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# The Walker Scale: Details of a Method for Assessing Beach-Spawning Runs of California Grunion *Leuresthes tenuis* (Atheriniformes: Atherinopsidae)

Karen L. M. Martin<sup>1</sup>, Michael Schadt<sup>2</sup>, and Susanne Lawrenz-Miller<sup>2</sup>

**The California Grunion *Leuresthes tenuis*, a marine atherinopsid, makes spawning runs onto some of the busiest urban beaches of southern California. Eggs remain buried under moist sand, tidally emerged from water throughout incubation. Concern over the effects of human activities on beaches holding incubating fertilized eggs of *L. tenuis* prompted a need to assess spawning runs consistently through time. A new metric, the Walker Scale, focused on the peak of the runs, was developed to train citizen scientists, also known as community scientists. Reports of sightings were verified by scientists by locating buried clutches and collecting eggs at locations identified by volunteers. Reports between multiple observers from the same run were highly correlated, and also positively correlated with the density of clutches of eggs. Over the past two decades, the Walker Scale method has been used by thousands of volunteers as well as resource managers, environmental consultants, coastal projects, the US Army Corps of Engineers, and the California Department of Fish and Wildlife. This paper provides details about the method and its correct use by citizen scientists and professional biological monitors. The Walker Scale method is reliable, easy to understand, and the most effective method for assessing this elusive, charismatic fish.**

SOUTHERN California beaches are prized for their recreational opportunities and natural beauty. They are also critical reproductive habitat for many organisms, including the California Grunion *Leuresthes tenuis* (Atherinopsidae; Robbins, 2006). This marine species rarely is seen except during its spectacular midnight beach-spawning runs (Walker, 1952; Martin and Swiderski, 2001). On spring and summer nights with semilunar high tides, thousands of fish emerge from water onto wave-swept beaches to deposit clutches of eggs (Fig. 1). The fish return to the sea, and the eggs remain buried in damp, well-drained sand above the mean high tide line, out of water throughout incubation. As the next semilunar tides rise, eggs wash free and are triggered to hatch by agitation in sea water (Griem and Martin, 2000; Speer-Blank et al., 2004).

California Grunion runs have long been part of California's cultural heritage (Thompson, 1919; Clark, 1938; Walker, 1952). Temporarily out of water, spawning California Grunion are vulnerable to capture by animal and human predators (Martin and Raim, 2014; Martin et al., 2020a). This is the only fish that can be observed and captured by people of all ages, without a boat, without fishing poles or nets, or gear of any kind. In this unique recreational fishery, people catch fish using only their bare hands (Clark, 1926; Sandrozinski, 2013). A fishing license is required (but not always obtained) for fishers above 15 years old. Licensed recreational fishers have no bag limit for California Grunion and are not required to report catch (Sandrozinski, 2013).

The California Department of Fish and Game in 1927 implemented a closed season for California Grunion fishing from April to June, the peak spawning season, to prevent overharvest, based on recommendations by F. N. Clark (1926). In 1949, the closed season was reduced to April and May, based on recommendations by B. Walker (1952). Regulations have remained, unchanged for over 70 years, as California's human population has greatly increased from 5

million in 1927 to 40 million today. Efforts are underway to return the closed season to its original three months, based on data indicating a decline in the California Grunion population (Martin et al., 2020a).

Monitoring for grunion spawning is important because of the many anthropogenic impacts on sandy beaches (Defeo et al., 2009; Schoeman et al., 2014; Schooler et al., 2017) that could injure or destroy eggs. If not environmentally triggered to hatch, California Grunion eggs can survive buried in beach sand for up to 35 days (Martin, 1999; Snyder and Martin, 2002), delaying larval development until hatch (Moravek and Martin, 2011).

California Grunion historically were endemic in a narrow coastal distribution from Punto Abreojos, Baja California to Point Conception, California (Gregory, 2001), along one of the most populous coastlines in the world. Recently, California Grunion expanded their spawning range to several beaches hundreds of kilometers north, within San Francisco Bay and beyond (Roberts et al., 2007; Martin et al., 2013; Love and Passarelli, 2020). This response to changing climate underlines the importance of ongoing assessment of this unique indigenous fish (Martin, 2015).

A systematic assessment of California Grunion population status is difficult because they are not easily counted (Gregory, 2001). This species usually does not appear in trawl nets for ocean fish surveys and rarely is taken in trawls within enclosed bays (Allen et al., 1983, 2002; Martin et al., 2013), but it may be captured by beach seine on days of spawning runs (Crabtree, 1987). As a planktivore (Horn et al., 2006), it does not take a hook.

