

Case Report

# Effects of Repeated Sand Replenishment Projects on Runs of a Beach-Spawning Fish, the California Grunion

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**Abstract:** Beach habitats are diminishing globally, particularly in urban areas, as sea-level rise, erosion, and shoreline hardening, along with reduced sediment inputs, combine to squeeze the coast. In California, USA an endemic marine fish, the California grunion, spawns on sandy beaches during late-night spring tides. Its unique recreational fishery is managed by the California Department of Fish and Wildlife. The City of Oceanside, CA contracts for annual harbor dredging and, after testing, places the sandy sediment on its public beach. The effects on local beach wildlife from this annual sand replenishment are not known. We examined the effect of this repeated activity as a case study over three years on the spawning runs of the California grunion. Some spawning runs occurred in all three years, but the fish avoided areas with high scarps in the intertidal zone that developed following sand placement activity. Grunion spawning runs have declined in the habitat range as a whole over the past two decades, and those in Oceanside have declined to an even greater extent. Increasing sandy beach habitat can be beneficial to wildlife, but the method of placement, timing of the project, and fate of the beach afterward can modulate or prevent beneficial effects. Frequent repetition of sand placement may accumulate impacts without allowing sufficient time for the ecosystem to recover. Rather than improving the habitat, these repeated projects in Oceanside may degrade the spawning habitat for the grunion. Alternative discharge methods and locations, slope and elevation designs, sediment volumes, and greater care in beach fill practices should be implemented to reduce future impacts.

**Keywords:** beach nourishment; beach restoration; ecosystem management; substrate; reproductive habitat; human impacts; beach-spawning fishes; essential fish habitat

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## 1. Introduction

Sand replenishment on beaches is commonly used as a means of restoring, building up elevation or expanding beach width [1,2]. It is also used as a beneficial use of discarding the materials of a dredge operation for harbor navigation. The slope, timing, frequency, amount and type of materials placed on the beach are all tested and managed, as all may affect the biota that either live there permanently or use the beach ecosystem for some part of their life cycle [3–6]. The effects of beach nourishment are poorly known for most beach biota, either in the shorter- or longer-term [7–9]. Knowing how coastal ecosystems and beaches and their sediments respond to storm conditions and repeated beach replenishments is a pressing question for resource managers, particularly because beach replenishment is now the preferred option in the United States for short-term stabilization of any eroding coastline which is used for valued recreation or tourism [10].

Oceanside Harbor in San Diego County, California, USA is a marina for commercial and recreational vessels and is also used by the United States Marine Base at Camp Pendleton. To maintain navigability for large vessels, the harbor is dredged on an annual basis under the auspices of the US Army Corps of Engineers (USACE). The harbor dredge materials are tested for grain size and contaminants. If found to be within suitable limits, they are placed on the shoreline on Oceanside City Beach nearby as a form of sand replenishment or “beach nourishment” to increase the width of a recreational beach adjacent to an urban shoreline.

Sand replenishment projects are often touted as being beneficial to beach wildlife because in theory, they create more habitat by the placement of substrate [2,5]. “Beach restoration” is a term often used for sand replenishment projects, but this “restoration” generally does not include plantings or re-introduction of native species, whether adults or propagules, as is typical for other types of ecological restorations [11–13]. The timing and frequency of projects also influence ecological recovery.

California is home to many animals that use sandy beaches as nursery areas, including birds, mammals, reptiles, and fishes. The California grunion *Leuresthes tenuis* (Atherinopsidae) is a beach-spawning marine fish that is famous for emerging fully from the water during spawning runs under a full or new moon [14,15]. They bury their eggs under 10–20 cm of sand, where the eggs remain out of the water above the water line, until being washed free nearly two weeks later by rising tides. The spawning season may start as early as February and go through to August, with April through to June as the months of peak activity [16]. Runs can be forecast according to the tides and are most likely to occur within four days after a full or new moon, in a two-hour window following each nightly high tide [17].

The main habitat range of the California grunion is a few hundred kilometers along one of the most populated coasts in the world [18,19]. The city of Oceanside is in the heart of the southern California range for this endemic species. The sandy beaches of Oceanside and nearby towns are historically known to host significant grunion runs, to the extent that they are touted by the tourist literature as a visitor activity [20].

