Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2019

Morro Bay National Estuary Program
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Contents

Introduction

Seagrass beds are among the most valuable coastal habitats worldwide. They perform a wide range of important ecosystem services, including carbon sequestration, water purification, sediment accretion and stabilization (Nordlund et al. 2017). Eelgrass (*Zostera marina*), like other seagrasses, is a critical foundational habitat. Eelgrass creates habitat that leads to increased abundance and diversity of many invertebrate and fish species, and it serves as a nursery for ecologically and commercially-valuable species.

Eelgrass is a marine flowering plant with long, ribbon-like leaves that grow from an underground stem (rhizome). It is found worldwide in coastal waters. Eelgrass reproduces both sexually (via flowers and seed production) and asexually (via spreading rhizomes).

Unprecedented declines in seagrass distribution have been observed worldwide and are a growing cause for concern. The reasons for the decline are attributed to many natural and anthropogenic factors in coastal ecosystems. Natural impacts may come from changes in water depth, salinity, wave velocity, turbidity due to sediment or phytoplankton blooms, and herbivory pressure. Anthropogenic impacts may be either direct or indirect. Direct impacts include seagrass removal by dredging, propeller scarring, or shading caused by boat moorings or pier construction. Indirect impacts include the introduction of invasive species and non-point source loading of nutrients, herbicides, and sediment, which can negatively impact water clarity (Hauxwell et al. 2003). The indirect effects associated with sea level rise and climate change are not well understood but are widely expected to negatively impact seagrass distribution globally (Ralph et al. 2007).

Morro Bay once supported the third largest eelgrass dominated ecosystem in the southern California region (Bernstein et al. 2011). However, eelgrass in Morro Bay declined by more than 90% from 2007 to 2016. This drastic decline spurred many restoration, monitoring, and research efforts. Since 2016 and 2017, eelgrass has begun to re-establish in areas where it previously declined.

This report summarizes all Morro Bay eelgrass-related activity in 2019, including small-scale experimental restoration and detailed monitoring of new sites and existing eelgrass beds.

Morro Bay Project Area

Morro Bay is a shallow coastal lagoon located on California’s Central Coast in San Luis Obispo County. Founded in 1870, the town of Morro Bay (population 10,640) is located in the northern extent of the estuary. The unincorporated community of Los Osos (population 14,276) is located on the southern shores of Morro Bay (Figure 1). Morro Bay was established as California’s first State Estuary in 1994, paving the way for inclusion in the National Estuary Program in 1995 and establishment of the Morro Bay National Estuary Program (Estuary Program). Today, Morro Bay is one of 28 recognized National Estuaries.

The Morro Bay watershed encompasses drainage from approximately 75 square miles. Freshwater inflows are delivered to the estuary via the Chorro Creek and Los Osos Creek sub-watersheds and through groundwater seepage in the Los Osos area. Non-urbanized lands in the Chorro Creek sub-watershed are used primarily as rangeland and public parks. Non-urbanized lands in the Los Osos sub-watershed are dominated by rangeland, row crop agriculture, and commercial greenhouse nurseries. There have been a number of water quality impacts within the Morro Bay watershed and estuary. For more information, refer to the Estuary Program’s Library at http://www.mbnep.org/library, under Data and Technical Reports.

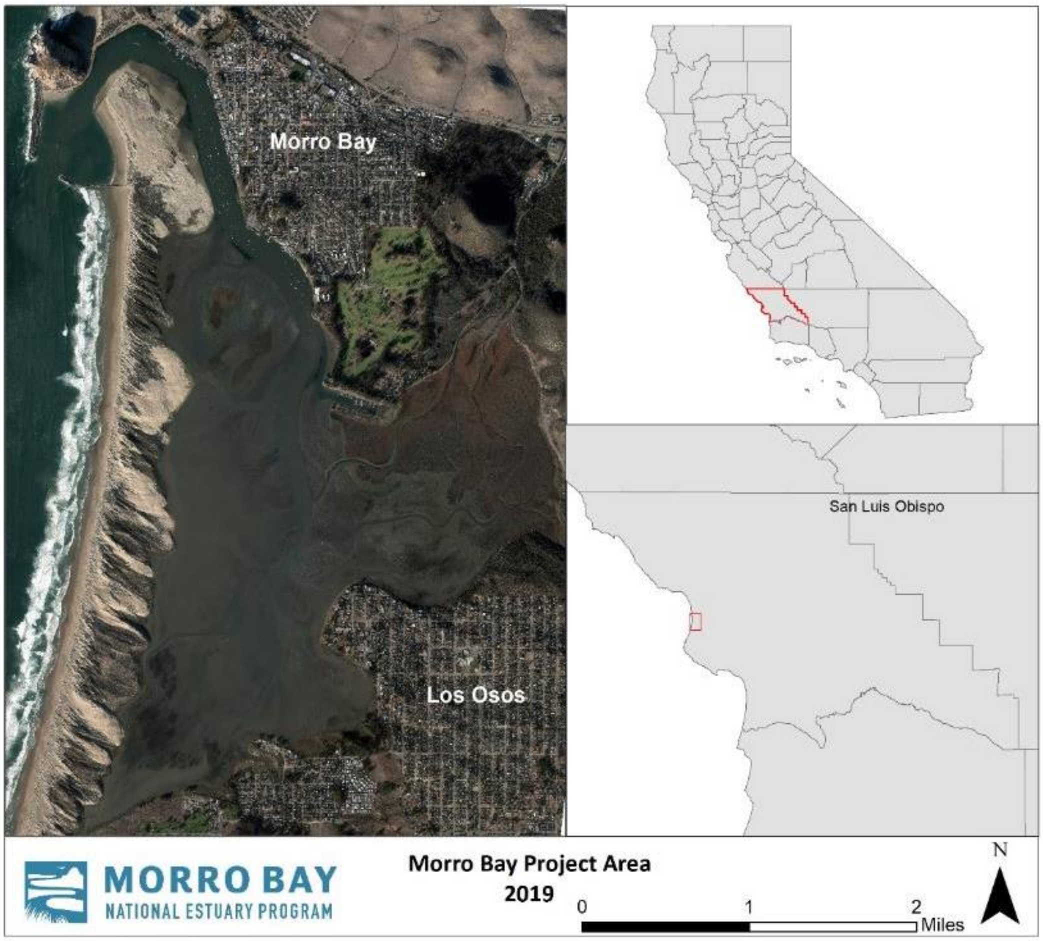


Figure 1. Morro Bay.

Morro Bay Estuary and Harbor

The Morro Bay estuary is comprised of approximately 2,300 acres of shallow, semi-enclosed intertidal and subtidal habitat. The estuary is bordered to the west by a four-mile vegetated natural sandspit that separates Morro Bay from the Pacific Ocean. Seagrass beds in Morro Bay are dominated by eelgrass (*Zostera marina*) with small patches of widgeon grass (*Ruppia maritima*) interspersed throughout the estuary. To date, Japanese eelgrass (*Zostera japonica*) has not been identified in Morro Bay. Habitat types and distribution are shown in Figure 2.

Morro Bay is a popular destination for outdoor recreation and supports a commercial fishing port and aquaculture operations. Recreational activities in the bay include kayaking, sailing, fishing, wildlife observing, and waterfowl hunting. Two commercial aquaculture operations grow Pacific oysters (*Crassostrea gigas*) and operate in conditionally-approved areas of the intertidal mudflats. The Morro Bay harbor is maintained by regular dredging events (see "Dredging Operations").

Eelgrass Distribution

Mapping Efforts

Morro Bay's eelgrass population has been mapped for decades, but the effort has not always been consistent in season and method. Many of the early eelgrass acreage estimates use subjective aerial photo interpretations, and discrepancies have not been fully quantified or reconciled for datasets generated prior to 2002. In 2002 and 2003, the Estuary Program contracted true color aerial flights, which were later re-analyzed using multispectral analysis to create a map of intertidal eelgrass similar to what was completed in later years. Between 2004 and 2013, intertidal eelgrass was mapped by multispectral aerial images. Flights were typically completed during extreme low tides in November. In 2012, the flight had to be canceled due to weather conditions and was instead completed in May 2013. Merkel & Associates (M&A) surveyed the bay in July 2013 and July 2015 using sidescan sonar, a method that targets mostly subtidal eelgrass.

In 2017, a combination of sidescan sonar and unmanned aerial vehicle (UAV) imagery were seamed together to map intertidal and subtidal eelgrass bay-wide. Multispectral aerial imagery was used to create a classification of intertidal submerged aquatic vegetation, which was groundtruthed by the Estuary Program. Since 2017, California Polytechnic State University (Cal Poly) has surveyed eelgrass in Morro Bay on a yearly basis using an unmanned aerial vehicle (UAV). For each survey, a UAV technician flies a drone over the bay at a standard height of 400 feet and captures nearly 5,000 photos. These photos are stitched together and georeferenced to create a bay-wide map. Then, the eelgrass is quantified in GIS by manually digitizing polygons.

Mapping efforts during 2019 included multispectral imaging conducted by Ocean Imaging (OI) and UAV drone imagery conducted by Cal Poly.

Multispectral Imagery

OI collected multispectral imagery on November 24, 2019 from 13:39 to 14:12 PST, at which time the tide levels were between -0.19 and -0.41 feet, as indicated by the National Oceanic and Atmospheric Administration (NOAA) Tides and Currents website. A guided classification was used to identify eelgrass bay-wide, as well as other exposed and submerged vegetation and substrate types. Details from this analysis are shown in Figure 2 and Table 1.

