Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2017

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, sediment accretion and stabilization, and water purification (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 reason for the decline is attributed to many natural and anthropogenic factors in coastal ecosystems. Natural impacts may come from natural 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 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 supported the third largest eelgrass dominated ecosystem in the southern California region (Bernstein et al. 2011). However, eelgrass in Morro Bay has declined by more than 90% since 2007. This decline has spurred many restoration, monitoring, and research efforts.

This report summarizes all eelgrass-related activity in 2017. This includes baywide mapping events in the spring and fall, small-scale experimental restoration efforts, and detailed monitoring of restoration 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. 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.

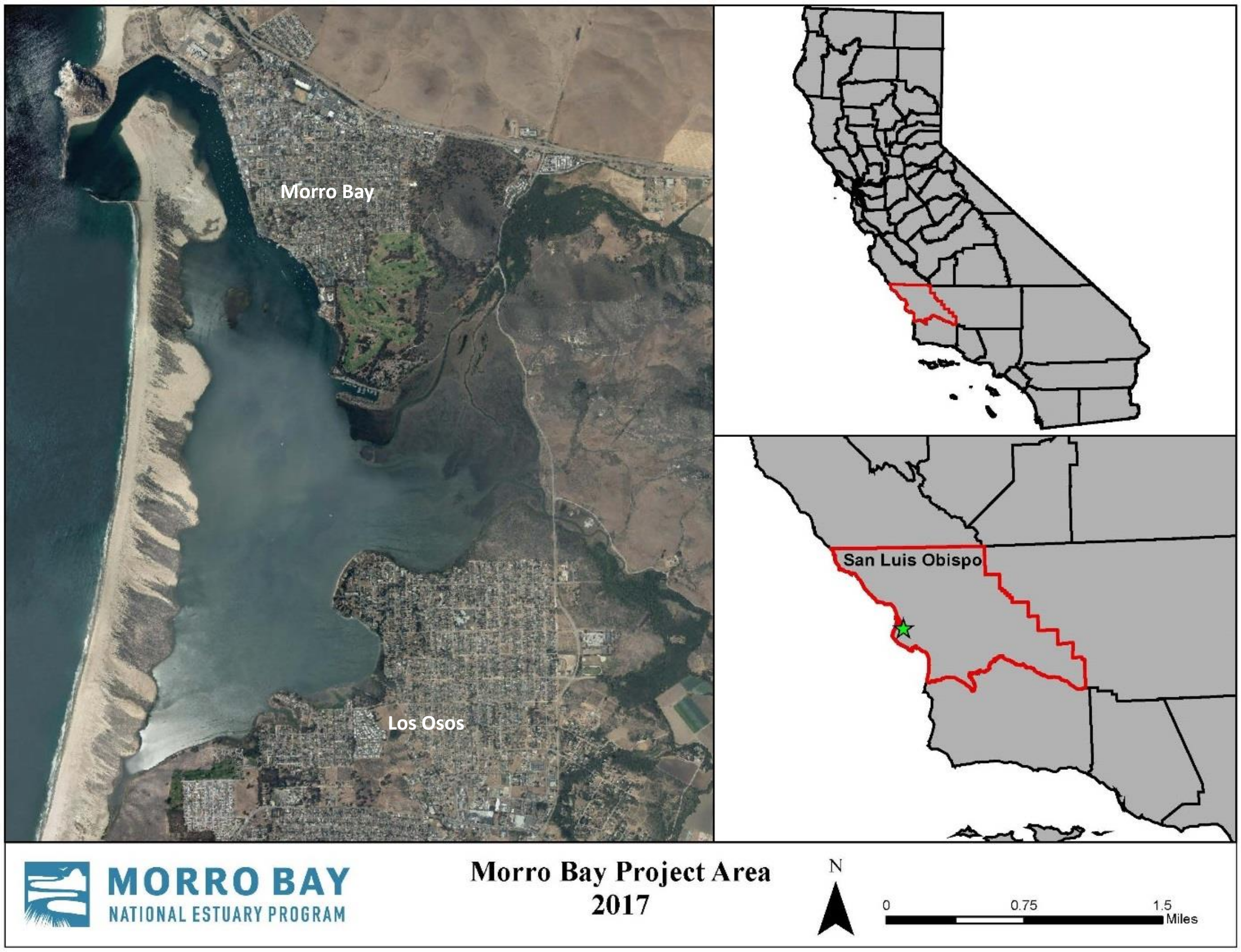


Figure 1. Morro Bay.