Most coastal construction projects in California must avoid disturbance to sandy beaches during key reproductive periods of beach-spawning birds and the California grunion [21,22]. Biological monitors may be required on beaches prior to, and for the duration of the project, and projects may be moved or temporarily halted if some species are present in the construction site.

Beach placement of harbor dredge material has taken place in Oceanside City Beach on nearly an annual basis since at least 1965. The permitting of this project is managed by the US Army Corps of Engineers and the California Coastal Commission. This annual dredging and beach replenishment project has in the past been completed by April, or before the peak spawning season of the California grunion. Recently, these projects have been permitted even during the peak spawning season for the California grunion. Sand replenishment projects were approved to take place during the grunion spawning season for Oceanside City beach in 2016, 2017 and 2018.

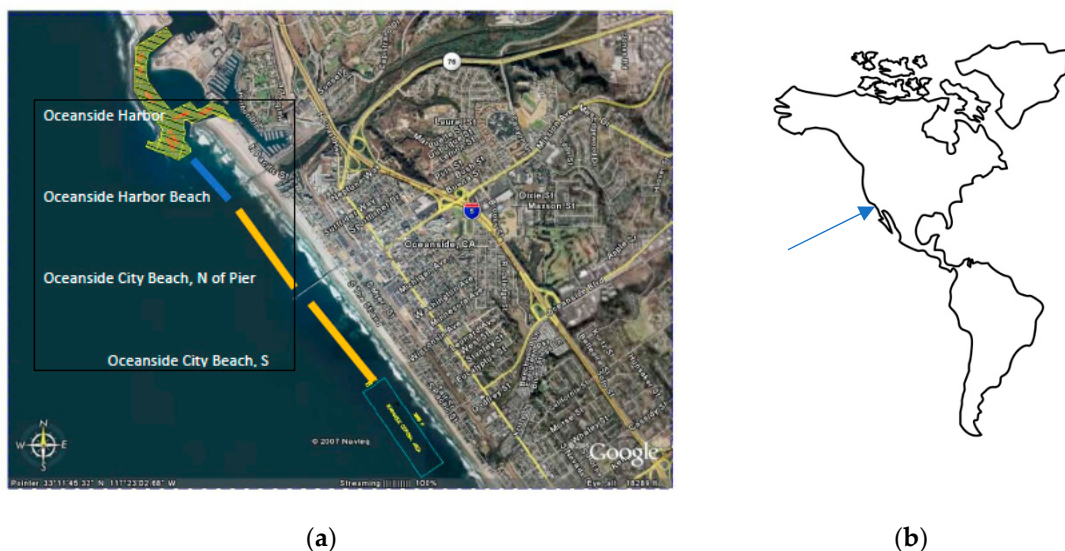
Although there have been dozens of sand replenishment projects along the coast of California over the past decades, the effects of beach sand replenishment on the California grunion have not been studied. For the California grunion, potential impacts could include disturbance to or stoppage of a spawning run during active beach filling, because of the disturbance of bright lights and noise [23]. Disturbance of the sand by vehicles during nest incubation and excessive burial of eggs by longshore drift after sand placement could prevent grunion hatchling emergence [3]. High turbidity of nearshore waters could alter survival during larval emergence, and changes to the substrate composition could affect the ability of the adult female fish to burrow into the sand for oviposition, or the eggs to wash free for hatching. How the California grunion chooses a beach for spawning is not fully understood, but changes in the substrate or sediment grain size may alter beach slope, and turbidity and sediment plumes may alter chemical signatures or strength and direction of waves that may assist in natal homing [24].

California grunion are difficult to monitor; they cannot be assessed by traditional fisheries methods such as trawl surveys or fishing reports, as they avoid nets and do not take a hook. Their legal recreational capture occurs only while on the shore during a bare-handed fishery [16,25]. Reporting a catch of California grunion is not required, and although individuals are required to have a California fishing license to hunt the grunion, observers suggest that many do not [25,26]. The most reliable method to monitor for grunion is to watch for spawning runs during the time of semilunar high tides [22,25].