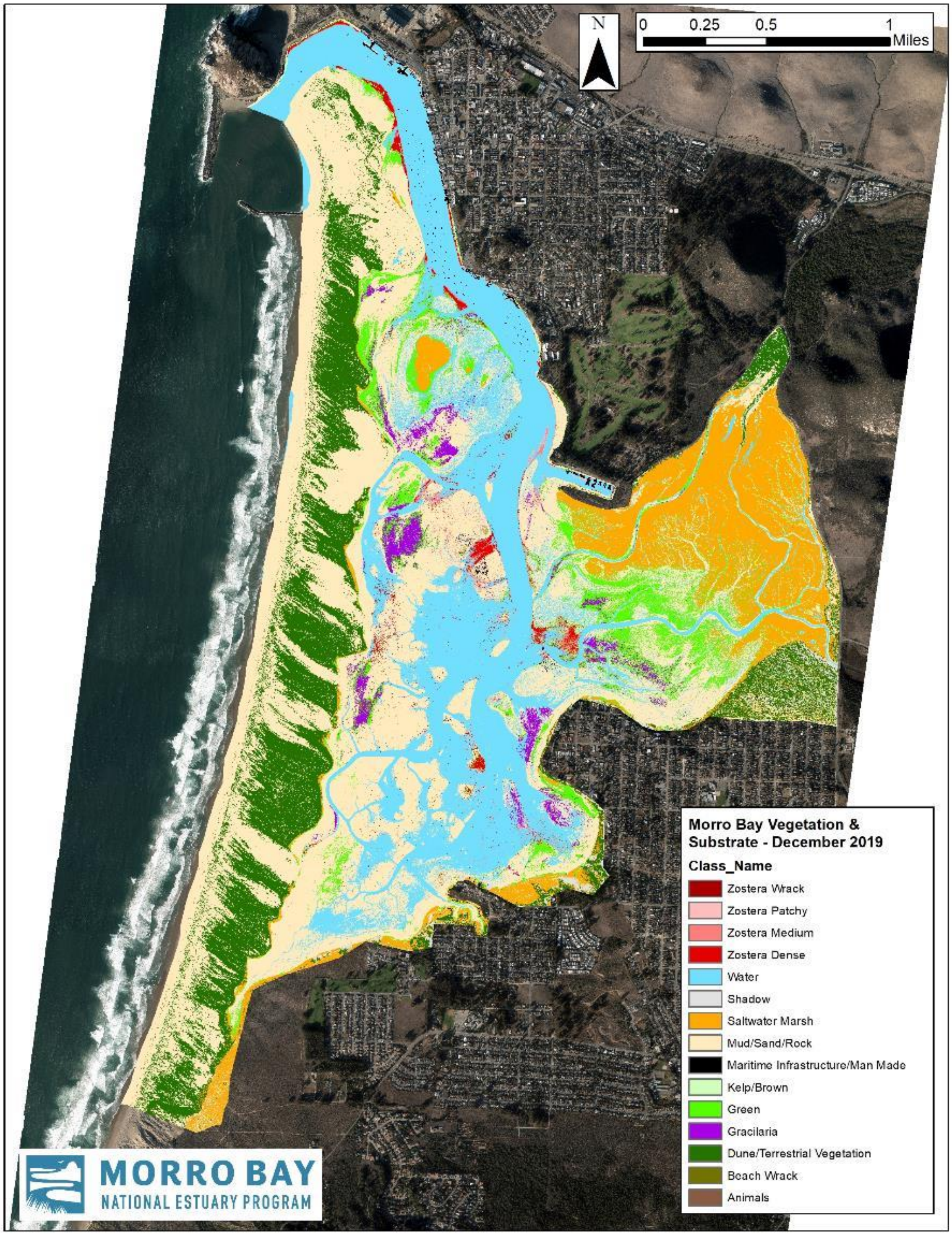


Figure 2. Morro Bay vegetation and habitat map from the December 2019 multispectral aerial imagery flight.

Table 1. Submerged aquatic vegetation and substrate types for the 2019 multi-spectral flight.

Vegetation / Substrate Type	Area (acres)
Zostera Wrack	0.23
Zostera (eelgrass)	42.41
Water	823.43
Shadows	32.71
Salt Marsh	400.84
Mud/Sand/Rock	1424.47
Maritime Infrastructure	9.34
Kelp/Brown Algae	0.69
Green Algae	197.43
Gracilaria Sp.	58.32
Dune/Terrestrial Vegetation	478.92
Beach Wrack	2.55
Animals	0.03

UAV Drone Mapping

Cal Poly has collected UAV drone imagery for eelgrass mapping on a yearly basis since 2017. Drone imagery is less cost-intensive than multispectral imaging, allowing it to be collected more frequently. Figure 3 illustrates eelgrass extent, as analyzed from Cal Poly UAV drone imagery in 2017, 2018, and 2019. Eelgrass acreage calculated from these flights are in Table 2.

Eelgrass Extent 2017 - 2019: Cal Poly UAV Drone Imagery

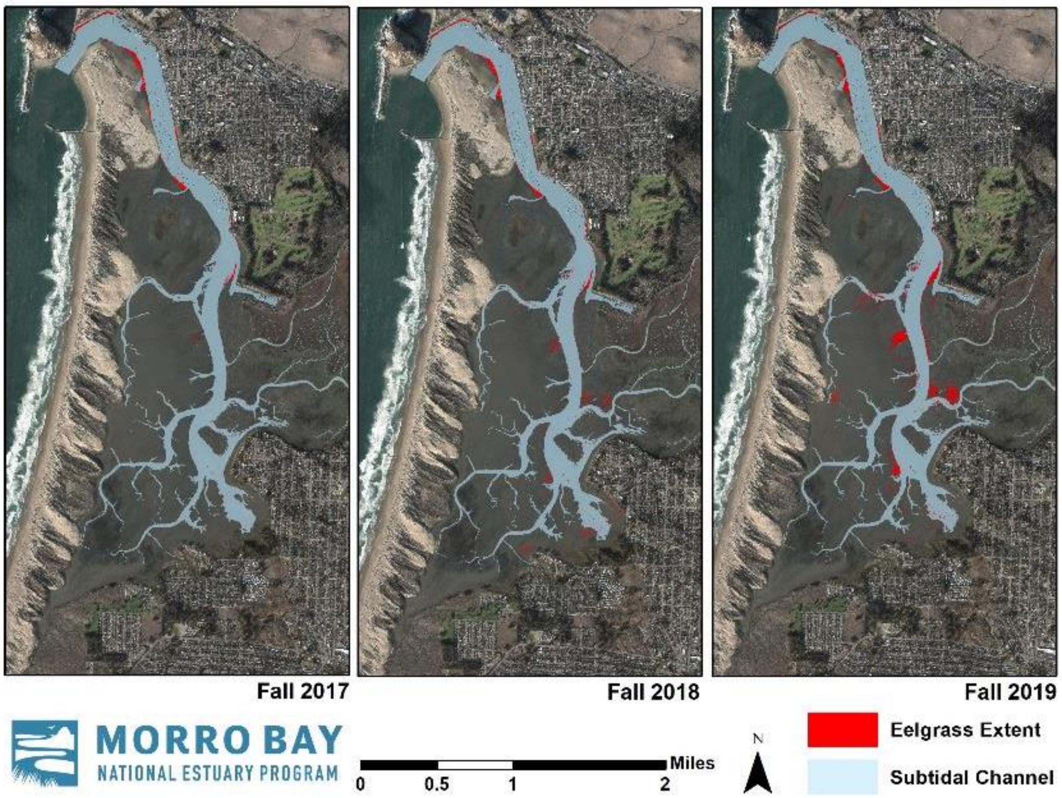
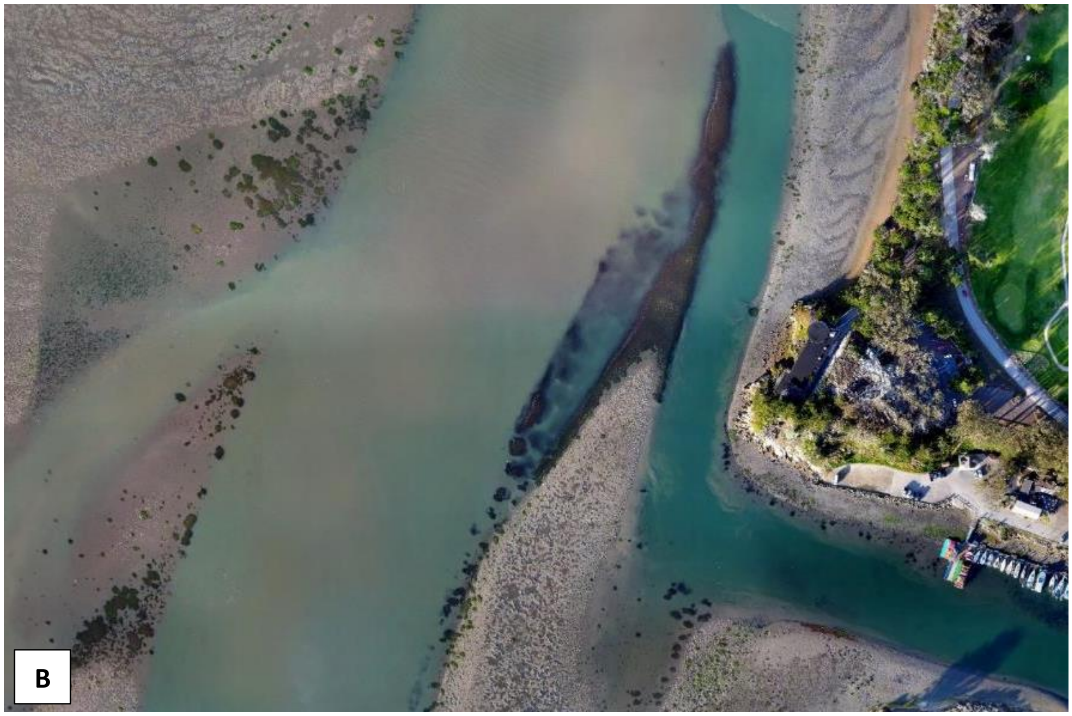


Figure 3. Eelgrass extent from Cal Poly UAV drone imaging, 2017 to 2019.

The following images from 2019 demonstrate the resolution of photos captured with the Cal Poly UAV. Figure 4A shows shellfish farm infrastructure, and Figure 4B shows a large eelgrass bed at State Park Marina. The dark green patches in each photo are eelgrass.



Figures 4A, 4B. Example photos showing resolution of images photos captured with Cal Poly's UAV during fall of 2019. Figure 4A shows shellfish farm infrastructure, and Figure 4B shows an eelgrass bed near State Park Marina.

2019 Eelgrass Mapping: Comparison of Methods

There were slight differences in the results from the OI multi-spectral flight and Cal Poly's UAV data. The multi-spectral flight and automated classification identified 42.4 acres of intertidal eelgrass, and the UAV imagery with manual classification identified 36.7 acres of intertidal eelgrass (Figure 5). This difference in acreage is related to differences in the methodologies of collection. The automated classification is thought to be able to more accurately capture small eelgrass patches (e.g., less than a meter in length) as compared to the manual classification process, although automated classification can overestimate eelgrass acreage by misidentifying algae as eelgrass.

2019 Eelgrass Extent: Ocean Imaging Multi-Spectral Flight vs. Cal Poly UAV

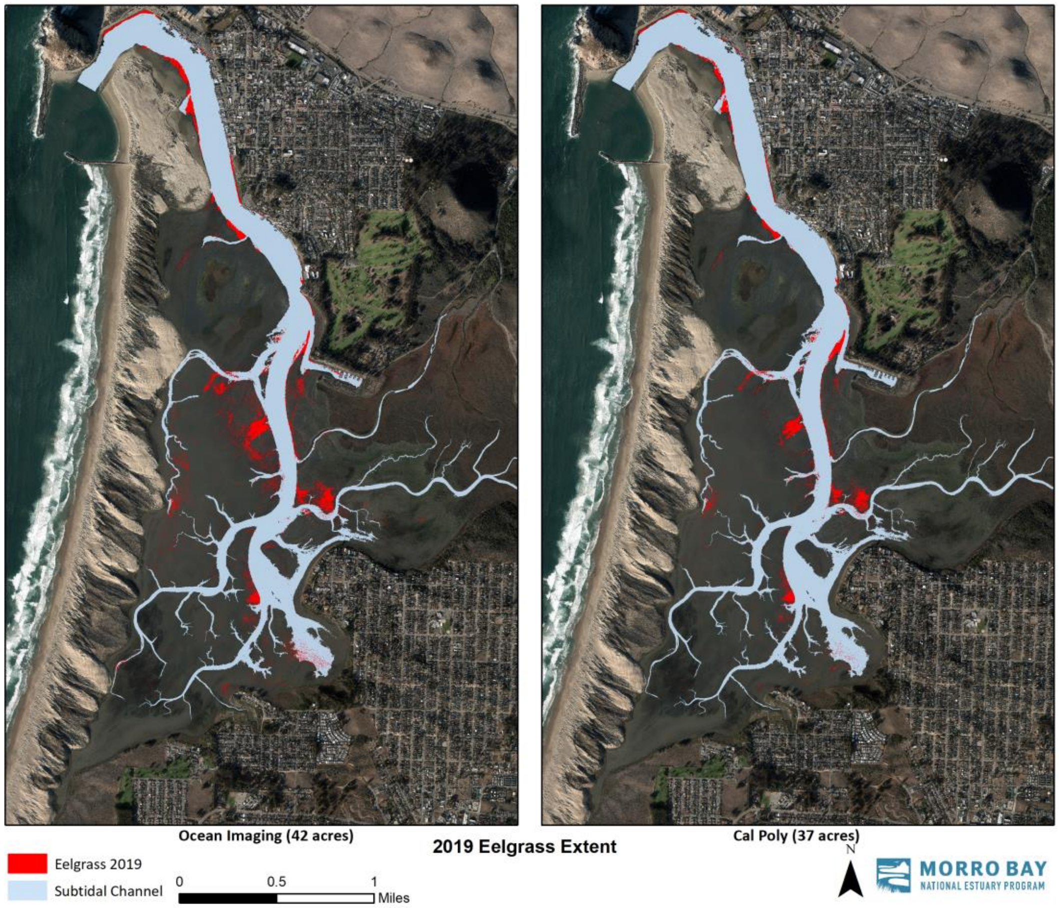


Figure 5. November 2019 map of bay-wide intertidal eelgrass from multispectral imagery with automated classification from Ocean Imaging (left), and a November to December 2019 map of bay-wide intertidal eelgrass from UAV imagery and manual classification from Cal Poly (right).