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 is an important port for commercial fishing 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 dredge events (see "Dredging Operations").

Eelgrass Distribution

Mapping Efforts

Morro Bay's eelgrass population has been mapped for decades, but it 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 done 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.

Two baywide mapping efforts were completed in 2017.

Spring 2017 Mapping

In April, M&A completed an eelgrass survey of the bay. Contracted by the Estuary Program, they used a combination of sidescan sonar data and unmanned aerial vehicle (UAV) imagery to map both intertidal and subtidal eelgrass and habitat. These data were important for comparison to the spring 2013 mapping effort, for documenting new patches of eelgrass observed in the midbay and backbay, and for helping to understand the impact of the previous rainy winter. See Figure 2 for the April 2017 baywide intertidal and subtidal eelgrass map.

Vessel-mounted interferometric sidescan sonar (ISS) was primarily conducted during high tides to capture mostly subtidal eelgrass and bathymetry data. For the sonar portion of the survey, the total propagated error with the system is approximately 0.5 to 1 m horizontal and 0.2 m in the survey water depths. Low altitude UAV color aerial imagery was collected at extreme low tides to capture mostly intertidal eelgrass. The combined area covered by ISS (662 acres) and UAV (1,591 acres) surveys totaled approximately 1,974 acres, which represents the portion of the bay that is considered suitable to support eelgrass and covers approximately 86% of the 2,300-acre bay. Groundtruthing was completed using a combination of underwater drop cameras, SCUBA diver inspections, low-tide observations, and extremely low-altitude UAV imagery.

M&A conducted an accuracy assessment as part of their analysis. They utilized 200 sample points divided nearly evenly among mapping methodologies and strata. The data included 101 eelgrass locations and 99 non-eelgrass locations. The assessment showed an overall accuracy of 99%, with a producer's accuracy of 99% for eelgrass and 99% for other, while the user's accuracy was 99% for eelgrass and 99% for other.

Winter 2017 Mapping

In December, Ocean Imaging (OI), contracted by the Estuary Program, mapped the bay by collecting multispectral aerial images. The flight occurred on December 3 between 14:25 and 14:40 PST, at tidal levels between -0.67 and -0.76 ft. The multispectral images were compiled into a comprehensive mosaic and then processed to classify substrate and vegetation types. While the classes mostly represented exposed substrate/vegetation, submerged substrate and vegetation were identifiable through the water in the multispectral imagery. However, because no field verification at the exact time of the flight was completed, it is unclear to what depth the imagery was able to identify. Figure 2 contains the baywide intertidal eelgrass map from December 2017, as compared with the April 2017 map which represents subtidal and intertidal eelgrass. Note that patchy eelgrass was present in the backbay in both mapping efforts but is difficult to illustrate in detail due to their size. The substrate and vegetation classification results from the December 2017 effort are presented in Table 1 and Figure 3.

