flood nearby, low-lying structures or land so breaching lowers the water level. In the fall steelhead are attracted to and accumulate in the ocean offshore of lagoons. Anglers and fishery managers may open lagoons to facilitate entrance of these fish. At the mouth of the Santa Clara River and several other coastal lagoons California State Park facilities or private land holdings are within zones often flooded by high lagoon levels. Opening the lagoons allows continuing use of these facilities. Lagoons may get warm and choked with green algae in summer and fall and perceived as a visual or olfactory nuisance to be drained away to the ocean. However, in some cases lagoon pollution, i.e. high coliform bacterial levels, will be spread along swimming beaches by artificial breaching. This creates conflict between needs to keep beaches healthy and lowering lagoon levels.

The outflow of the City of Ventura Wastewater treatment plant just north of the lagoon also contributed substantially to the water volume in the Santa Clara River lagoon and a small volume of wastewater flow was in Aliso Creek as well. These inputs may keep the lagoons larger than would otherwise be the case but may also substitute for water no longer reaching the lagoons due to upstream diversions and extractions for municipal, agricultural, and recreational use. Additional water originating from the Owens River (Los Angeles Aqueduct) and the California Aqueduct intermittently enters the Santa Clara drainage upstream also complicating any exact assessment of how today's lagoons correspond to a "natural" state. Given large historical runs of Southern Steelhead in the system (Boughton et al. 2006, 2007) known elsewhere to depend considerably on coastal lagoon systems for recruitment (Satterthwaite et al. 2012) lagoon development should have been substantial and reliable in the past. Aliso Creek lagoon was larger and supported a large population of tidewater goby and southwestern pond turtle, *Actinemys marmorata*, early in the first decade of the 20^{th} century before its narrowing for the development of U. S. Hwy 1 and State Park parking lot (Fig. 1a, Metz 1912).

Many management proposals for restoration of lagoons favor opening them to the ocean to improve circulation and water quality and increase biodiversity. The increase in biodiversity comes at the expense of the species adapted to the original brackish non-tidal habitat, some of which are now threatened and endangered species. Extreme modification has occurred historically to many larger lagoons that have been transformed into marinas and harbors maintained by artificial jetties at their mouths and requiring periodic dredging to prevent the natural tendency for the openings to close. The fish communities of these modified systems have been extensively studied (Allen et al. 2006). Many smaller systems remain in somewhat natural condition, such as the Santa Clara River lagoon, and should be managed to mimic natural hydrological and sedimentary cycles that benefit the native species. Awareness of the importance of intact and natural seasonal cycles to the health and success of two high profile fish species, namely tidewater goby (Swift et al. 1989; Swenson 1999; U.SFWS 2005; Swift et al. 2018) and southern and south central California steelhead (Boughton et al. 2006, 2007; NMFS 2011; Satterthwaite et al. 2012), has developed into wider appreciation for the importance of preserving the dynamic original geological and hydrological cycle of these habitats for conservation and recovery of these declining species.

Our observations clearly document some of adverse effects of artificial breaching of coastal lagoons in California. If accomplished repeatedly in a given dry season, the effects will be magnified. It is clear from the historical record and analyses of hydrological and sedimentary processes dry season breaches of lagoons were infrequent or absent under natural conditions in many systems[3]. The breaches at the Santa Clara River often only occur once or twice in September of each year and as noted here often initiated artificially. If natural dry season breaches took place, they would be expected to be random in relation to the tide cycle and would often cause much less draining. A smaller breach allows only a muted tide to develop before the berm closes again. From spring through summer, the surf from the southwest and south builds up the sand berms (Bascom 1980) and they get progressively wider through late summer and fall, becoming less likely to breach. The wave action also deflects the lagoon opening along the beach and the lowest point in the berm often is found at the extreme downcoast end of the lagoon (Fig. 1a). This means overtopping by high waves rarely if ever results in dramatic lowering of the lagoon. Today the coastal beach sediment supply is reduced by dams upstream and the lower watercourses are channelized more or less straight to the beach. Less sediment comes down to build the beach and the force of winter flows impinge more directly and forcefully against the barrier berm. The lagoons cannot extend as widely along the coast behind the dunes as originally and may breach more now because of these factors. In any case natural breaching is less frequent under natural or historical conditions and restoration efforts should mimic these conditions for the associated habitats, fauna, and flora to maintain themselves[3].

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