The multi-spectral analysis classified eelgrass beds as dense, medium, and patchy, since the eelgrass was often intermixed with other substrate types such as algae, mudflat, etc. To convert the mapped information into an acreage value, eelgrass percent cover values had to be assigned to each category. OI assumed that patchy areas contained 25% eelgrass, medium areas contained 50% eelgrass, and dense areas contained 100% eelgrass. Because of this assumption, the multi-spectral imagery overestimated eelgrass in areas designated as “patchy,” as many likely had less than 25% eelgrass coverage. There were also some locations where the multi-spectral imagery misidentified algae as eelgrass, further overestimating eelgrass extent.

While the UAV survey can be conducted more frequently due the lower cost, the multi-spectral collection has been conducted consistently in the bay since the early 2000s. This allows a direct comparison of current eelgrass acreage to pre-decline levels.

Eelgrass Acreage Data

The following table and figure present Morro Bay’s eelgrass acreage over time and the method of data collection. It is important when comparing these data to keep in mind that the mapping methodology has changed over time. Previous versions of this report are available at http://www.mbnep.org/library and include additional historical data information and sources. Note that with different mapping techniques, there can be overlap between eelgrass captured with subtidal methods versus with intertidal methods, depending on the method and the conditions (e.g., water clarity, tide height, etc.) during the survey.

Table 2. Eelgrass acreages and mapping methods, 1960 – 2019.

Year	Time of Year	Eelgrass Acreage	Method
1960	Unknown	335	Field surveys (Haydock)
1970	Unknown	452	Aerial photos (CA Fish & Game)
1988	Unknown	404	Aerial photos (Josselyn), reinterpreted (Chesnut)
1994	Late Sept to early Nov	435	Quadrat sampling (Chesnut)
1995	Late Sept to early Nov	260	Quadrat sampling (Chesnut)
1996	Late Sept to early Nov	165	Quadrat sampling (Chesnut)
1997	Late Sept to early Nov	98	Quadrat sampling (Chesnut)
1998	Unknown	125	Aerial photos (Tetra Tech)
2002	November 25, 2002	149	True color aerial images, reanalyzed (Estuary Program with Golden State Aerial and Ocean Imaging)
2003	November 21, 2003	167	True color aerial images, reanalyzed (Estuary Program with Golden State Aerial and Ocean Imaging)
2004	November 24, 2004	267	Multispectral aerial images (Estuary Program with Ocean Imaging)
2006	November 6, 2006	287	Multispectral aerial images (Estuary Program with Ocean Imaging)
2007	November 24, 2007	344	Multispectral aerial images (Estuary Program with Ocean Imaging)
2009	November 13, 2009	240	Multispectral aerial images (Estuary Program with Ocean Imaging)
2010	November 4, 2010	176	Multispectral aerial images (Estuary Program with Ocean Imaging)
2013	May 28, 2013 for multi-spectral imagery, July 2013 for sonar	15	Multispectral aerial images (Estuary Program with Ocean Imaging) and sonar (M&A)
2015	July 2015	13.23	Sonar (M&A)
2017	April 2017	13.6	Sonar and UAV (M&A)
2017	December 3, 2017	13.25	Multispectral aerial images (Estuary Program with Ocean Imaging)
2017	December 1 to 4, 2017	9.37	UAV (Cal Poly, Sea Grant)
2018	December 6, to 8, 20 and 21, 2018	16.4	UAV (Cal Poly, Sea Grant)
2019	November 26, December 11 to 13, 23 and 24, 2019, and January 8, 2020	36.7	UAV (Cal Poly)
2019	November 24, 2019	42.4	Multispectral aerial images (Estuary Program with Ocean Imaging)

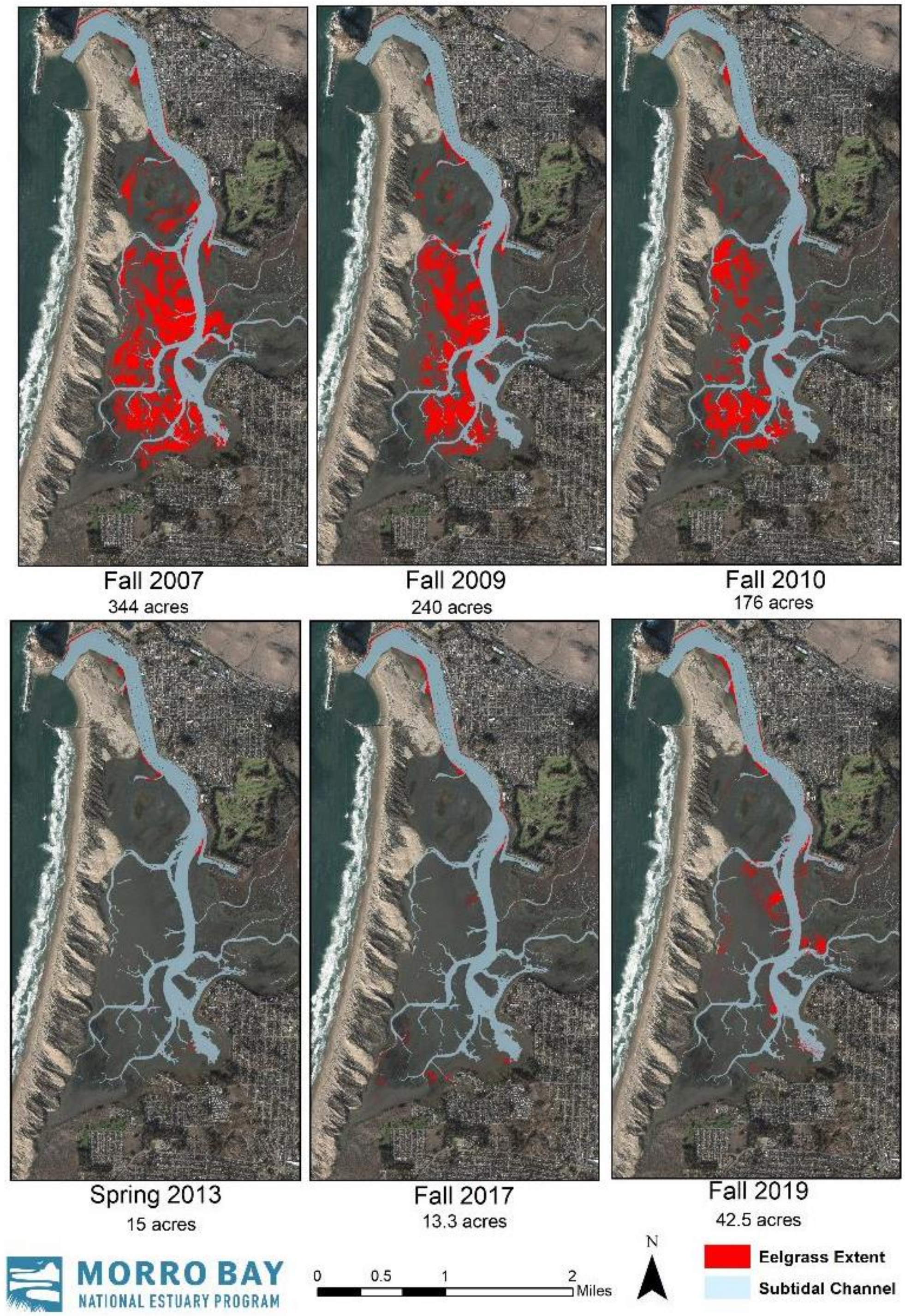


Figure 6. Changes in Morro Bay intertidal eelgrass density from 2007 to 2019, using multispectral imagery analysis.

Figure 6 illustrates a time series of six multi-spectral images collected and analyzed by OI from 2007 to 2019. While eelgrass in the front bay appears to be relatively stable in the 2013 and 2017 maps, new patches of eelgrass appeared in the mid and back bay in 2017. These patches continued to grow into 2019, and additional larger patches have been forming in the mid bay and back bay. Although this represents a relatively small area of eelgrass when compared to prior years, growth is still occurring in areas where eelgrass has not been seen for several years. Some of the patches of eelgrass appear to be seasonal, with patches disappearing and new ones forming in areas from year to year. Other areas seem to be persistent and are expanding outward from year to year.

Restoration Efforts

The Estuary Program conducted an eelgrass restoration effort in 2019. Eelgrass rhizomes were collected from three donor beds: Coleman Beach (1,505 rhizomes), Tidelands (1,288 rhizomes), and North Sandspit (1,045 rhizomes). See Figure 7 for a map of locations. Harvesting was avoided at eelgrass mitigation beds and areas used for long-term monitoring . Eelgrass was collected on foot and by hand at when the intertidal area was exposed at low tides. Three rhizomes per square meter were collected, as designated in the scientific collection permit issued by the California Department of Fish and Wildlife (CDFW). Harvesting only occurred once in each bed to avoid negative impacts to donor beds.