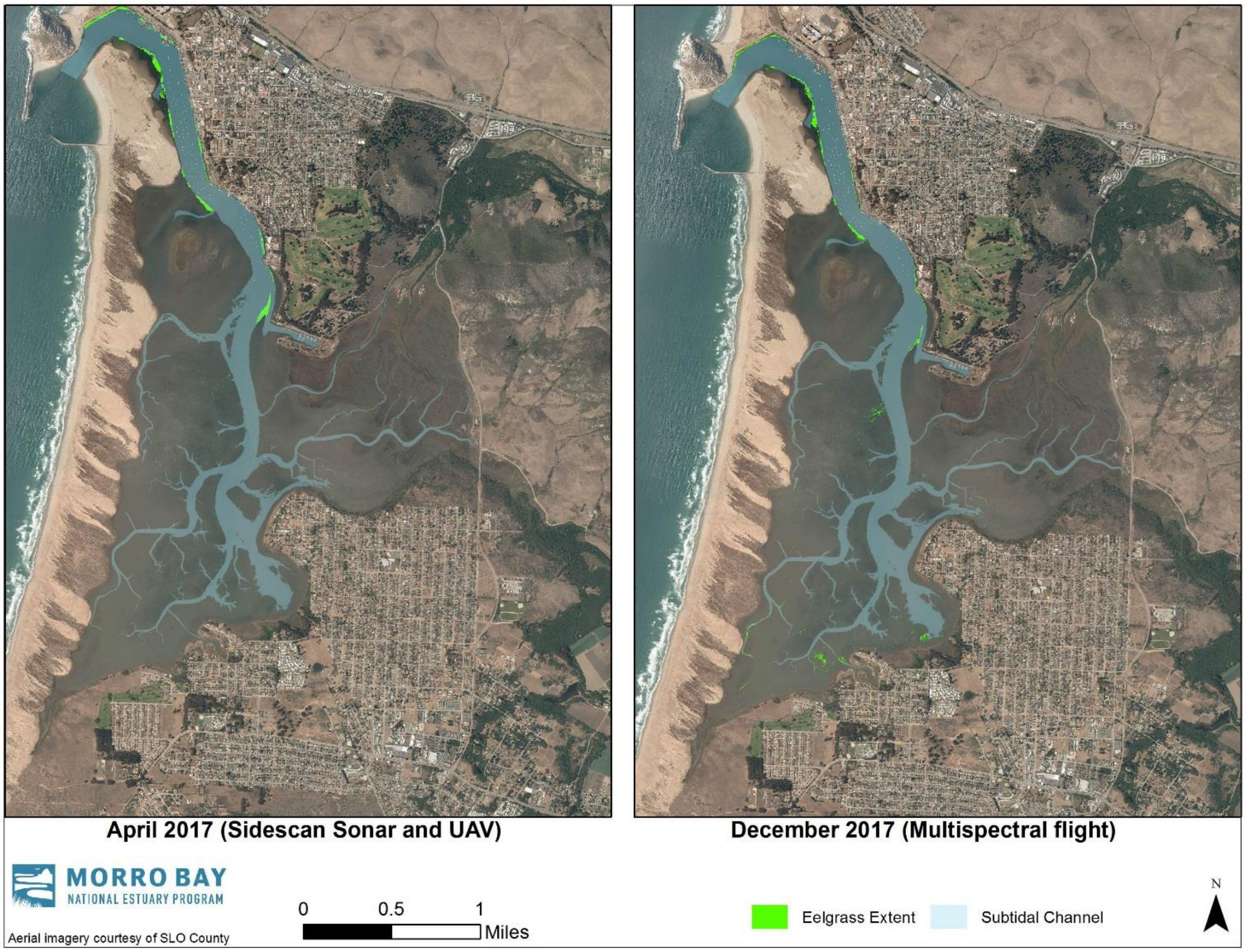


Figure 2. April 2017 map of baywide subtidal and intertidal eelgrass and December 2017 map of baywide intertidal eelgrass.

Table 1. Submerged Aquatic Vegetation Type and Acreages from December 2017 Flight.

Vegetation / Substrate Type	Area in Acres
Mud/Sand	1842.1
Water	619.46
Tidal marsh	391.52
Dune/Terrestrial vegetation	303.05
Green algae	105.73
Shadows	65.31
Gracilaria sp.	36.71
Eelgrass (*Zostera*)	**13.25**
Maritime infrastructure	9.5
Eelgrass wrack	0.04