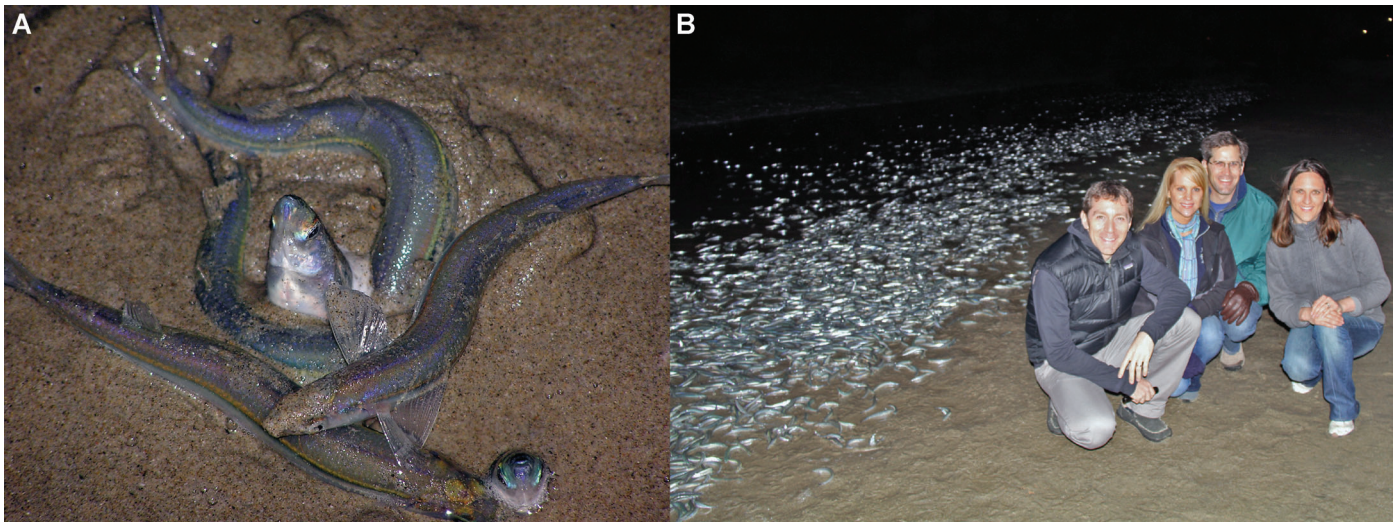
The only way that California Grunion are observed reliably is during a spawning run, when they are momentarily out of water on a beach. However, spawning runs only occur a few nights each month, during a few months each year. Semilunar high tides occur late at night during the spawning season, when standard public beach cameras do not

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**Fig. 1.** (A) California Grunion spawned out of water on beaches in southern California. Photo by Arnold Liu (used with permission of Grunion.org). (B) Grunion Greeters at a spawning run, scored as W-4. Photo by Harris Lakisic (used with permission of Grunion.org).

function. Runs occur within a window of an hour or two after the peak tide, on the same nights all along the coast. Each fish may come onto shore briefly, and males may beach several times during a run (Walker, 1952). Females dig vertically, tail-first into sand up to their gills, to deposit eggs. Males remain on the sand surface and provide milt when they encounter a buried female (Fig. 1). In a small run, the numbers of males and females may appear approximately equal, but in larger runs, males outnumber females by up to 8 or 10 to 1 (Byrne and Avise, 2009).

Numbers of fish on shore are highly variable over time within one night, across the several nights within one run series, and across the season. Runs also differ between beaches at different locations on the same night (Walker, 1949; Martin et al., 2020a). The fish actively avoid potential human observers (Thompson, 1919; Walker, 1952). Too much noise, artificial light, or disturbance on the shore can disrupt or stop a grunion run.

A reliable method for multiple observers to assess the runs simultaneously is necessary to provide consistent data about the prevalence of California Grunion. Several methods to assess California Grunion were attempted previously. From 1946 to 1948, Boyd Walker observed every spawning run on Scripps Beach in La Jolla, California, for his dissertation research (Walker, 1949). He extended this survey to other beaches along the Pacific coast on two consecutive nights in April 1947, with the help of volunteers at each location (Walker, 1949). The team assessed the strength of the runs by counting the number of California Grunion on the beach that could be seen within the beam of a flashlight with fresh batteries, pointed parallel to shore (Walker, 1949). Walker represented the counts by the thickness of a line over time for each beach (Supplemental Fig. S1; see Data Accessibility). Thin lines represent 1–19 fish per minute, medium lines 20–99 fish per minute, and thick lines 100 or more fish per minute within the beam (Walker, 1949).

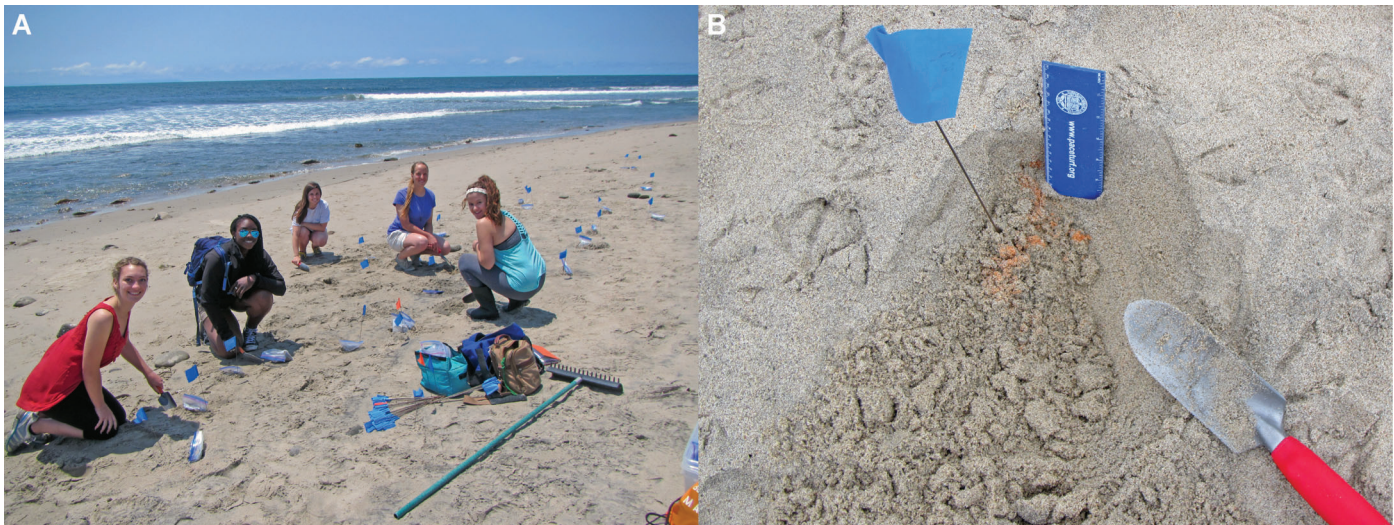
In 1978, the Southern California Ocean Studies Consortium (SCOSC) monitored California Grunion at McGrath State Beach in Ventura County, in advance of a project by the US Army Corps of Engineers (USACE). This team walked along that beach during times of predicted grunion spawning

runs along quarter-mile transects (SCOSC, 1978). Observers stopped every 150 feet and recorded the number of grunion present in 1 m<sup>2</sup> according to a scale from 0 to 5. A score of 0 meant no fish within the transect; 1 indicated some fish present but no spawning, while a score of 5 meant 90 or more fish per square meter and no room to step.