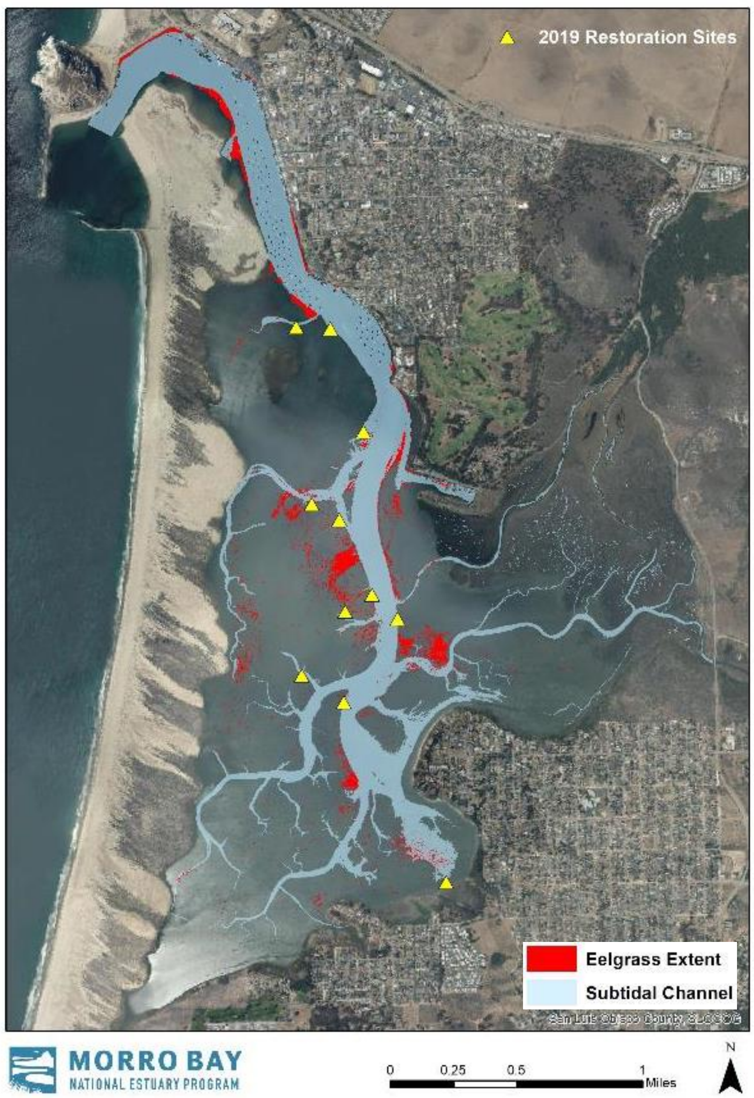


Figure 7. Map of 2019 eelgrass restoration locations, with eelgrass extent (2019 multispectral imaging) in red.

For the efforts on February 1 and 3, harvesting days had low tides at -0.5 feet. For the efforts on February 16, 18, and 19, low tides were between -1 and -1.5 feet. For the efforts from March 16 to 19, low tides were between -0.6 to -1 feet. Eelgrass was collected during the lowest daily tide during both months. A few collection dates had to be postponed or canceled due to lightning or high winds. Post-density counts of the donor beds were higher than pre-density counts, likely due to eelgrass being harvested during the spring growing season. Densities in the donor beds ranged from 163 to 364 shoots per square meter prior to harvesting. Collection of three rhizomes per square meter at these densities equated to harvesting between 0.8% and 1.8% of the bed, which was well below the 10% allowed in the permit.

Collected eelgrass did not undergo any processing such as removal of epiphytes. Longer rhizomes (greater than 10 cm) were left intact. All plants were counted and placed in large plastic transport containers with small ice packs and estuarine water. A small portion of the eelgrass collected did not meet planting specifications (e.g., rhizomes less than 7 cm in length and rhizomes with less than four nodes) and were replanted at the donor site rather than inside a plot (332 total rhizomes). Care was taken to keep the plants in fresh, cool estuarine water that was covered and shaded. All rhizomes were mixed between collection buckets at one donor location to maximize diversity among the transplant plots. Harvested eelgrass was not mixed between donor beds. Harvested eelgrass was placed in dive bags and held overnight off a floating dock in the fore bay about halfway between Coleman Beach and Tidelands.

Eelgrass was transplanted at three fore bay, seven mid bay, and one back bay location within Morro Bay. The fore bay plot location (site T1) extended immediately north from the planting site that was completed there in 2017 and 2018 and now has four additional plots. At the mid bay sites T10 and T11, six plots were planted with three plots being anchored with garden stakes and three plots which were not anchored. At the mid bay site T13, nine total plots were planted with three plots each at three different depths. The three shallower plots were planted at approximately 0.4 feet elevation, the middle plots were planted at approximately –0.1 feet, and the deepest plots were at approximately –0.5 feet. The T13 site appeared to be erosional, and elevation depths were approximate for this site based on 2010 bathymetric data. T7 was accessed and planted on foot, and T9, T12, and T14 were placed via snorkeling at low tides (approximately 2 to 4 ft of water at site when planted). No plots were planted at these four sites. For all other locations (T8, T15, T16), three plots and three rebar pieces were planted, all at similar depths within the site. For the 34 plots and 21 rebar pieces planted in spring 2019, the total rhizomes transplanted totaled 2,973. Some individual rhizomes had more than one shoot present and were counted before planting for future monitoring.

The 2019 eelgrass transplant locations were as follows:

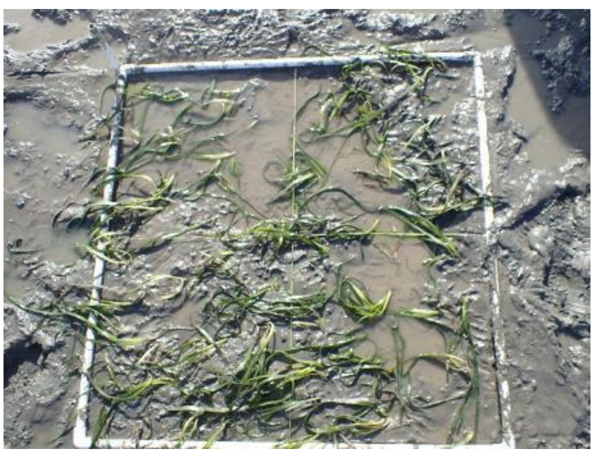
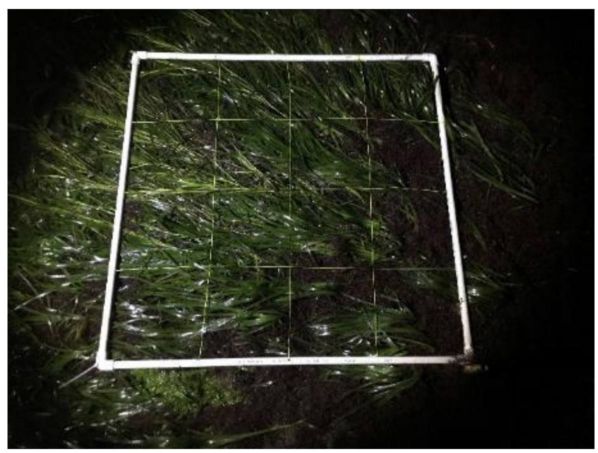
- Fore bay T1: 35.35471, -120.84982
- Fore bay T7: 35.35486, -120.85220
- Fore bay T8: 35.34876, -120.84764
- Mid bay T9: 35.34468, -120.85136
- Mid bay T10: 35.34373, -120.84945
- Mid bay T11: 35.3395402, -120.8472410
- Mid bay T12: 35.33848, -120.84918
- Mid bay T13: 35.33800, -120.84552
- Mid bay T14: 35.33483, -120.85234
- Mid bay T15: 35.3330, -120.84941
- Back bay T16: 35.32276, -120.84249

To transplant anchored eelgrass within plots, two eelgrass rhizomes were crisscrossed to form a “bundle” and secured in the sediment with a u-shaped garden stake, similar to the 2017 and 2018 Estuary Program transplanting efforts. A sub-set of restoration plots had eelgrass crisscrossed in bundles and covered in sediment without adding the garden stake. A putty scrapper was used to create a shallow slot for placing rhizomes horizontally just below the sediment. Bundles were spaced approximately 15 cm apart for a total of 36 bundles or 72 rhizomes in each one-meter plot. Small PVC poles (20 cm above substrate) were also placed immediately outside of the plot corners to aid in locating restoration sites for future monitoring. Plots were planted approximately four meters from each other.

Eelgrass was also planted using rebar pieces, similar to 2018 plantings. Rather than garden stakes, eelgrass was anchored with jute string to 3/16” smooth rebar pieces that were three feet long with one end bent to hold the rebar into the sediment. Twenty-five rhizomes were tied to each rebar piece. There were three rebar pieces at each of the three sites (T7, T8, T9, T12, T14, T15, T16), totaling 21 rebar pieces. The rebar plantings were placed at approximately the same depth as the plots when rebar pieces and plots were at the same site. Rebar plantings were spaced two meters apart from each other and marked with small PVC poles (20 cm above substrate) for future monitoring.

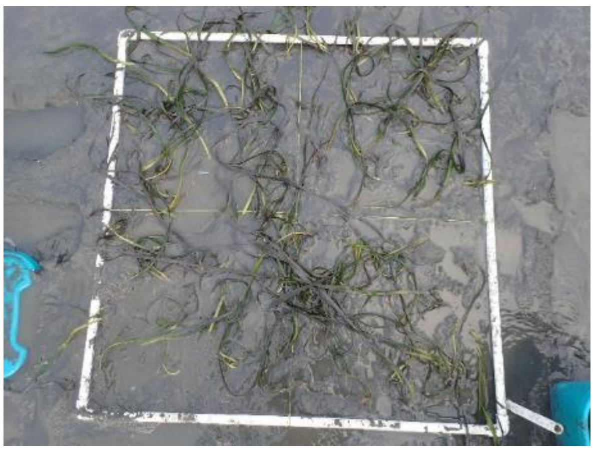
Spring 2019 Planting Photos

Monitoring of the plots and rebar plantings have shown an increase in both shoot density and expansion beyond the original one-meter plots. The fore bay and mid bay plots have increased substantially, while the single back bay site has not showed results of growth during the six-month monitoring period. The following photos illustrate growth and percent survival from each site.

Fore bay Plot (T1). Immediately after planting in spring 2019 (left). Six months of growth (right).


Mid bay Plot (T8). Immediately after planting in spring 2019 (left). Six months of growth (right).



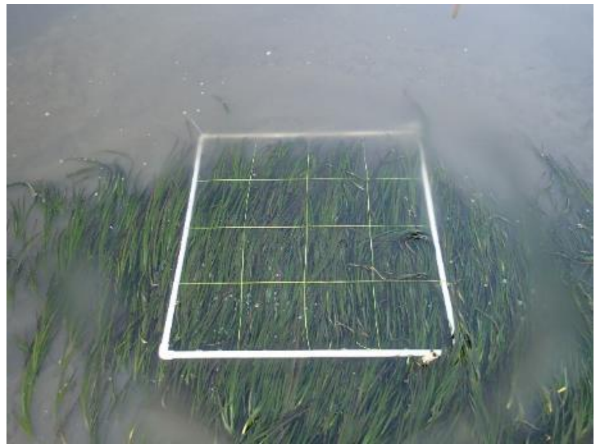

Mid bay Plot (T10). Immediately after planting in spring 2019 (left). Six months of growth (right).


Mid bay Plot (T11). Immediately after planting in spring 2019 (left). Six months of growth (right).

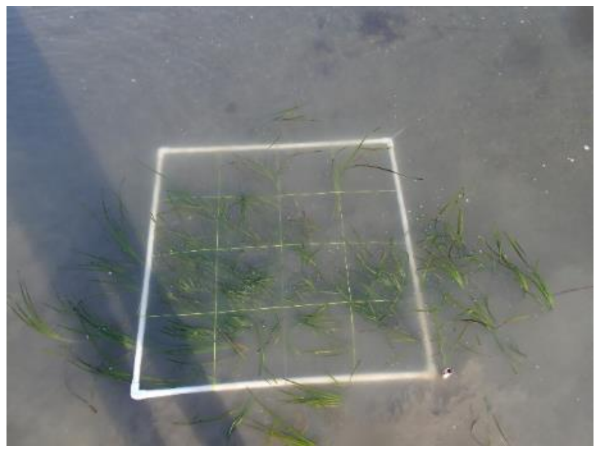
Mid bay Plot (T13). Immediately after planting in spring 2019 (left). Six months of growth (right).

Mid bay Plot (T15). Immediately after planting in spring 2019 (left). Six months of growth (right).

Back bay Plot (T16). Immediately after planting in spring 2019 (left). Six months of growth (right).