Previous projects have not been required to monitor for grunion after the completion of sand placement. We hypothesized that grunion runs could be negatively affected by sand replenishment activities on the shoreline. We also hypothesized that grunion populations may be negatively impacted by frequent disturbances of repeated projects in Oceanside near to or during their spawning season.

## 2. Materials and Methods

The City of Oceanside has two sandy public beaches: Oceanside Harbor Beach, in front of a residential area south of the San Luis Rey River mouth, and Oceanside Harbor Beach, in front of a marina north of the river mouth (Figure 1). Prior to the harbor jetties being built, the beaches south of San Luis Rey River were naturally wide beaches.



**Figure 1.** (a), Camp Pendleton is north and east of Oceanside, just above the map outline. Oceanside Harbor Beach (blue line) is upcoast of the San Luis Rey River and outside of the filling zones. On Oceanside City Beach, for grunion spawning observation sites, Area 1 (yellow line) is north of the pier and Area 2 (yellow line) is south of the pier. Discharge pipe locations for 2016–2018 were within Areas 1 and 2. (b) Oceanside is on the West Coast of North America, shown by the blue arrow.

In the late 19th century, Oceanside’s beach was approximately 100 m wide and used as a thoroughfare for horse-drawn wagons [27]. In Oceanside, CA, the prevailing ocean current direction is to the south. Long-shore sand transport typically moves sand slowly to replenish down-coast beaches [28], and tidal cycles affect beach profiles as well [29].

In 1942, the marine base Camp Joseph Pendleton was created, along with a jetty and a boat basin. However, the harbor soon silted up with sediments that previously maintained the width of Oceanside beaches [27]. After dredging the harbor to maintain its function, between 1942 and 1980 over 10 million cubic yards of material, including cobble, were deposited on Oceanside beaches [27]. Cobble did not appear on Oceanside beaches before 1965 [27].

Oceanside Harbor Beach (33° 12' 12.86" N, 117° 23' 34.08" W), upcoast from the replenishment project, is a 1500 feet long sandy beach from San Luis Rey Jetty, to North Jetty (Figure 2). It is a relatively

flat beach with all three intertidal zones present as well as a wide supratidal and dry beach area. There was no beach-filling or bulldozing here between 2016 and 2018, although the beach was regularly raked and groomed to remove litter and debris.



**Figure 2.** Photo of Oceanside Harbor beach (South end), on 19 March 2018. This beach was outside of the project area and did not change in profile or character during the course of this study. Photo by L. C. Adams,

Two sites on Oceanside City Beach were monitored for habitat and grunion spawning activity before, during and after beach fill. Beach Area 1 is north of the Pier (33° 11' 54.83" N, 117° 23' 16.97" W). Beach Area 2 is south of the Pier (33° 12' 7.7" N, 117° 23' 29.6" W). This beach was the site of the sand replenishment project (see Figure 1).

In 1998, a method for assessment of grunion runs, the Walker Scale, was developed that evaluates the number of fish on shore, the extent of shoreline involved, and the duration of the run [30], shown in Table 1. This has been in use in conjunction with a group of trained citizen scientists, the Grunion Greeters, since 2002 [31]. Their reports are reliable and consistent [25]. Since they are volunteers, the beaches they observe and the number of nights they go out are not as regular as one might wish. Nevertheless, Oceanside City and Oceanside Harbor Beaches have both been monitored for spawning runs on many occasions by Grunion Greeters since 2004.

**Table 1.** The Walker Scale scoring system. Grunion Greeters watch a given stretch of beach for 2 h beginning at the highest nightly tide, usually within the first four days following a new or full moon.

<b>W0:</b>	No fish or only a few individuals appear, with little or no spawning; not a run
<b>W1:</b>	Between 10–100 fish present on the beach over the time of the run, in one or more locations, with little spawning; poor run
<b>W2:</b>	During the peak of the run, 100–500 fish on the shore simultaneously, spawning in one or more locations along the beach; small run
<b>W3:</b>	During the peak of the run, hundreds to thousands of fish spawning at the same time in one or several areas of the beach; peak is less than 20 min; good run
<b>W4:</b>	During the peak of the run, thousands of fish are on the beach together, with little sand visible between them, in a restricted or large area of the beach. Peak lasts less than one hour.
<b>W5:</b>	At the peak of the run, fish fully cover an extensive area of the beach in massive numbers, several individuals deep, a silver lining along the surf. It is not possible to walk through the run without stepping on a fish. The peak lasts over an hour.