Although on a scale from 0 to 5 (SCOSC, 1978), for observations of spawning runs on McGrath State Beach all but one of the scores was 3 or lower. The team took photographs on four nights in three quadrats of four meters square, to count the fish later. Many of the counts differed when more than one person observed, so that one person reported 0 fish and another 14; a third reported 7 while a fourth 28, in the same transect. On one night, an observer reported every minute for one transect; within eight minutes the number of fish in 1 m<sup>2</sup> went from 0 to 5 to 10 to 130 to 49 to 23, and back to 0 (SCOSC, 1978). These data indicate the difficulty, and futility, of accurately counting the rapidly changing number of fish on shore even within a restricted space.

Middaugh (1981) used a “Spawning Run Index” as a similar metric for the Atlantic Silverside, *Menidia menidia*. This atherinopsid from the east coast of North America makes spawning runs at high tides to deposit its eggs aquatically on vegetation at the edges of bays and estuaries. Middaugh’s scale spans 0 to 5 and combines observations on the duration of the run and the discoloration of the water by spawning products, as well as the behavior of the fish. Middaugh (1981) was satisfied that he and a partner were able to make independent observations of the same run that were consistent within one “Spawning Run Index” unit.

Another previous method for California Grunion run assessment, at Cabrillo Marine Aquarium (CMA), used line transects in the sand to locate egg clutches following grunion runs (Lawrenz-Miller, 1991). Digging up these eggs is quite labor-intensive and requires a scientific collecting permit, so is not suitable for widespread use or for citizen scientists (Fig. 2). If done improperly, collecting eggs can disturb and damage incubating embryos. In a different monitoring experiment at CMA, 1 m<sup>2</sup> transects and photographic records were taken during grunion runs (Fig. 3), requiring special



**Fig. 2.** (A) Collecting eggs after a run. Clutches are indicated with blue flags. These were found within 10 min following a run scored at W-5. Not all clutches present are marked. (B) Grunion eggs. Photos by Karen Martin.

equipment and many volunteers during the runs. The frantic human activity to place transects near fish for photos drove fish back into the water.

A more urgent need for a reliable assessment of California Grunion populations resulted from a concerned citizen's complaint in San Diego, California in the summer of 2001. The citizen accused beach maintenance workers of causing the loss of this species from local beaches by their maintenance activities, raking with large tractors, grooming the sand and potentially destroying any incubating eggs. After this announcement to the local press, alarmed volunteers looked for California Grunion in late July and August. They saw very few, lending urgency and credibility to the complaint. Public concern prompted the San Diego City Council to convene a panel of scientists to address the possible effects of beach maintenance on grunion (Martin et al., 2006).

This crisis on San Diego's beaches provided the opportunity to test a new method to find out if it could be used reliably by trained observers from the general public, to

determine whether California Grunion still were present nearshore (Martin et al., 2007). Since then, the new method has been employed by multiple independent entities in support of coastal construction projects, reinforcing the necessity of a detailed, published explanation of the method.

#### MATERIALS AND METHODS

From 1951 until the present, CMA has provided a popular public program for observing California Grunion runs on Cabrillo Beach in San Pedro, Los Angeles County, California (Idyll, 1969; Harzen et al., 2011). Author MS participated in those programs between 1989 and 2018. Author SLM conducted a quantitative study of egg clutches in 1990–1991 prior to a planned beach renourishment project by the County of Los Angeles. Monitoring of eggs by CMA volunteers then continued through 2005. Starting in 1996 author KLM observed runs at Malibu Surfrider State Beach, Los Angeles County, California. Both locations show vari-



**Fig. 3.** Two examples of PVC pipe square meter transects deployed during a California Grunion run at Cabrillo Beach. Photos by Michael Schaadt.

ability in the strength of the runs over time, and both have large fluctuations in spawning runs from year to year.

In order to assess long-term trends and keep records about the runs, the co-authors formulated a new metric for assessing California Grunion spawning runs, the Walker Scale, named in honor of Boyd Walker's pioneering work (Walker, 1949, 1952). Observers describe spawning runs at their peak by the location, intensity, extent, and duration on the beach. The Walker Scale goes from W-0, representing few or no fish and no spawning, to W-5, representing thousands of fish spawning along the entire length of the beach in a peak that lasts over an hour (for details please see below). The divisions are approximately logarithmic, distinct enough that trained observers should be able to discriminate them. Walker Scale numbers are categorical rather than absolute counts, similar to the Richter Scale for earthquakes or the Saffir-Simpson scale for tropical storm intensity, with specific phenomena associated with each level.

San Diego's concern provided an opportunity to test whether the Walker Scale metric would be reliable for observers with relatively little experience. Because of the large area, multiple observers were required. Volunteers were recruited using newspapers, radio, websites, and community outreach. The Birch Aquarium at Scripps Institution of Oceanography provided space for a workshop for 100 people, and when it reached capacity, a second one was added that was equally popular.