Mid bay Rebar Planting (T8). Immediately after planting in spring 2019 (left). Six months of growth (right).

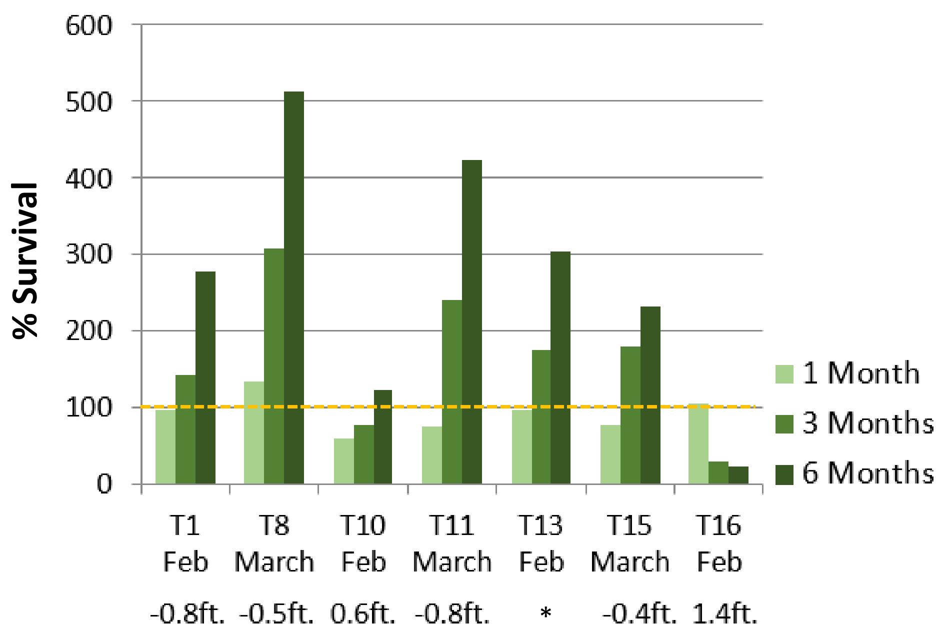
Mid bay Rebar Planting (T15). Immediately after planting in spring 2019 (left). Sixmonths of growth (right).

Mid bay Rebar Planting (T9). Planted with scuba. Six months of growth.

Mid bay Rebar Planting (T12). Planted with scuba. Six months of growth.

Spring 2019 Planting Results

Growth rates of restored eelgrass plots have varied on a by site but have generally shown steady growth. The following charts illustrate percent survival from each site, at one month, three months and six months after planting. On the horizontal axis, the first row is the site code and second row is the month the site was planted. The third row of the horizontal axis describes the depth at which the site was planted.



**T13 was planted at three varying depths: -2.0ft (deep), -1.4ft (mid), -0.2ft (shallow).*

Figure 8. Percent survival of 2019 plot plantings at seven locations.

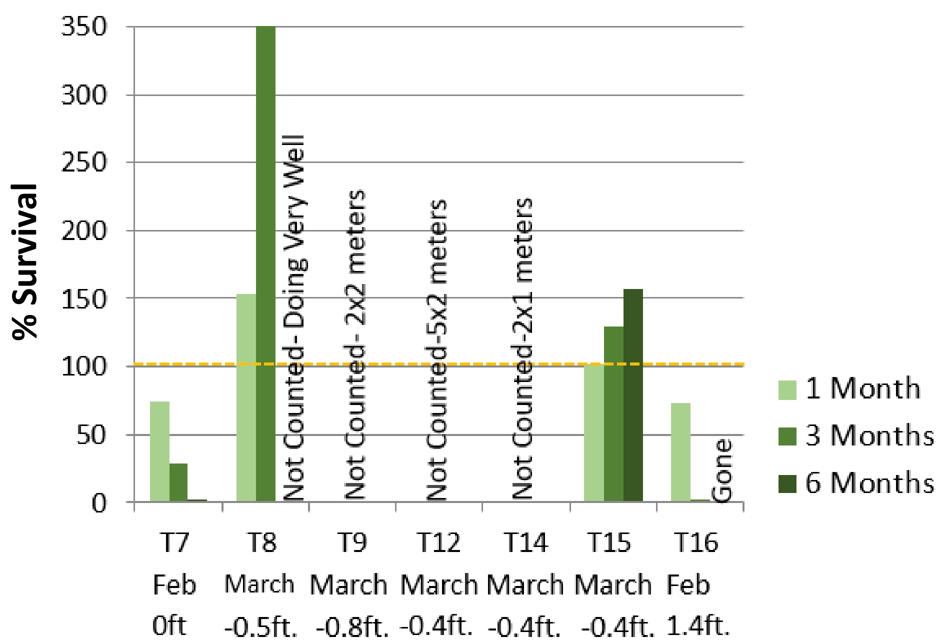


Figure 9: Percent survival of 2019 rebar plantings at seven locations. Sites T8, T9, T12, and T14 could not have detailed plant counts conducted due to the limitations of the appropriate tide windows. However, visual observations and estimates of bed expansion were made at six months post planting.

Two sites, T10 and T11, were experimental planting plots without anchoring (Figure 10). No major difference was found between plots with anchoring and those without. There was a difference in the percent survival of the two locations, possibly due to the different depths at the two sites.

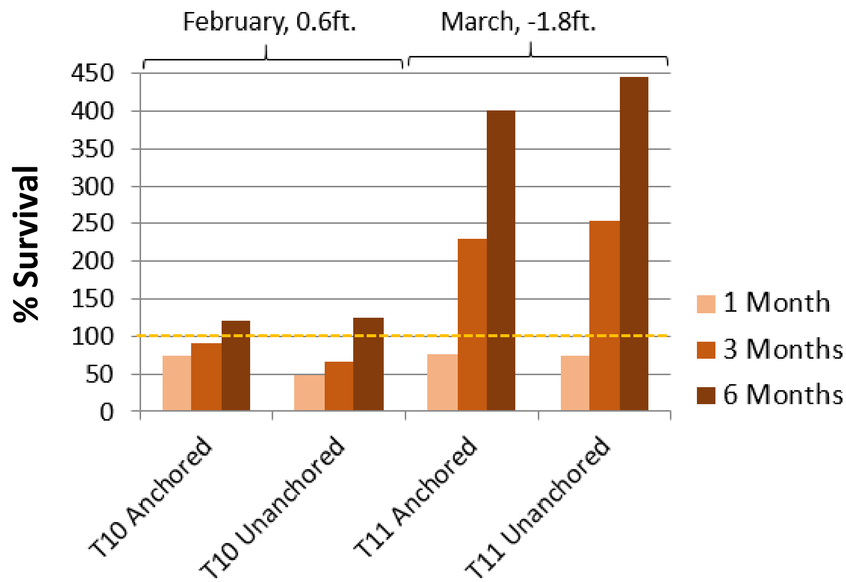


Figure 10: Percent survival of 2019 unanchored and anchored planting sites. Month planted and elevation of the site listed above chart.

Monitoring of restoration sites was also conducted approximately 12 months post-restoration to track presence and expansion. Of the remaining 2019 transplanted plots at T1, T8, T10, T11, T13, and T15 (31 total plots), on average plots had grown to seven square meters, from their original one square meter size. The transplanted rebar pieces at T8 and T15 (six total rebar pieces) grew even larger and expanded on average 15 times larger than their original size.

Other Monitoring Efforts

In addition to monitoring the restoration plots, there were several supplementary monitoring efforts to track eelgrass changes throughout the bay. The Estuary Program established permanent transects beginning in early 2005 to measure average shoot density at sites located throughout the bay. California Sea Grant and Cal Poly established bed condition monitoring beginning in late 2015 to measure average density and overall condition of remaining eelgrass. Cal Poly and California Sea Grant established permanent plots in 2018, and the Estuary Program continued to monitor these sites into 2019.

Permanent Transects

History

The Estuary Program established permanent transects to track changes in eelgrass shoot density throughout Morro Bay. There are currently six permanent transects, some having been established as far back as 2005. Four transects (Coleman, Reference, Chorro, and Pasadena) were monitored annually from 2006 to 2010 (Figure 11). No data were collected in 2011 due to staffing logistics. In November 2012, a fifth transect was established near the State Park Marina. Some sites were not surveyed due to poor weather or tide conditions from 2012 to 2016. In December 2017, a new transect was established on the eastern side of the channel at Tidelands Park, called

“Embarcadero”. The transect now called “Reference” was originally named “Tidelands,” but has since been changed to avoid confusion.

Figure 11. The six current permanent transect monitoring locations: Coleman, Embarcadero, Reference (previously named Tidelands), Marina, Chorro, and Pasadena.

Methods

Monitoring was conducted during extreme low tides (-0.4 feet and below) during the late fall, as this period provides the best tidal windows for accessing sites. At each site, a GPS unit was used to identify the transect location (most sites have no permanent markings), and a meter tape was set out along a 50-meter transect. A 0.5 meter x 0.5 meter quadrat was used to take measurements at points along the tape. Percent coverage of eelgrass, macroalgae (*Gracilaria* and *Ulva*), and bare substrate were measured. If eelgrass was present, shoots density counts were conducted.

While there are six permanent transect locations, some sites have more than one transect. If an eelgrass bed was fairly wide, additional transects were established that ran parallel to each other to measure eelgrass at various depths. Note that when analyzing the data, all data from a site in a particular year were combined to represent eelgrass at that general location.

Initially, the effort included an eelgrass biomass measurement. From 2005 to 2012, eelgrass samples were collected adjacent to each transect and dried and weighed for biomass measurements. However, as eelgrass declined, it became too damaging to collect samples, and the biomass study was halted.

Results

Average shoot densities for each site are summarized in Figure 12.