Using the Walker Scale, a section of beach is observed during a night when a run may occur ([www.Grunion.org](http://www.Grunion.org)) [22], four nights following a new or full moon. In many cases, with beaches that

extend a long distance along the shore, only part of the beach may be involved in a run on a given night [15,16]. Once a run starts, it may continue for several minutes to over an hour, however, the peak of the run generally lasts between 20 min and 1 h. Runs typically do not continue beyond two hours after the tide, as the ebb makes the proper tidal placement of the eggs difficult [15].

In 2016, 2017 and 2018, Oceanside Harbor and City Beaches were observed by CDFW staff and Grunion Greeters on nights when the grunion were predicted to spawn. Professional biological monitoring staff were contracted as required for the USACE permits to observe for grunion spawning during the project activities. Their reports were compared with our reports for the same dates and provided data for additional dates. Archival Grunion Greeter data were accessed for past grunion run reports.

The grunion run on the sloped beach face in the intertidal zone, riding waves into the upper intertidal zone. Scarps are sharp steep drops in the beach face that can block access to the upper intertidal zone, where grunion normally spawn. Formation of scarps was documented with photos and by measuring height and length. Beaches were compared for both the changes to the beach face and grunion spawning activity. Photos were taken of spawning on cobble and sandy beaches, as well as next to the discharge pipe and other activities related to beach filling.

### 3. Results

#### 3.1. Effects on Sand Habitat

Beach-fill projects took place on Oceanside City Beach from 6 June to 31 October. The dredge pipe length on the Oceanside Harbor beach was buried parallel to the shore in the dry beach sand above the higher high tide. A ten-inch diameter pipe extended south across the San Luis Rey River and ran on top of Oceanside City Beach. Approximately 50,000 cubic yards were deposited at the first discharge point in Area 1. About 1000 feet farther south, 10,000 cubic yards were added. Finally, 190,000 cubic yards were added just north and south of the Oceanside Pier (Figure 1), for a total of 250,000 cubic yards of material.

The northern half of Area 1 on Oceanside City Beach initially showed very little upper intertidal habitat suitable for grunion spawning due to cobble mounds. Adequate upper intertidal habitat was initially present on Area 2, from Oceanside Pier South 1300 feet down the coast. In 2016, no new scarps developed after beach filling (see photo Figure 3a).



**Figure 3.** (a), Before beach filling, 28 March, 2017, Area 2 near the Oceanside Pier had a low scarp. Right, (b), Night of 26 June, 2017 in Area 1 showed a W3 spawning intensity, the highest seen on Area 1 that season. Beach filling blocked habitat in Area 2, diverting fish to Area 1. Photos by L. C. Adams.

In 2017, before beach fill, the northern half of Area 1 and the southern-most portion of Area 2 were mostly cobble or gravel. Closer to the pier, adequate grunion spawning habitat with flat, sandy beach existed prior to beach fill (Figure 3b).

In 2017 beach fill took place again during the peak of grunion season, from 17 April to 11 June. A 28-inch discharge pipe diameter was used to deposit 420,000 cubic yards of sediment. During the project, Area 1 beach developed steep scarps about 4 feet high on the north side adjacent to the pier area, and in the north part of Area 1 (Figure 4). This steep scarp blocked the transition to the upper intertidal zone, where grunion spawning could have otherwise occurred. The beach had a lot of cobble below the scarp, with no sand patches between cobble swales.



(a)

(b)

**Figure 4.** (a), On 12 June 2017 in Area 2 south of Pier, a steep 5-foot scarp formed in upper intertidal. No grunion spawned in this area after the scarp formed. (b), After beach fill, on 25 July 2017 in Area 1, the scarp is lined with cobble in upper intertidal. Cobble was present before and after beach fill. Photos by L. C. Adams.