At the workshops, volunteers dubbed "Grunion Greeters" learned about the California Grunion life cycle, the importance of the sandy beach habitat for incubating eggs, and how to use the Walker Scale. Four city beaches, La Jolla Shores, Pacific Beach, Mission Beach, and Ocean Beach, were monitored along about five miles of shoreline, divided into ten sites to provide easy walking distances of about 1 km. Greeters signed up in pairs to monitor specific locations for two hours on spawning run nights as predicted by the California Department of Fish and Wildlife following semilunar high tides (<https://wildlife.ca.gov/Fishing/Ocean/Grunion>).

Observers arrived on site shortly before the highest expected tide and stayed until two hours after the peak tide. Because the high tides occur at night, observers walked back and forth on the dark beach to see whether any fish appeared, using flashlights sparingly. Initial sightings are typically one or a few fish surfing onto the beach, then quickly returning to the water. Volunteers were advised that over time, a run may build. More fish may arrive at one or more places along the shoreline. Numbers of fish emerged onto the sand are highly variable and change rapidly especially in the presence of noise or other disturbance, such as predation or chasing by humans for catch.

The Walker Scale is intended to measure the peak of the run. All male and female California Grunion on shore are considered in the estimate for the Walker Scale (Table 1). The period when the run peaks is of greatest interest. If the run starts small but builds, then the run is scored for the total California Grunion on shore during the peak 20 minutes or more. Runs may be localized in one or a few sites along the beach or may encompass a large area.

### Walker Scale

**W-0.**—If no fish appear, or fewer than ten or so appear briefly without spawning, the score is W-0.

**W-1.**—If only a few fish arrive on shore at a time, scattered throughout the two-hour window of observation after the highest tide, and little or no spawning is observed in scattered spots, it is scored a W-1, even if a total of up to 100 fish arrive over time, without a real peak. Egg clutches are absent or few in number following a run.

**W-2.**—If the fish are few and far between, or close together but over a fairly small area, and some spawning occurs, then the score is a W-2. This may be 100 or more fish at a time, concentrated in one area or fish may be scattered in small groups, spread out along the shoreline. Numbers of fish vary from moment to moment but at the peak, dozens to several hundred spawn on shore at the same time. Egg clutches can be found at low densities if the exact spawning location is known.

**W-3.**—Larger runs show a greater concentration of California Grunion. A W-3 run may be an intense run in one area of the beach, with thousands of fish on shore, for a peak of less than an hour, or the run may spread out over a wide area and involve thousands of fish with plenty of space between them, but last only a few minutes at the peak. The peak number of fish is approximately an order of magnitude greater than a W-2. Egg clutches are at high densities in large numbers in patchy locations for runs with scores of W-3 and above.




**W-4.**—If the crowded conditions of a W-3 run extend over more than one localized area, or spread over a greater length of shoreline, with the peak still less than one hour, then the run is scored as W-4. The density of the fish on shore may be similar, but spread out over a wider area, or may be in one area but much more intense at its peak than a W-3. Multiple thousands of fish appear on shore during a W-4 run.

**W-5.**—For a very large W-5 run, massive numbers of California Grunion emerge along the majority of the length of the beach, for a peak that lasts over an hour. Thousands of fish constantly come onto shore during a W-5 run, and at the peak the fish are so thick that one cannot see the sand between them. This is a rare event, typically 1% to 3% of observations in a given year or fewer.

Within 24 hours after each run, volunteers reported data via the internet directly into a database. For large runs of W-3 or higher, observers called a "Grunion Hot Line" to identify appropriate sites for egg collection for additional studies. Observers noted the weather, any animal predators, and the number and activity of other people on shore, particularly if they were attempting to catch California Grunion. The accuracy of the volunteer reports was tested by comparing concurrent observations from multiple observers on the same beach.

To confirm the Walker scores, eight beaches were visited by the scientific team to locate the buried grunion clutches, at the locations and in the numbers expected based on the reports. Once the egg zone was located initially, eight quarter-meter transects were laid out and excavated to a depth of 20 cm, and clutches were counted within each transect. Over subsequent years, additional records of egg collections were confirmed with Walker Scale reports by ease of locating egg clutches within 20 min of searching on the beach.

**Table 1.** Description of Walker Scale for evaluation of California Grunion spawning runs. Scores may be for a local concentration or for the entire length of the beach. Photos by W. Hootkins, K. Martin, H. Lakisic. Used with permission of Grunion.org.

Scale	Numbers of grunion	Duration	Descriptor	
W-0	No fish or only a few individuals, little or no spawning, fish do not remain on beach	< 1 h	Not a run	
W-1	10–100 fish scattered on beach at a time, moving about, limited spawning	< 1 h	Light run	
W-2	100–500 fish spawning at different times, fish ashore with many of the large waves	< 1 h	Good run	
W-3	Hundreds of fish spawning at once in one or several areas of beach, locally heavy, may be brief or intermittent	≤ 1 h	Strong run	
W-4	Thousands of fish together for an extended time, little sand visible between fish in one area, may extend along much of the shoreline	≤ 1 h	Excellent run	
W-5	Fish covering the length of the beach, a silver lining along the surf, several individuals deep, impossible to see sand between fish	Peak density lasts ≥ 1 h	Incredible run	

In 1990–2005, along Cabrillo Beach, line transects of 10 m were done at 30 m intervals perpendicular to shore on mornings following the predicted run series at low tide. Clutch density was calculated by digging for eggs within 15 cm of the line, counting the clutches in the transects and measuring the width of the grunion egg zone perpendicular to shore. Independently, the runs were assessed with a Walker score for Cabrillo Beach for eight runs that were measured subsequently with line transects, between 2003 and 2005.