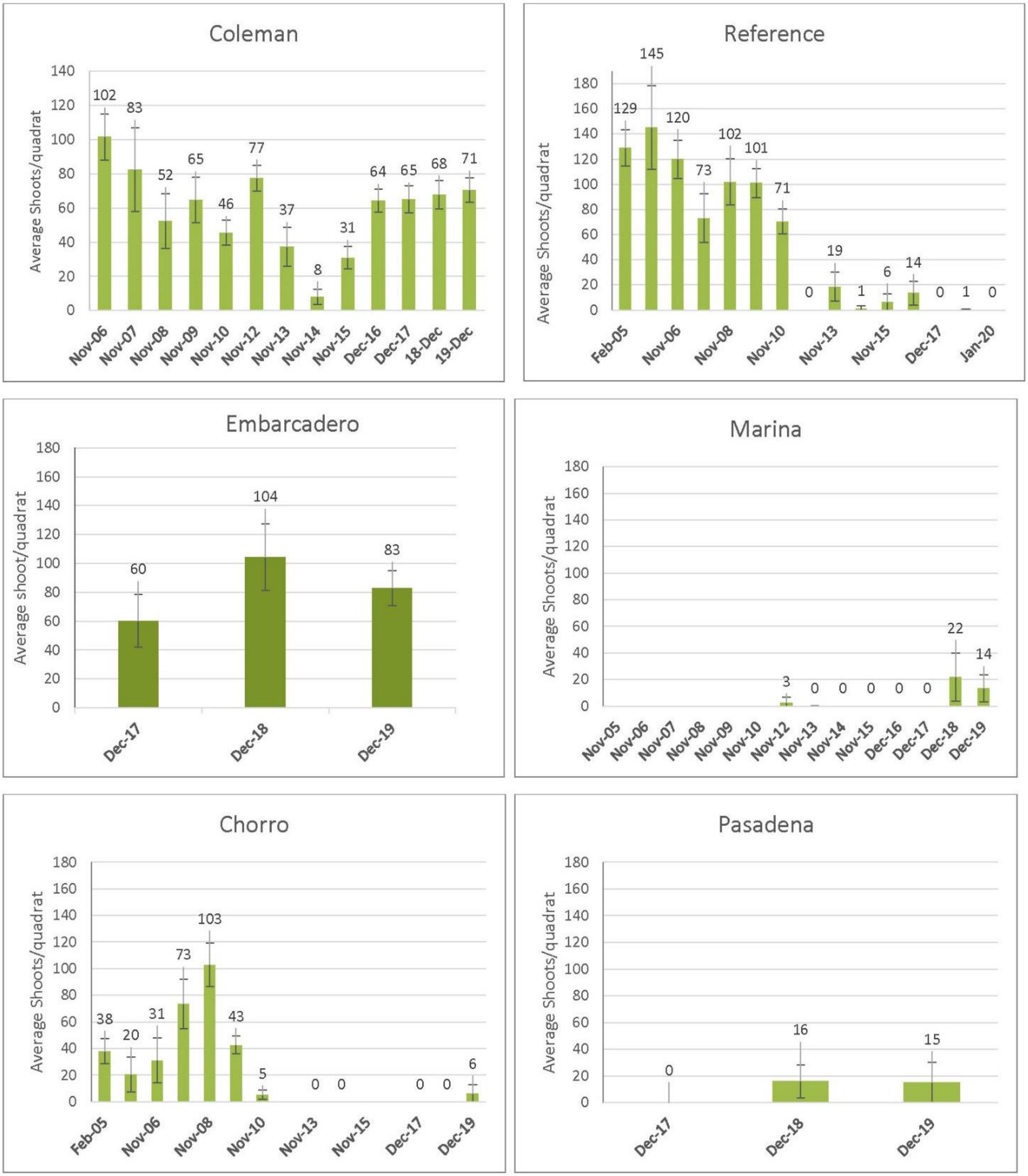


Figure 12. Average shoot density counts per year at six sites. Shoots were counted within a 0.5 m x 0.5 m quadrat. Error bars represent the 95% confidence interval.

Average shoot densities have clearly declined at each site, and Coleman Beach appears to be the only site where densities have recovered. Densities at Coleman have remained stable since 2016. While the new Embarcadero transect has no historic data for comparison, in 2017 it had an average of 60 ± 18 shoots per 0.5 m x 0.5 m quadrat, which is about the same density seen at Coleman the last three years. In 2019, the average density was 83 ± 12 shoots. While this is lower than it was in 2018, it was the densest of the sites in both 2018 and 2019.

Permanent Transect Photos and Observations

Photos were taken to document site conditions.

Coleman Transect

The shoot density counts have been very similar since 2017. In 2018 and 2019, eelgrass at the Coleman transect was less dense than at the Embarcadero site, but the density has remained stable. Photos for the Coleman Transect were not available for 2019.

Figure 13. Coleman Transect, 2013 to 2018.

Reference Transect

While there was no eelgrass on the transect at the Reference site (previously known as Tidelands), new small patches of eelgrass were developing within a three-meter distance from the transect. This eelgrass grew at higher elevation than other sites, forming small, patchy, eelgrass islands. Because of how water moves in this area, it may be difficult for dense, contiguous eelgrass beds to become established. This sandy substrate in the area is experiencing erosion, so areas without vegetation may continue to erode over time. The deeper transects at Reference have been too deep to monitor for the last four years. This site was last monitored on January 21, 2020 as a part of the 2019 monitoring effort, as tide conditions did not allow for all sites to be completed during calendar year 2019.

Figure 14. Reference Transect (previously “Tidelands”), 2013 to 2019.

Embarcadero Transect

This site was established in 2017 after an eelgrass bed became reestablished. This bed is on the eastern side of the channel at Tidelands Park, at the south end of the dock. Since 2017, the eelgrass bed has been mostly continuous with a high shoot density and low epiphytes. In 2019, eelgrass appeared healthy and dense, without many epiphytes. In 2018 and 2019, Embarcadero had the highest density of all sites. This site has been a harvest site for restoration efforts for two years, but this does not appear to have impacted the health or density of the bed.

Figure 15. Embarcadero Transect, 2017 to 2019.

Marina Transect

Patchy eelgrass has been present in the area in 2016, 2018, and 2019 but not always directly on the transect. In 2019, patchy eelgrass was present along all three transects, as well as in the surrounding area.

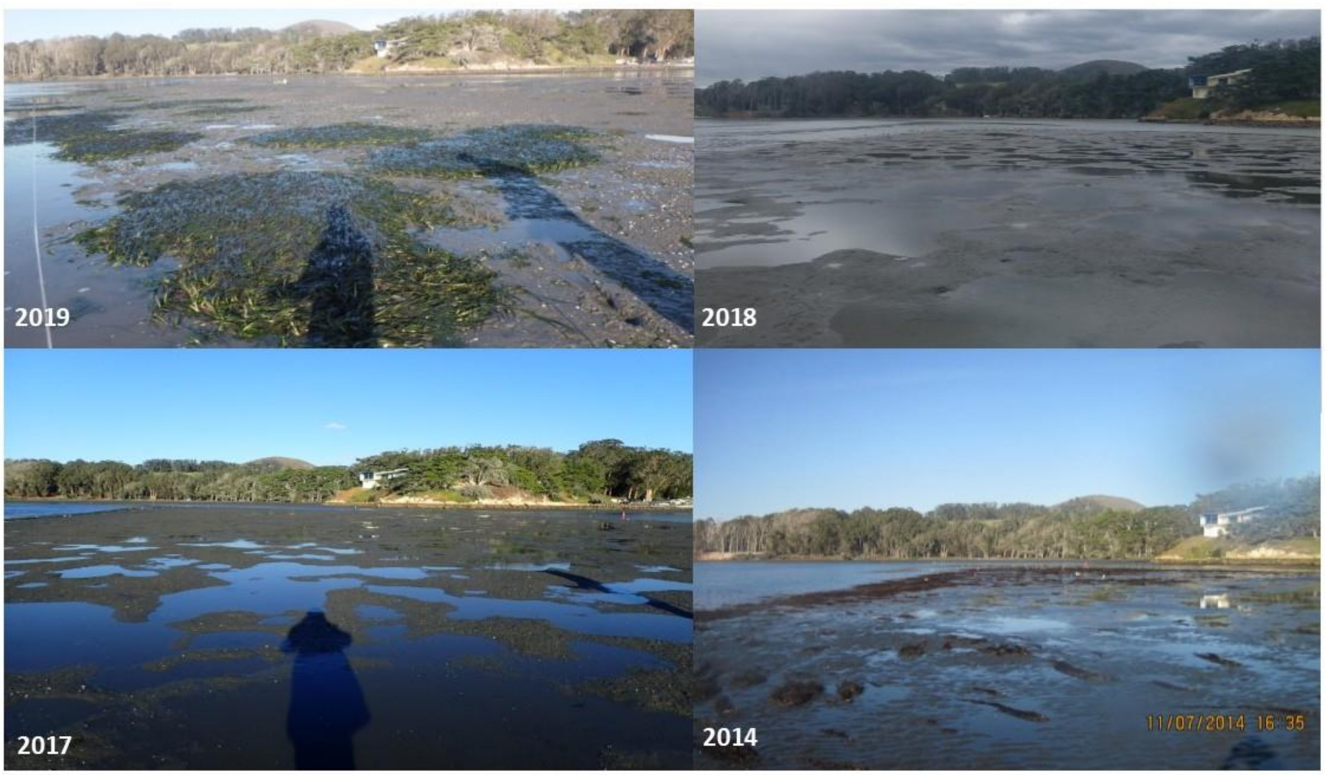


Figure 16. Marina Transect, 2014 to 2019.

Chorro Transect

The area was surveyed in 2014, and there was no eelgrass present. It was not surveyed in 2015 nor 2016. In 2017, no eelgrass was found on the transect, but two small patches were found in the area. In 2018, no eelgrass was found. In 2019, there was one patch of eelgrass along the transect.

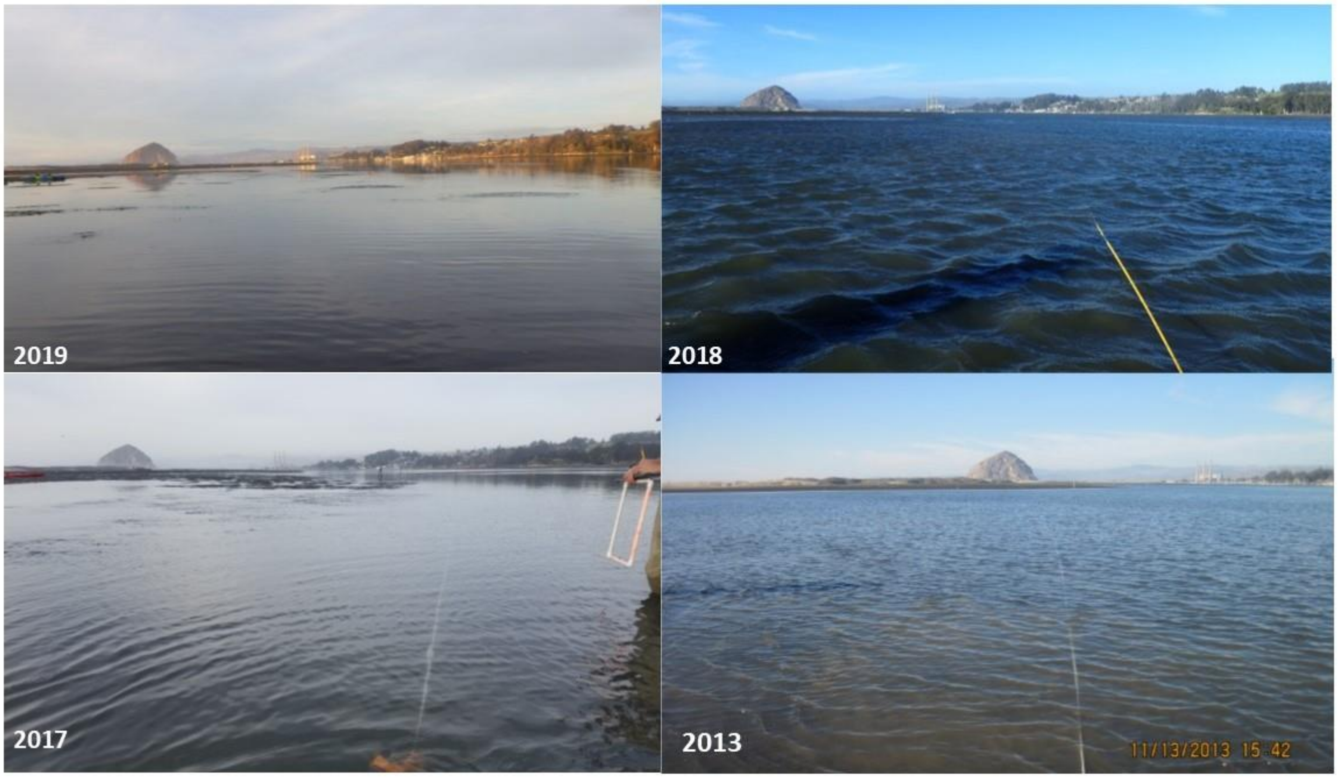


Figure 17. Chorro Transect, 2013 to 2019.