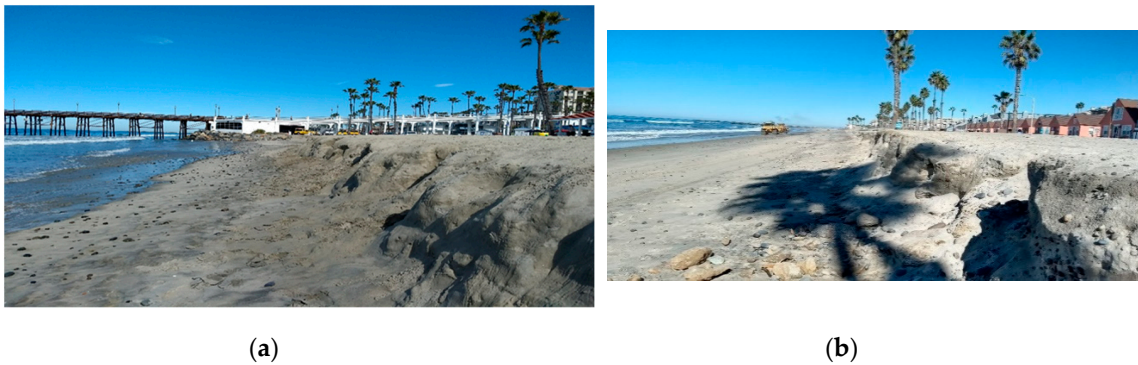
The beach fill project included bull-dozers building a dike and sand discharge that caused a large pit to form due to scouring on the north side of the pier on 17 May 2017. Sand was also deposited onto the south side of the pier (Figure 5). Natural sand transport contributed to the building up of the Area 2 beach. The pits were later filled in. The Area 1 scarp leveled out, but Area 2 spawning habitat was impacted when a new steep 5-foot scarp formed (Figure 6). In 2017, a lot of cobble was still visible on the beach even after completion of the beach fill project.



(a)

(b)

**Figure 5.** (a), On 17 May 2017: Dykes were built up in the foreground, and pits were scoured out near the Oceanside Pier in Areas 1 and 2 during peak grunion spawning season, causing temporary impacts on grunion spawning habitat. (b), Area 2 south of Oceanside Pier. Photos by L. C. Adams.



**Figure 6.** (a), Area 2 south of Oceanside Pier in March, 2018, showing scarp lingering from the 2017 project. (b), Area 1 north of the Pier showing scarps before the 2018 beach fill in October. Photos by L. C. Adams.

In 2018, although beach fill did not occur during the grunion spawning season, tall scarps still lingered in the high intertidal grunion spawning zone from the 2017 beach fill project (Figure 6). In 2018, the beach fill project occurred from 18 October through to 6 November, after grunion spawning season ended. A 28-inch pipe diameter was used for deposition of 285,000 cubic yards of dredged sediments onto Oceanside City Beach. Along with the lingering scarps from 2017, new scarps developed, shown in photos from September 2018. These were contoured flat by bulldozers by the end of the project in November 2018.

### 3.2. Grunion Spawning Observations

From 2004–2018, Grunion Greeters provided 90 observations of grunion runs on Oceanside City Beach and 82 observations on Oceanside Harbor Beach.

Observers from the contracted project provided Walker scores and observations on 25 nights in 2016 and 13 nights in 2017 on Oceanside City Beach, during nights when runs were forecast, and the project was ongoing. Because the 2018 project took place after the grunion spawning season, observations of grunion were made only by volunteer California Department of Fish and Wildlife staff and Grunion Greeters, not by contracted project staff. Volunteers contributed reports for eight nights in 2016, six nights in 2017, and seven nights in 2018 on the three areas of Oceanside beaches.

The Walker Scale is categorical, not parametric, so scores were compared with non-parametric statistics. Reports from the observations by professional biologists agreed with the reports from the CDFW and Grunion Greeters when both were present in the same areas on the same nights (Mann-Whitney comparison of two groups, range W0–W3,  $N = 15$ ,  $U = 112.5$ ,  $z = 0.02$ ,  $p = 0.985$ ). During the recreational fishing open season, it was difficult to tell how many fish were present in some locations because people caught them as soon as they appeared; often, nearly every fish that approached the shore was taken before it had the opportunity to spawn.

In 2016, runs ranging from W0 to W2 were reported in Oceanside Harbor, with a median of W1. At Oceanside City Beach within the project footprint, the range reported was W0–W1, with a median of W1.