In 2007, ten individual clutches were collected from each of seven southern California beaches following California Grunion runs ( $n = 70$ ). Each was measured for volume and the eggs were counted. Beaches surveyed were Paradise Cove (Little Dume), Malibu Lagoon (Surfrider) Beach, Topanga Beach, Santa Monica City Beach, Cabrillo Beach, Doheny State Beach, and Pacific Beach in San Diego.

## RESULTS

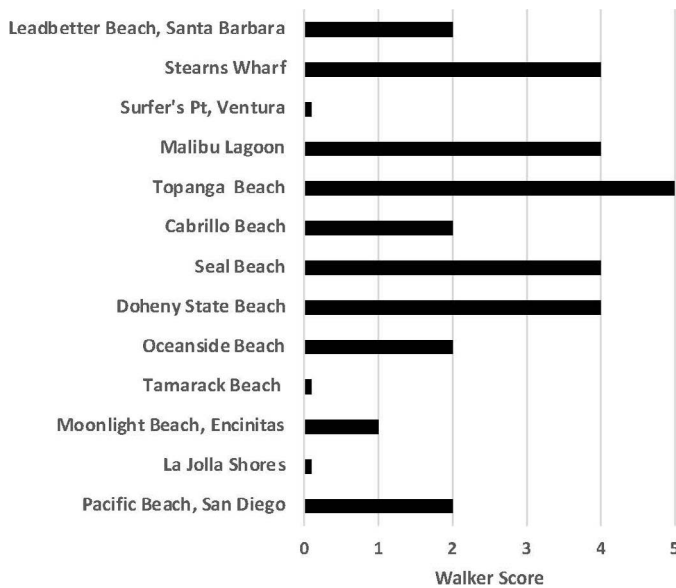
Grunion Greeter citizen scientists showed up in the middle of the night, observed carefully, and filled in their web questionnaires promptly. More than 200 individuals from universities, corporations, environmental organizations, the military, retirees, and the general public volunteered to “Greet the Grunion” in 2002. They arrived at their scheduled

locations reliably, in spite of the inconvenient nighttime hours and dark, chilly conditions. They reported their results quickly with the web-based data acquisition portal.

In subsequent years, workshops were held at multiple locations along the coast of California with the assistance of many community partners. Over 4,800 volunteer Grunion Greeters have provided over 5,400 observational reports in the past two decades. Most data arrived within 18 h of the field observations. Many volunteers reported with their smart phones on the beach or their computers within minutes of their return home. Comparisons of concurrent reports for the same run are highly positively correlated (Pearson coefficient  $r = 0.95$ ,  $df = 240$ ,  $P < 0.0001$ ).

During the first year of the study, California Grunion spawned in large numbers throughout the spawning season in San Diego in 2002, on all four study beaches. Spawning runs were seen at all ten sites, from early March 2002, continuing on the appropriate nights through July. Heaviest runs occurred between April and June, and intensity decreased toward the end of the season. Subsequent years showed similar variation between sites and over time. The Walker scores for late April, 2017 on 13 beaches (Fig. 4) shows an example of variability between sites for the same run.

Observations by Grunion Greeters were confirmed for location and intensity of the runs by site visits. Clutches of eggs in the sand were found in the specific locations



**Fig. 4.** Comparison of Walker scores across 13 different beaches, late April 2016. Compare to Supplemental Figure S1 (see Data Accessibility), with some of the same beaches.

identified, in numbers appropriate to the report (Fig. 5). Walker scores were highly positively correlated with clutch density on the beach ( $r = 0.71$ ,  $P < 0.0001$ ,  $df = 33$ ,  $t = 5.8$  by Spearman rank correlation).

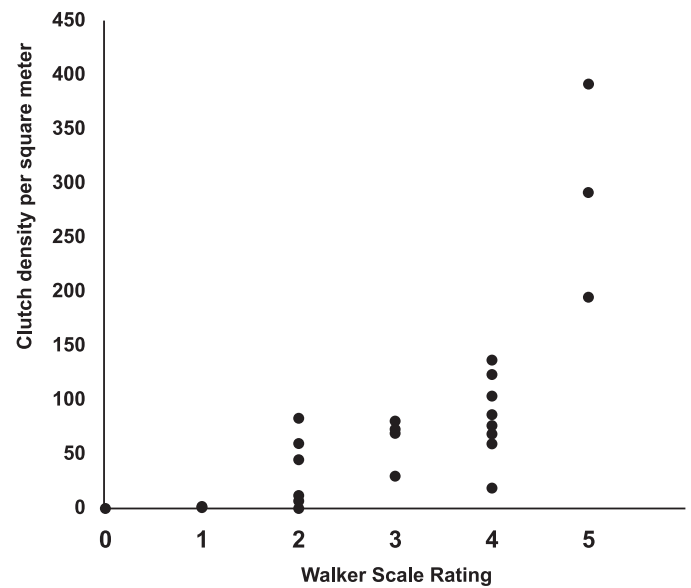
At Cabrillo Beach, clutch densities measured between 1996 and 2005 ranged from 0 up to a high of 392 clutches per square meter, from a line transect taken April 13, 2001 (Fig. 5). At W-1 and W-0, few if any clutches can be found. At W-2, clutches may be widely spaced with one or a few clutches per square meter. At W-3 to W-5, clutches are readily located by experts, and density is much greater.

Clutch volumes for southern California Grunion have a mean of  $12.2 \pm 1.2$  mL, with a mean of  $2936 \pm 319$  eggs per clutch ( $n = 70$  clutches). At the highest densities, the number of eggs in the sand is over one million per square meter.

The horizontal width of the spawning zone is  $5.6 \pm 2.5$  m at Cabrillo Beach, and ranges between less than 1 m to around 10 m (Fig. 6). The water line at low tide and the height of the run above the water line varied somewhat between runs, but eggs were clustered between the mean high tide and the highest semilunar high tide, with the majority of clutches between 3 and 10 m above the water line at low tide.