Pasadena Transect

There was some confusion over the location of the transects as the area was not surveyed in 2015 or 2016, and there is only one PVC marker at the site. In 2017, one transect was monitored based on the markers in the field, and two were identified using maps from 2014. The same three transects were monitored again in 2018, but due to the lack of permanent markers and difficulty locating the transect, data from one transect was omitted. There was no eelgrass on the two included transects. In 2019, two transects were eliminated as monitoring locations because eelgrass was planted along the transect as part of the 2019 restoration efforts. Because of the confusion around the location of the transects and the elimination of some transects, data prior to 2017 is no longer included in the graphs.

Figure 18. Pasadena Transect, 2014 to 2019.

Permanent transects were established to track eelgrass density, however the overall decline has prevented this from being the optimal method of monitoring eelgrass. There are often instances of eelgrass near the site (even within just a few meters), but because it was not on the transect, it was not captured in the data collection. Additionally, most transects are not permanently marked, making it challenging to return to the exact spot each year. Therefore, a different method was needed to more fully capture the health of existing eelgrass. The Estuary Program collaborated with Cal Poly and Sea Grant to develop an additional monitoring protocol called Bed Condition Monitoring. Permanent transect monitoring will continue as it is the longest running eelgrass data set for the bay and helps document pre and post-decline conditions.

Bed Condition Monitoring

Bed condition monitoring was established as a joint effort between Dr. Jennifer O'Leary of California Sea Grant and the Estuary Program in late 2015. This method measures eelgrass conditions in terms of density, blade length, evidence of necrotic tissue, and competition with algae and other organisms. Monitoring occurs at five significant beds in Morro Bay along a 150-meter, seven-quadrat survey. Both intertidal and subtidal eelgrass are surveyed, as much of the intertidal eelgrass was lost in the decline. Monitoring has occurred twice per year since 2015, once in late fall and again in the spring. Due to the lack of adequately low tides during daylight hours during the fall, the decision was made to halt the fall monitoring and only conduct the monitoring in the spring. In 2018, Cal Poly conducted the spring monitoring and there was no fall effort. The Estuary Program plans to continue this monitoring each spring, with analysis to be conducted by Cal Poly.

The Estuary Program conducted spring 2019 monitoring at Coleman Beach, Reference Bed, and Windy Cove sites. The North Sandspit was monitored from 2015 to 2017 but was not monitored in 2019 due to lack of adequate low tides. The data analysis is underway.

Figure 19. Bed condition monitoring at Coleman Beach, North Sandspit, Reference Bed, and Windy Cove. Eelgrass extent data is from the Ocean Imaging classification created with imagery acquired in November 2019.

Permanent Plots

In addition to bed condition monitoring, Dr. O'Leary developed a two-year permanent plot study to assess seasonal trends in eelgrass. The sites were established in 2018 throughout the front, mid, and back bay and are identified as Mitchell, Oyster Bed, Windy Point, Reference, and Coleman Beach. These plots were monitored every three months to track seasonal changes in eelgrass condition. Dr. O'Leary has generally found density to be declining at all five of these sites. Additionally, she has found that eelgrass stipe density may not be the best predictor of condition. Initial data indicates that other parameters including blade length, blade condition, blades per stipe, epiphyte cover, and presence of necrotic tissue are better predictors.

Additional Activity

Dredging Operations

The Morro Bay harbor is a designated Harbor of Safe Refuge and is the only safe harbor between Santa Barbara and Monterey. Maintenance of this important harbor requires frequent dredging operations. The harbor mouth is dredged annually by the ACOE to maintain a channel depth of approximately 40 feet.

ACOE began their annual dredging in Morro Bay on May 28, 2019 and completed the project on June 16, 2019. Pre and post-dredge surveys were conducted to identify and evaluate potential impacts correlated with the project. These surveys were conducted within the area of potential effect (APE) and over the entire federal channel area and surrounding waters. Both pre and post-project bathymetry surveys found no eelgrass within or in proximity to the 2019 preliminary APE dredge footprint. The nearest eelgrass to the APE was located approximately 90 m (295 ft) from the northernmost portion of the main channel.

A post-dredge eelgrass survey was conducted from June 17 to June 19, 2019. This survey consisted of eelgrass areal coverage and eelgrass density investigations within the project footprint and surrounding areas. Within the surveyed area, eelgrass decreased by 0.8%, while eelgrass within the bounded reference sites at the Coleman Beach Reference and the ACOE Transplant Site Reference declined by 7.7% and 12%, respectively. Given the distribution of loss, these declines are not expected to be a product of the project itself but rather related to condition of the upper bed margin (M&A 2019).

Embarcadero Projects

Eelgrass grows intermittently along the Morro Bay Embarcadero, and impacts to eelgrass must be considered before any construction may occur. Surveys to monitor eelgrass changes have typically been completed by Tenera Environmental using SCUBA divers and/or sonar before, during, and after construction projects. In 2019, surveys were conducted to support two construction projects on the Embarcadero. The conclusions of the pre-construction surveys were as follows:

- A survey for a proposed over-water public walkway which would replace the existing 75 feet long walkway and extend it 22 feet to the north and 10 feet to the south. This survey did not find any significant effects to eelgrass and identified the surrounding habitat as rocky and unsuitable for eelgrass development.
- A survey for a project to replace a single cracked pile foundation. The survey found no eelgrass in the footprint of the project area, largely due to the unsuitable rocky habitat.

Partnerships

The Estuary Program is continuing their partnership with Cal Poly to support eelgrass research efforts. The effort also involves CDFW, NOAA, Pacific Marine and Estuarine Fish Habitat Partnership, and U.S. Fish and Wildlife Service (USFWS) partners. These partnerships promote sharing of data and expert opinions to help guide eelgrass activity.

Research Efforts

Various research efforts are underway related to Morro Bay eelgrass.

Topo Bathymetrtric LiDAR Survey

A topobathymetric digital elevation model (DEM) of Morro Bay was completed in 2019, in partnership with NOAA's Office for Coastal Management. The survey combined swath acoustic bathymetry and Light Detection and Ranging (LiDAR) data to create a comprehensive topographic-bathymetric map. The effort serves multiple purposes: 1) Provides further understanding of the circulation and hydrodynamics of Morro Bay, 2) Provides elevation data which supports eelgrass restoration efforts, and 3) Provides data for a tidal prism calculation for comparison to historical data. For more information on the 2019 topobathymetric survey, refer to the Estuary Program's 2019 Sediment Report, available at www.mbnep.org/library, under Data and Technical Reports.

Water Quality Monitoring

Dr. Ryan Walter from Cal Poly's Physics Department continues to maintain a water quality sensor array instrument package at the mouth of the bay and in the back bay. Funding for these instruments are provided by the Central and Northern California Ocean Observing System (CeNCOOS). A real-time data stream is available here: https://www.cencoos.org/data/shore/morro. Additionally, Dr. Walter maintains temperature sensors at the mouth of the bay and back of the bay. This work is funded by CeNCOOS.

Dr. Walter, in collaboration with Dr. Emily Bockmon of Cal Poly's Chemistry Department, conducted two cruises in early 2019 to look at water mass properties throughout the bay. A conductivity-temperature-depth (CTD) sensor measured water mass proportions at ten different stations throughout the bay at different points in the tidal cycle. Seawater samples were preserved and went to the laboratory for analysis of dissolved inorganic carbon, pH, and total alkalinity. Water samples indicated high carbon and high alkalinity waters in the back bay. This was similar to the results of work in summer 2018 but with much more extreme values. These high values were thought to be the product of increased contributions from creeks and runoff associated with winter rains and may indicate that the bay is less well buffered in the winter than other times of year, potentially making it more susceptible to future acidification.

Dr. Bockmon also oversaw the deployment of two autonomous pH sensors, placed at the bay mouth T-Pier and back bay stations. These pH sensors collected data every five minutes from January 10, 2019 through February 15, 2019. The average pH at the T-Pier was found to be slightly higher than at the back bay location, and values were lowered substantially following a major freshwater discharge. This data is available on the CeNCOOS website.

In addition, Dr. Bockmon and her students completed carbonate chemistry sampling at six shoreline locations throughout the bay. Sampling was conducted on ten different occasions between January and December 2019. Many of these samples are still awaiting analysis due to the lab shutdown in response to COVID-19.

Sediment Substrate Mapping

The Estuary Program also partnered with Dr. Ryan Walter to study hydrodynamics and sediment in Morro Bay during 2019. A portion of the project focused on sampling sediment from the bottom of the bay to determine differences in different regions of the bay. Results found nearly 100% of sediment at the mouth of the bay to be sand and gravel (Figure 20A). This composition is likely due to tidal flushing and wave action, which sweep away finer silt and clays. In comparison, sediment in the mid to back bay was composed of only about 30% to 60% sand and gravel, with the remaining sediment made up of finer silts and clays (Figures 20B, 20C).

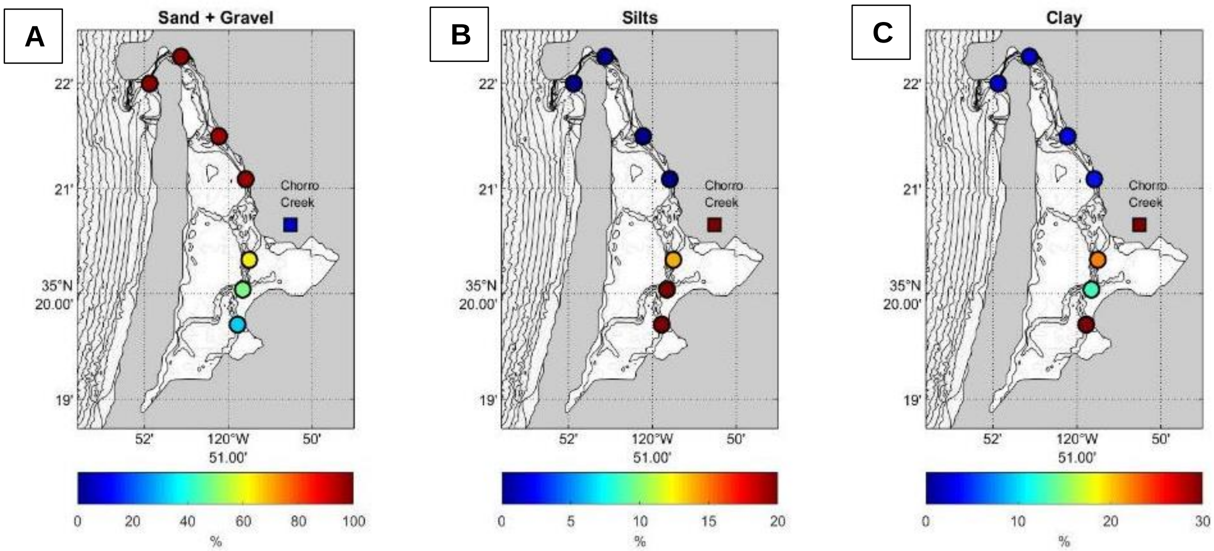


Figure 20. Sediment composition in Morro Bay (Walter, 2019). Higher concentrations of sand and gravel where found at the bay mouth, while higher concentrations of silts and clay were found in the back bay.

Summer 2019 Eelgrass Wasting Disease Research

Eelgrass blade sampling was completed in Morro Bay in June 2019 by Cuesta College students under the guidance of Cuesta College professors Dr. Laurie McConnico and Dr. Silvio Favoreto, as well as Estuary Program staff. Individual blades were collected to examine for the presence of *Labyrinthula spp.* on eelgrass at four sites within the estuary.