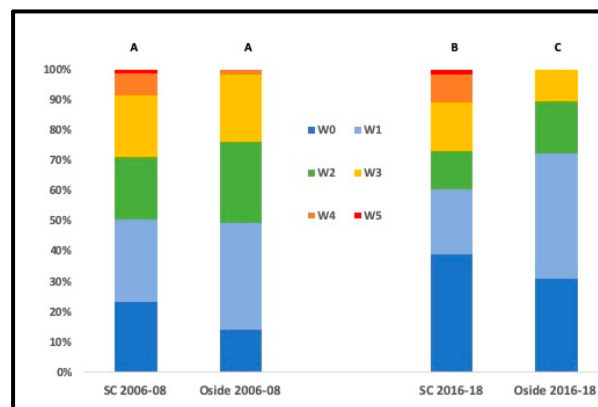
In May 2017, during beach fill, on Area 1 groups of about 5–6 grunion (W0) appeared along the beach in a few locations, near the pipe while discharging a sand slurry directly seaward into the intertidal zone (Figure 3B). In late May, no grunion were sighted on any of the run nights in either project Areas 1 or 2. In July, no grunion were seen on Oceanside Harbor Beach. A spawning intensity of W3 was seen in Area 1 of Oceanside City Beach in July on sand areas in between cobble. No grunion spawning occurred in locations with high scarps. In Area 2, grunion were seen in the water only, with no spawning as a scarp was still present over the intertidal zone. The upper intertidal scarps on the affected beach areas blocked grunion spawning habitat. Waves ran up and hit the face of the scarps, and sometimes reflected back or over-topped the scarp.

All grunion runs in 2018 were scored W2 or lower on both Oceanside Harbor and Oceanside City beaches.

Spawning run scores on Oceanside Harbor Beach were not significantly different from scores on Oceanside City Beach, either in 2006–2008 or in 2016–2018 (Wilcoxon Signed Rank test of paired data for two groups,  $W = -13$ ,  $z = -0.44$ ,  $p = 0.66$ ; Mann–Whitney test of all data,  $U = 102$ ,  $z = 0.02$ ,  $p = 0.98$ ). The majority of runs on Oceanside Harbor and Oceanside City Beaches from 2016–2018 were small, with 86% of nights scored as Walker 0 or 1, and fewer than 100 fish seen during the run, with little or no spawning. No runs at any of these beaches scored as Walker 4 or 5 over these three years.

In 2006–2008, grunion runs on Oceanside beaches were not different from southern California beaches as a whole, but in 2016–2018, both the southern California grunion population and the Oceanside grunion population show declines in run strength. In 2006–2008, the distribution of frequencies of scores of Oceanside’s runs were not significantly different from those across southern California ( $\chi^2 = 8.57$ ,  $df = 5$ ,  $p = 0.128$ ).

However, comparing reports from Oceanside City and Harbor Beaches in 2016–2018 with those from 10 years earlier, 2006–2008, a significant difference in frequencies of Walker scores was found (Chi-Square,  $\chi^2 = 32.14$ ,  $df = 4$ ,  $p < 0.0001$ , Figure 7). Low Walker scores were reported with significantly higher frequency in both Oceanside beaches in recent years than in the past ( $\chi^2 = 32.14$ ,  $df = 4$ ,  $p < 0.0001$ ), with the median dropping from W2 in 2006–2008 to W1 in 2016–2018. Some nights in April, May and June when spawning was forecast, no grunion were observed on affected beaches. The likelihood of seeing few or no fish (W0) in Oceanside on a night when a run is forecast almost quadrupled, from 14% in 2006–2008 to 54% in 2016–2018.



**Figure 7.** Comparison of grunion run frequencies between the years 2006–2008 and 2016–2018, for reports from all of Southern California (SC) as compared with combined data from Oceanside Harbor and Oceanside City Beaches (Os). Different letters above the bars indicate significant differences in run frequencies from SC 2006–2008. Small runs were significantly more frequent in 2016–2018 than in 2006–2008.