## DISCUSSION

Historically, California Grunion run on some of the most popular public beaches in southern California (Thompson, 1919; Clark, 1938; Robbins, 2006). California Grunion eggs incubate out of water from spawning until rising tides of the next full or new moon release them for hatching. Because of the California Grunion's unique terrestrial spawning habits, this fish is vulnerable to human impacts during reproductive stages of its life cycle, including beach grooming (Martin et al., 2006), salinity changes (Matsumoto and Martin, 2008), coastal construction (Dugan et al., 2008; Martin and Adams, 2020), and oil spills (Martin et al., 2020b), as well as climate change (Martin et al., 2013; Martin, 2015; Tasoff and Johnson, 2019).



**Fig. 5.** Clutch densities measured following spawning runs at several southern California beaches show a high positive correlation with Walker Scale reports,  $r = 0.71$ ,  $df = 33$ ,  $P < 0.0001$  by Spearman Rank correlation.

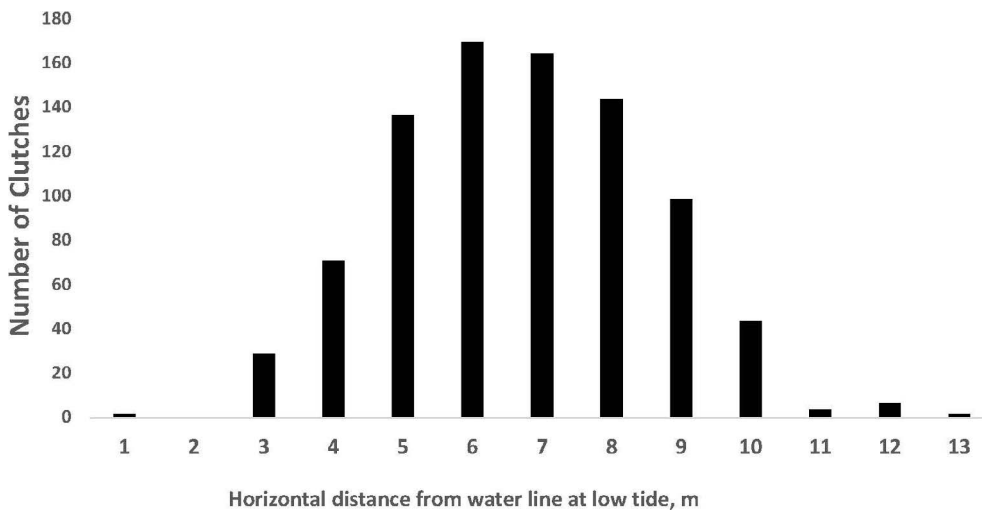
Although initial reports from 2001 in San Diego were not encouraging, observers were on beaches late in the California Grunion season, when runs are typically smaller and less frequent (Walker, 1949). In 2002, using the Walker Scale method, Grunion Greeters found many California Grunion with more observers in more areas at the appropriate time during the spawning season (Martin et al., 2007).

The Walker Scale report predicts the distribution of buried clutches on shore. This can provide additional protection for the embryos during their two-week incubation period (Figs. 5, 6). The egg zone ranges horizontally on shore from 1 to 10 m wide (Fig. 6) and is wider with a flatter beach face. Clutch density within the egg zone is patchy but may be nearly 400 clutches per square meter; heavy footprints may turn up eggs to the sand surface with every step.

Each clutch contains 2,000 to 3,500 eggs (Gregory, 2001). A large run leaves thousands to millions of eggs buried under the sand. Beach grooming with heavy machinery has been seasonally adjusted to avoid buried grunion clutches on many California beaches (Martin et al., 2006; <https://www.beachecologycoalition.org/index.html>).

The Walker Scale is a reliable metric when used by citizen scientists and by professional monitors for coastal construction projects (Martin and Adams, 2020). The high correlation between Walker scores, location, and intensity of the runs have been confirmed repeatedly by the scientific team, by independent observers, and by egg collection after Grunion Greeter reports. Grunion Greeters take additional data during the runs (Supplemental Fig. S2; see Data Accessibility), and their data are checked for accuracy and quality before being used for analysis (Supplemental Text; see Data Accessibility).

Permits issued by the California Coastal Commission and/or the California Department of Fish and Wildlife for beach construction activities that take place during the California Grunion spawning season require monitoring for spawning runs. This allows restrictions based on presence or absence of



**Fig. 6.** Cumulative distribution of egg clutches in a band perpendicular to shore for eight run series on Cabrillo Beach between 2003 and 2005. Width of the band of egg clutches was  $5.2 \pm 2.5$  m,  $n = 874$  clutches, with the majority of clutches between 3 and 10 m above the water line at low tide.

eggs on shore. The Walker Scale method is modified slightly for professional biologists. Observers stay for all four nights of a forecast run series. During coastal construction, professional monitors use the Walker Scale method, often splitting beaches into smaller segments, allowing precise mitigation to avoid impacts on local concentrations of high nest density (Fig. 7). Professional monitors report data for each beach segment separately over the four nights of a run forecast. Example wording on a permit is as follows:

“Grunion monitoring shall be conducted by a qualified biologist for 30 minutes prior to, and two hours following, the predicted start of each nightly spawning event. Sufficient qualified biologists shall be employed to ensure that the entire construction site is monitored during the predicted grunion run. The magnitude and extent of a spawning event shall be defined in 300-foot segments of beach using the Walker Scale. Every individual fish shall be counted to determine the Walker Scale value (e.g., 0, 1, 2, 3, 4, or 5) of each 300-foot segment within the proposed work area” (California Coastal Commission from 2020).