A total of 60 blades were collected from the outside of plants by hand picking blades at the base of their attachment points. Twenty blades were collected from each of the three sampling sites and included ten healthy blades and ten necrotic blades. Sampling locations included Coleman Beach, Windy Cove, and the back bay near the Doris Avenue public access trail in Los Osos. Individual blades were processed for culture of *Labyrinthula spp*. and future DNA extraction and qPCR. Blades were also used to quantify necrotic tissue and a metric called Excess Green Index using high-resolution digital images taken in the laboratory. Preliminary data analysis indicates that *Labyrinthula spp.* is found at all sample locations within the estuary in both green and necrotic eelgrass tissue (Cuesta College, 2019).

Black Brant Population and Behavior Changes

The black brant (*Branta bernicla nigricans*) is a small goose that feeds primarily on eelgrass. Morro Bay is an important stop on its annual migration between summer nesting sites in Alaska and wintering sites in Baja California. Although shifts in climate are thought to be altering migratory behavior, the brant populations are likely impacted by the eelgrass decline.

John Roser, a local biologist, has been counting brant in Morro Bay for the past 20 years and estimates brant numbers by using a seasonal use-day estimate. This is calculated by counting brant one day during the middle of each month that brant occupy Morro Bay (typically November to April), using those counts to estimate the number of brant in Morro Bay each day, and then totaling the numbers per day to achieve a seasonal use-day estimate. Figure 21 illustrates brant numbers in Morro Bay over the past 20 years (Roser, 2020).

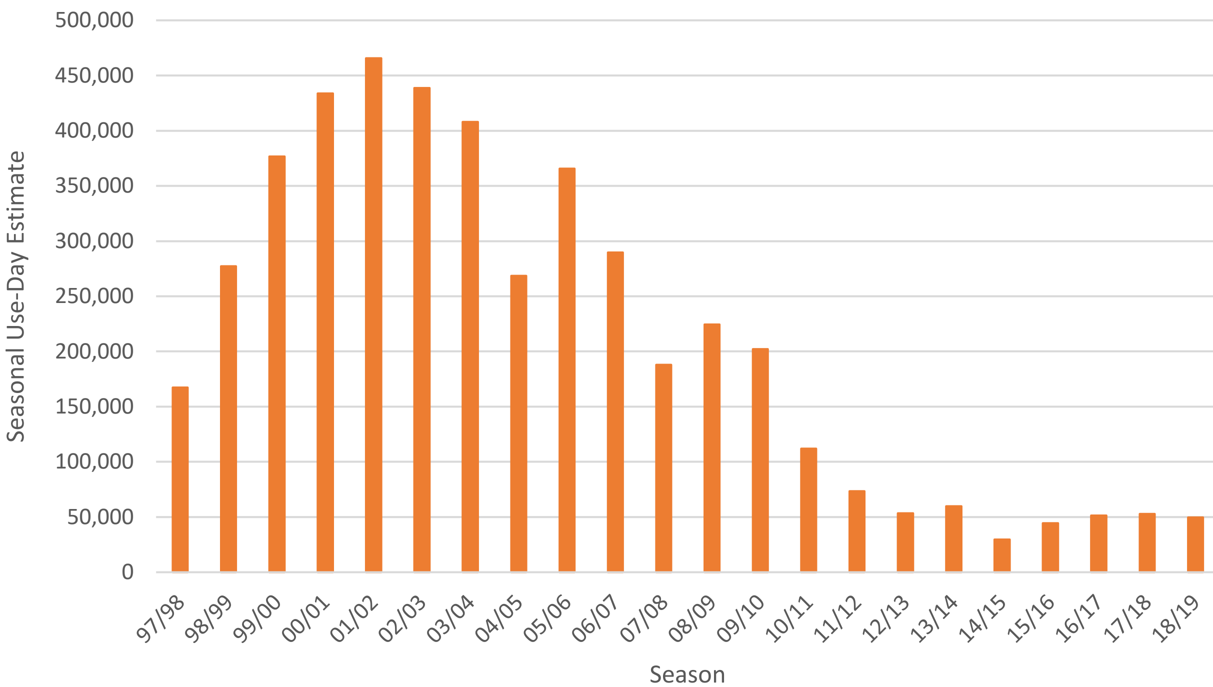


Figure 21. Brant seasonal use-day estimates in Morro Bay from 1997 to 2019 (data adapted from Roser 2020).

Several Cal Poly students have also studied brant foraging behavior over the past few years. In 2018, Cal Poly graduate student Dakota Osborne began studying the impacts of brant grazing on eelgrass. He installed eelgrass enclosure cages, which are fairly open cages which the brant will not enter, thus preventing them from feeding on eelgrass. He has installed these cages in eelgrass beds and has been recording measurements to determine brant grazing effects in caged area as compared to uncaged areas. Results from this research are expected in 2021.

Upcoming Projects

Tidal Prism Analysis

Data from the 2019 topobathymetric survey will be used for tidal prism calculations. The anlaysis will be compared to historic tidal prism volumes to assess bay circulation and hydrodynamics. The analysis is expected to be available in 2021.

Drone Mapping

The Estuary Program plans to partner with Cal Poly for a bay-wide UAV drone survey and mapping effort during Fall 2020. This work involves the drone flight, as well as the manual quantification of eelgrass coverage in GIS.

Restoration and Monitoring

Restoration and survival monitoring will be conducted in 2020, as well as permanent transect and bed condition monitoring. Results from restoration and monitoring will be available in the Estuary Program's 2020 Eelgrass Report.

Additional Research Activity

Research efforts by Cal Poly, Cuesta College, and others will continue to collect data to further our understanding of suitable conditions for eelgrass in the bay. Sediment loading and transport are thought to play a central role in eelgrass health, and proposals to further study this technical area have been created.

Conclusions

Eelgrass (*Zostera marina*) plays a vital role in the health of the Morro Bay ecosystem. While the Morro Bay eelgrass population has fluctuated in the past, the last decade has seen a drastic loss. One encouraging sign is the presence of eelgrass in the mid and back bay beginning in fall 2016, in areas where eelgrass has not been seen for several years. Anecdotally, it appears a portion of this eelgrass is ephemeral, coming and going with the seasons rather than forming permanent beds. This new growth was documented in fieldwork in late 2016 as well as in the mapping efforts of 2017 and 2019. Observations in 2018 and 2019 support the conclusion that some of these small eelgrass patches are ephemeral, as their locations shift from year to year. Other patches seem to be perennial and have been growing and expanding in 2019, including the 2018 and 2019 transplant plots. Further seasonal monitoring over a larger scale is needed to better understand the portion of eelgrass patches that are ephemeral versus present year-round.

In 2020, more projects will continue to investigate the many facets of eelgrass. The Estuary Program and its many partners will continue to strive toward understanding conditions in the bay that impact eelgrass survival and identifying actions to support a sustainable eelgrass population in Morro Bay.

References

Aiello, Erin. Spatial and Temporal Differences in Restoration Success of Eelgrass (Zostera Marina L.) in Morro Bay, California. Thesis presented to California Polytechnic State University, San Luis Obispo faculty. August 2018.

Bernstein B, Merkel K, Chesney B, Sutula M. 2011. Recommendations for a Southern California Regional Eelgrass Monitoring Program. Technical Report 639. Prepared for the National Marine Fisheries Service. Southern California Coastal Water Research Project. Costa Mesa, CA

Chesnut J. 1999. Eelgrass Habitat in Morro Bay. Morro Bay National Estuary Program.

Cuesta College. Nov 2019. Role of *Labyrinthula spp.* in the development of eelgrass wasting disease in the Morro Bay Estuary. Final Community Project Report, Project Number 7219RF. Prepared for the Morro Bay National Estuary Program.

Harenčár J.G., G. Lutgen, Z. Taylor, N. Saarman, J.M. Yost. 2017. How population decline can impact population genetics: A case study of eelgrass (*Zostera marina*) in Morro Bay. Estuaries and Coasts. Accepted with revision.

Harwell MC, Orth RJ. May 1999. Eelgrass (*Zostera marina* L.) seed protection for field experiments and implications for large-scale restoration. Aquatic Botany. 64(1): 51-61.

Hauxwell J, Cebrian J, Valiela I. 2003. Eelgrass (*Zostera marina)* loss in temperate estuaries: relationship to land-derived nitrogen loads and effect of light limitation imposed by algae. Marine Ecology Progress Series 247, 59-73.

Heim R. June 2016. Habitat use and time-activity budgets of black brant (*Branta bernicla nigricans*) during a season of reduced eelgrass coverage in Morro Bay, California. Biological Sciences Department, Cal Poly San Luis Obispo. *In preparation.*

Kitajima A. Jan 2016. Morro Bay National Estuary Program's Data Summary Report 2015. Morro Bay National Estuary Program.

Merkel & Associates. Sept 2014. Re: Morro Bay Eelgrass Recovery Program 2014 Eelgrass Transplant Report. Prepared for the Morro Bay National Estuary Program. M&A #12-090-05

Merkel & Associates. Sept 2015. 2015 Monitoring Report, Morro Bay Eelgrass Recovery Program. Prepared for the Morro Bay National Estuary Program.

Merkel & Associates, 2019. Final Post-Dredge Eelgrass Survey Report in Support of the Morro Bay 2019 Maintenance Dredging Project. M&A #17-022-02.

Morro Bay National Estuary Program. July 2017. Morro Bay Eelgrass Report 2014-2016.

Morro Bay National Estuary Program. April 2019. Morro Bay Eelgrass Report 2018.

Nordlund LM, Koch EW, Barbier EB, Creed JC. 2017. Seagrass ecosystem services and their variability across genera and geographical regions. PLOS ONE 12(1): e0169942. https://doi.org/10.1371/journal.pone.0169942

Ocean Imaging. November 2020. 2019 Morro Bay Submerged Aquatic Vegetation (SAV) Mapping in Morro Bay Utilizing Multispectral Imagery - Final Report (Revision 4). Prepared for the Morro Bay National Estuary Program.

Pei-Dong Z, Chao F, Jie Liu, Qiang X, Wen-Tao L, Yan-Shan L. June 2015. An effective seed protection method for planting *Zostera marina* (eelgrass) seeds: Implications for their large-scale restoration. Marine Pollution Bulletin. 95(1): 89-99.

Pickerell CH, Schott S, Wyllie-Echeverria S. Aug 2005. Buoy-deployed seeding: Demonstration of a new eelgrass (*Zostera marina* L.) planting method. Ecological Engineering. 25(2): 127-136.

Ralph PJ, Durako MJ, Enriquez S, Collier CJ, Doblin MA. 2007. Impact of light limitation on seagrasses. Journal of Experimental Marine Biology and Ecology 350, 176-193.

Roser J. April 2019. Brant Counts for Morro Bay, California, 2018 - 2019 Season. *Unpublished.*

Tenera Environmental. January 2019. Eelgrass Pre-Construction Planning Survey, Document ESLO2019-01.

Tenera Environmental. February 2019. Eelgrass Pre-Construction Planning Survey, Document ESLO2019-03.

Walter, R.K., 2019. *Hydrodynamics, water quality, sediment, and drone mapping in Morro Bay, CA.* Sea Grant Partner Meeting: Understanding the Past and Predicting the Future in a California Estuary. San Luis Obispo, CA. December 6, 2019.