No runs above W3 have been reported on Oceanside beaches in recent years. By comparison, between 2016–2018 across southern California, large runs (W4 or 5) occurred for 10% of the reports, on many different beaches. Oceanside City and Harbor Beaches in 2016–2018 were significantly lower in frequencies of medium (W2–3) and larger (W4–5) runs as compared with the southern California grunion habitat range as a whole ( $\chi^2 = 77.4$ ,  $df = 5$ ,  $p < 0.0001$ , Figure 7).

#### 4. Discussion

Multiple stressors impact marine organisms, especially those along the coast [21,32,33]. California grunion have never been an abundant species [14]. Currently, they face a dwindling spawning habitat within a limited habitat range, along one of the most densely populated coastal zones of the world [15,18]. Human recreational activities, capture during spawning, and coastal development



activities can interfere with the critical portion of their life cycle during reproduction by scaring away spawning fish and interrupting or stopping runs that depend on tidal timing [15,25,26]. California grunion are important in the marine ecosystem and food web [17,34], although they are not state or federally listed. They are a popular sport fish when they come ashore to spawn [18,25,35]).

Grunion Greeters have been monitoring grunion spawning for nearly two decades, in cooperation with the California Department of Fish and Wildlife (CDFW). The stock size is difficult to assess, but it is a restricted resource [14]. In recent years, grunion have expanded their spawning range north of San Francisco [36], but the main population in southern California shows signs of decrease [25]. The California Fish and Game Commission is currently considering changes in the open season for the recreational fishery, which takes place while grunion are spawning.

Spawning runs in Oceanside at both the Harbor and City beaches were scored significantly lower in the past three years than in three years a decade ago (Figure 7). No large runs occurred at Oceanside during the past three years, although some other southern California beaches saw repeated large runs [25]. The decline in runs was seen at both beaches, even though beach filling took place only on one. This suggests that a nearby beach may have negative impacts from a beach filling project even if it is not directly receiving dredged sand. It is likely that the individual fish that spawn at both nearby beaches are part of the same metapopulation [36,37], thus changes to the reproductive success at one beach may affect the other.

In 2016, dredgers deposited less than half the volume placed in 2017. Sediments were placed slowly onto the beach by a 10-inch diameter discharge pipe, and high wave events caused some project delays. Even with El Nino oceanographic conditions and a high amount of beach erosion during 2016, beach scarps did not develop (Figure 3). Dredged sand remained on the beaches with mild slopes throughout the summer and fall. The good sandy beach and spawning habitat conditions present long after the 2016 beach fill may have occurred because the sediments were placed slowly. This may have allowed build-up of beach height and time for waves to re-distribute and winnow away the sediments naturally, keeping the beach sand stabilized with only temporary, low scarp formations (Figure 3).

In spring 2017, before beach fill, good spawning habitat conditions were present on most of the grunion survey areas north and south of the pier. In 2017, a 28-inch diameter pipe was used, and the beach in front of the discharge pipe built up quickly, likely causing beach scarps to form when large quantities of sediment were placed in a short amount of time (Figure 4). After beach filling ended, the 5-foot scarp that formed south of the pier left no upper intertidal spawning habitat to support grunion spawning in Area 2 along 700 feet of beach (Figure 6). The sandy beach habitat around the pier was in better condition before the 2017 fill project, with no scarps and very little cobble, as compared to afterward (Figure 6). Spawning in Area 2 before beach filling was a W3 (Figure 3B), but after beach filling, no spawning was seen.

Sand scarps can create grunion spawning impacts by blocking access to the appropriate tidal height and by eroding and burying nests during the incubation period [3,27]. During the observations throughout the study, Oceanside Harbor Beach never developed significant scarps and remained a mildly sloped, sandy beach (Figure 2), while Oceanside City Beach within the fill zone developed steep, significant scarps blocking access to the tidal zone required for grunion spawning.

Small scarps form naturally on Oceanside City Beach, but beach fill can significantly contribute to the steepness and elevation of the scarp, as well as its tidal height location. A sand cliff, much like a seawall, can cause wave scouring of the intertidal zone [38,39]. A high beach scarp can linger in that condition for many weeks or months, as one did from 2017–2018, until a bulldozer or high waves knock it down (Figure 6).