Assessments of marine species, though difficult, are important (Martin, 2015). The advantage of the Walker Scale method is a consistent, systematic characterization of the abundance, extent, and duration of the peak of the spawning run. By focusing on the peak rather than descriptions of momentary details, the pitfalls of observer inconsistencies in previous studies (Walker, 1949; SCOSC, 1978) are avoided.

Grunion Greeters represent the first systematic effort to assess the distribution of California Grunion along its habitat range for over 70 years (Martin et al., 2020a), since Walker (1949). Although his measurement techniques differed, the two approaches reveal comparable variability between sites and across nights (Fig. 3, Supplemental Fig. S1; see Data Accessibility). The Walker Scale can be flexibly adapted to smaller locales as needed (Fig. 7).

Walker (1949) warned against using reports from the public for assessing California Grunion runs, advising that most people overestimate the numbers of fish on the beach. Experience with casual observers concurs; these reports are typically unreliable and inconsistent. For example, an individual reporting a “great run” with fish “all over the beach” may admit, when pressed, that only a small number of fish were seen, but it was still the most impressive run they

themselves had observed (pers. comm.). In spite of this caveat, Walker himself used volunteers in his study in 1947. No one person or group can observe large areas of beach in the dark across hundreds of kilometers of coast, during the brief duration of any predicted spawning run, so multiple observers are necessary to understand the total population across the range.

In summary, trained, committed citizen scientists observed reliably with minimal supervision, made detailed field observations using the Walker Scale, and submitted data electronically on the internet via a web portal. Results are highly consistent among observers and easily understood by volunteers, the public, resource managers, and government. The method, originally used by a few scientists with the help of citizen scientists, also called community scientists, has been adopted for general use by professional biologists for resource management and critical habitat protection. The unique, long-term hyperlocal data from the Grunion Greeters on behalf of this unique natural and cultural resource could not have been obtained any other way.

#### DATA ACCESSIBILITY

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**Fig. 7.** Report using Walker Scale in smaller segments, in the context of a coastal construction project. Map of Santa Ana River, California from Merkel & Associates, 2017 (used with permission of Keith Merkel). This would be reported as a W-4 for the Grunion Greeters for 4/12, a W-2 on 4/13, and a W-1 on 4/14. The detailed locations given for the run assist in project management along the shoreline to avoid nest sites during construction.

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#### LITERATURE CITED

- Allen, L. G., A. M. Findlay, and C. M. Phalen. 2002. Structure and standing stock of the fish assemblages of San Diego Bay, California from 1994 to 1999. *Bulletin of the Southern California Academy of Sciences* 101:49–85.
- Allen, L. G., M. H. Horn, F. A. Edmonds II, and C. A. Usui. 1983. Structure and seasonal dynamics of the fish assemblage in the Cabrillo Beach area of Los Angeles Harbor, California. *Bulletin of the Southern California Academy of Sciences* 82:47–70.
- Byrne, R. J., and J. C. Avise. 2009. Multiple paternity and extra-group fertilizations in a natural population of California Grunion (*Leuresthes tenuis*), a beach-spawning marine fish. *Marine Biology* 156:1681–1690.
- Clark, F. N. 1926. Conservation of the grunion. *California Fish and Game* 12:163–166.
- Clark, F. N. 1938. Grunion in southern California. *California Fish and Game* 24:49–54.
- Crabtree, C. B. 1987. Allozyme evidence for the phylogenetic relationships within the silverside subfamily Atherinopsinae. *Copeia* 1987:860–867.
- Defeo, O., A. McLachlan, D. S. Schoeman, T. A. Schlacher, J. Dugan, A. Jones, M. Lastra, and F. Scapini. 2009. Threats to sandy beach ecosystems: a review. *Estuarine, Coastal and Shelf Science* 81:1–12.
- Dugan, J. E., D. M. Hubbard, I. F. Rodil, D. L. Revell and S. Schroeter. 2008. Ecological effects of coastal armoring on sandy beaches. *Marine Ecology* 29:160–170.
- Gregory, P. A. 2001. Grunion, p. 246–247. *In: California's Living Marine Resources: A Status Report*. W. S. Leet, C. M. Dewees, R. Klingbeill, and E. J. Larson (eds.). California Department of Fish and Game, Sacramento, California.
- Griem, J. N., and K. L. M. Martin. 2000. Wave action: the environmental trigger for hatching in the California grunion *Leuresthes tenuis* (Teleostei: Atherinopsidae). *Marine Biology* 137:177–181.