In 2017, a large pit developed due to discharge scouring effects near the pier (Figure 5), which was later filled in. This had immediate impacts preventing spawning runs in these locations. The scarp in Area 1 leveled out, however, the steep scarp that formed in Area 2 from the rapid sand build-up remained for the rest of the spawning season of 2017 and blocked the grunion spawning zone. In the future, placement of the pipe on a mostly cobble beach could be a less impactful location for sand

discharge. Alternatively, depositing sediments in areas in the nearshore within the depth of closure would allow for gradual onshore beach replenishment via waves and currents [40,41].

Animals and plants on California's sandy beaches face multiple stressors, both human-caused and natural [42–44]. Climate change, sand erosion and sea-level rise exacerbate seasonal sand volume changes [45–47]. Efforts to replenish sands and deposit dredge material must take into account the impact of these projects on local beach biota [6,7,44], particularly as these projects become more common and frequent in the future [48,49]. Complicating the issue, many marine organisms are shifting their habitat ranges as climate changes [50], including the California grunion [36,37]. Movement into a new habitat range has led to changes in ecological and life history characteristics that make predicting the future of the California grunion difficult [19,25].

Grunion hatch timing is not consistently predictable. Embryos hatch according to an environmental cue, being washed out of the sand into waves as the tides rise for the next semilunar high tides [51]. Because of this, grunion embryos may remain unhatched but viable on shore for up to four weeks (two semilunar tidal cycles) or more, if not washed free into seawater [52,53]. Because of California's mixed semidiurnal tide regime, the height of the highest tides, on which the grunion spawn, differ greatly between the new and full moons [16,54], and thus all eggs may not be washed back to sea to hatch within a subsequent tidal cycle. However, some beach fill permits allow activity to re-commence in a known grunion spawning site after 10 days (the earliest time that embryos are likely to be viable for release) rather than avoiding the area until after the highest high tides occur.

The presence of numerous anthropogenic disturbances may create synergistic effects on vulnerable organisms and ecosystems, particularly with high disturbance frequency [9,33,43]. The decline of the grunion spawning runs in Oceanside probably is due to multiple stressors, and is similar to the decline seen across southern California. However, in 2006–2008, Oceanside's runs were not significantly different from those seen in the total southern California population (Figure 7). Now, the runs at Oceanside beaches are significantly lower than runs across southern California as a whole. Particularly troubling is the complete absence of large runs (W4–5) in the past few years. This differs from many other grunion beaches, that continued to have large runs between 2016–2018. The long-standing history of frequent sand replenishment at Oceanside may explain this decline in runs today relative to the past, or it may be affected by more recent changes in procedures or timing.

## 5. Conclusions/Recommendations:

1. Beaches are ecosystems. Beach replenishment projects done for human purposes of harbor dredging have ecosystem effects that are not fully understood and may be negative rather than positive for the ecology. Projects should take care to avoid or minimize disturbing critical habitats during reproductive seasons. Ideally, beach fill in Oceanside and other California beaches should be completed by the end of March to avoid the peak grunion spawning months of April, May and June.
2. The addition of new substrate should be done gradually. The beach should build up slowly over time, allowing for a more natural beach face with a gradual slope rather than a steep scarp. Then, even if high wave events occur, a steep scarp is less likely to form or will have a lower elevation allowing for waves and tides to break down the scarp naturally.
3. Pipe discharge scouring and bulldozing should be avoided on sandy beaches close to piers. Pier locations are hot spots where grunion have historically spawned in high numbers [16,54].
4. Dredge sediments must continue to ensure a grain size similar to the natural sandy beach baseline conditions, in order to provide an appropriate slope of the beach face and suitable habitat for local biota.
5. Frequent repetition of sand placement and harbor dredging may accumulate impacts by not allowing sufficient time for the ecosystem to recover before additional disturbance occurs. Rather than improving habitat, these repeated projects in Oceanside may actually be degrading the spawning habitat for grunion, both at the project site and neighboring beaches. Project impacts

from 2017 lingered through the grunion season of 2018, even though the 2018 project itself started after grunion spawning season.

- Alternative discharge methods, attention to slope and elevation designs, smaller sediment volumes, less impactful locations for placement, and greater care in beach fill practices should be implemented to reduce future impacts.

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