- Harzen, S. E., B. J. Brunnick, and M. Schaadt. 2011. An Ocean of Inspiration: The John Olguin Story. Rocky Mountain Books, Toronto.
- Horn, M. H., A. K. Gawlicka, D. P. German, E. A. Logothetis, J. W. Cavanaugh, and K. S. Boyle. 2006. Structure and function of the stomachless digestive system of three related species of New World silverside fishes (Atherinopsidae) representing herbivory, omnivory, and carnivory. *Marine Biology* 149:1237–1245.
- Idyll, C. P. 1969. Grunion, the fish that spawns on land. *National Geographic* 135:714–723.
- Lawrenz-Miller, S. 1991. Grunion spawning versus beach nourishment: nursery or burial ground? Proceedings of the 7<sup>th</sup> Symposium on Coastal and Ocean Management. Coastal Zone '91:2197–2208.
- Love, M. S., and J. K. Passarelli (Revised and Edited). 2020. Miller and Lea's Guide to the Coastal Marine Fishes of California. Second edition. University of California Agriculture and Natural Resources Publication 3356, Davis, California.
- Martin, K., T. Speer-Blank, R. Pommerening, J. Flannery, and K. Carpenter. 2006. Does beach grooming harm grunion eggs? *Shore & Beach* 74:17–22.
- Martin, K., A. Staines, M. Studer, C. Stivers, C. Moravek, P. Johnson, and J. Flannery. 2007. Grunion Greeters in California: beach spawning fish, coastal stewardship, beach management and ecotourism, p. 73–86. *In*: Proceedings of the 5<sup>th</sup> International Coastal & Marine Tourism Congress: Balancing Marine Tourism, Development and Sustainability. M. Lück, A. Gräupl, J. Auyong, M. L. Miller, and M. B. Orams (eds.). New Zealand Tourism Research Institute, Auckland, New Zealand.
- Martin, K. L. M. 1999. Ready and waiting: delayed hatching and extended incubation of anamniotic vertebrate terrestrial eggs. *American Zoologist* 39:279–288.
- Martin, K. L. M. 2015. Beach-Spawning Fishes: Reproduction in an Endangered Ecosystem. CRC Press, Taylor & Francis Group, Boca Raton, Florida.
- Martin, K. L. M., and L. C. Adams. 2020. Case study: effects of repeated sand replenishment projects on runs of a beach-spawning fish, the California grunion. *Journal of Marine Science and Engineering* 8:178.
- Martin, K. L. M., K. A. Hieb, and D. A. Roberts. 2013. A southern California icon surfs north: local ecotype of California Grunion *Leuresthes tenuis* (Atherinopsidae) revealed by multiple approaches during temporary habitat expansion into San Francisco Bay. *Copeia* 2013:729–739.
- Martin, K. L. M., E. A. Pierce, V. V. Quach, and M. Studer. 2020a. Population trends of beach-spawning California grunion *Leuresthes tenuis* monitored by citizen scientists. *ICES Journal of Marine Science* 77:2226–2233.
- Martin, K. L. M., and J. G. Raim. 2014. Avian predators target beach spawning marine fish, California Grunion, *Leuresthes tenuis*. *Bulletin of the Southern California Academy of Sciences* 113:187–199.
- Martin, K. L. M., and D. L. Swiderski. 2001. Beach spawning in fishes: phylogenetic tests of hypotheses. *American Zoologist* 41:526–537.
- Martin, K. L. M., D. Witting, and R. Donohoe. 2020b. The 2015 Refugio Beach Oil Spill. Field and laboratory assessment of injury to California grunion *Leuresthes tenuis*. Appendix G-2, Refugio Beach Oil Spill Draft Damage Assessment and Restoration Plan/ Environmental Assessment. Refugio Beach Oil Spill Trustees (eds.). California Department of Fish and Wildlife, California State Lands Commission, California Department of Parks and Recreation, Regents of the University of California, U.S. Department of the Interior, U.S. Fish and Wildlife Service, and National Oceanic and Atmospheric Administration, Sacramento, California.
- Matsumoto, J. K., and K. L. M. Martin. 2008. Lethal and sublethal effects of altered sand salinity on embryos of beach-spawning California Grunion. *Copeia* 2008:483–490.
- Middaugh, D. P. 1981. Reproductive ecology and spawning periodicity of the Atlantic silverside, *Menidia menidia* (Pisces: Atherinidae). *Copeia* 1981:766–776.
- Moravek, C. L., and K. L. M. Martin. 2011. Life goes on: delayed hatching, extended incubation, and heterokairy in development of embryonic California grunion, *Leuresthes tenuis*. *Copeia* 2011:308–314.
- Robbins, E. 2006. Essential fish habitat in Santa Monica Bay, San Pedro Bay, and San Diego Bay: a reference guide for managers. Unpubl. M.S. thesis, Duke University, Durham, North Carolina.
- Roberts, D., R. N. Lea, and K. L. M. Martin. 2007. First record of the occurrence of the California Grunion, *Leuresthes tenuis*, in Tomales Bay, California: a northern extension of the species. *California Fish and Game* 93:107–110.
- Sandrozinski, A. 2013. California Grunion. Status of the Fisheries Report, an Update Through 2011. California Department of Fish & Wildlife, Sacramento, California.
- Schoeman, D. S., T. A. Schlacher, and O. Defeo. 2014. Climate-change impacts on sandy-beach biota: crossing a line in the sand. *Global Change Biology* 20:2383–2392.
- Schooler, N. K., J. E. Dugan, D. M. Hubbard, and D. Straughan. 2017. Local scale processes drive long-term change in biodiversity of sandy beach ecosystems. *Ecology and Evolution* 7:4822–4834.
- Smyder, E. A., and K. L. M. Martin. 2002. Temperature effects on egg survival and hatching during the extended incubation period of California grunion, *Leuresthes tenuis*. *Copeia* 2002:313–320.
- SCOSC (Southern California Ocean Studies Consortium of the California State University and Colleges). 1978. Report on grunion spawning at McGrath State Beach, Ventura County, California. Unpubl. Contract #DACW09-78-C0008 for the United States Army Corps of Engineers, Los Angeles District, California.
- Speer-Blank, T., and K. L. M. Martin. 2004. Hatching events in the California grunion, *Leuresthes tenuis*. *Copeia* 2004: 21–27.
- Tasoff, A. J., and D. W. Johnson. 2019. Can larvae of a marine fish adapt to ocean acidification? Evaluating the evolutionary potential of California Grunion (*Leuresthes tenuis*). *Evolutionary Applications* 12:560–571.
- Thompson, W. F. 1919. The spawning of the grunion (*Leuresthes tenuis*). *California Fish and Game* 5:1–27.
- Walker, B. W. 1949. Periodicity of spawning by the grunion, *Leuresthes tenuis*, an atherine fish. UC San Diego: Library—Scripps Digital Collection. Retrieved from <https://escholarship.org/uc/item/1j33928x>
- Walker, B. W. 1952. A guide to the grunion. *California Fish and Game* 38:409–420.