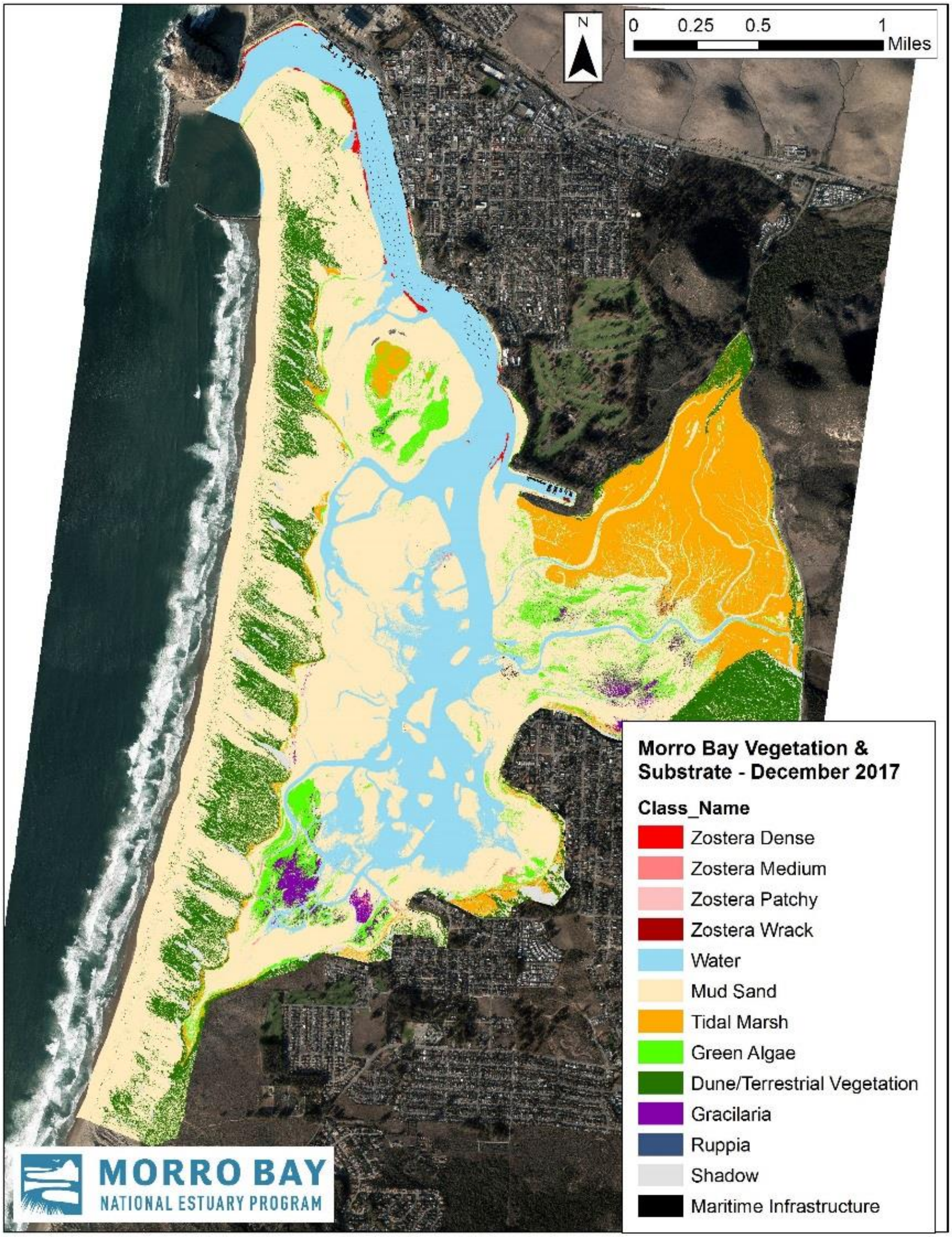


Figure 3. Morro Bay vegetation and substrate map from the December 2017 multispectral aerial imagery flight (Ocean Imaging 2018).

Drone Mapping
Dr. Jennifer O'Leary, California Sea Grant Extension Specialist and California Polytechnic State University, San Luis Obispo (Cal Poly) professor, received a grant from Cal Poly's Center for Coastal and Marine Studies to purchase a drone to develop methodologies to routinely survey eelgrass area in Morro Bay. She hired a drone technician, who was able to photograph the entire bay from a height of 400 feet in the same period as the airplane-based multi-spectral aerial surveys funded by the Estuary Program in December 2017. It took approximately four half-days to collect data for the entire bay. These drone data are currently being compared to the December flight results to determine if shifting to more frequent drone surveys would be useful.

Eelgrass Acreage Data
The following table and figure present Morro Bay's eelgrass acreage over time and the method by which the data were collected. It is important when comparing these data to keep in mind that the mapping method has changed over time. See the Estuary Program's Eelgrass Report 2014-2016 available at http://www.mbnep.org/library for more on the historical data sources. Note that with the different mapping techniques, there can be overlap between which eelgrass is captured with subtidal methods and which is captured with intertidal methods, depending on the method and the conditions (i.e., water clarity) during the survey.

Table 2. Eelgrass Mapping Methods and Acreages.

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	Unknown	435	Quadrat sampling (Chesnut)
1995	Unknown	260	Quadrat sampling (Chesnut)
1996	Unknown	165	Quadrat sampling (Chesnut)
1997	Unknown	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) + sonar (M&A)

Year	Time of Year	Eelgrass Acreage	Method
2015	July 2015	13.23	Sonar (M&A)
2017	April 2017	13.6	Sonar + UAV (M&A)
2017	December 3, 2017	13.25	Multispectral aerial images (Estuary Program with Ocean Imaging)

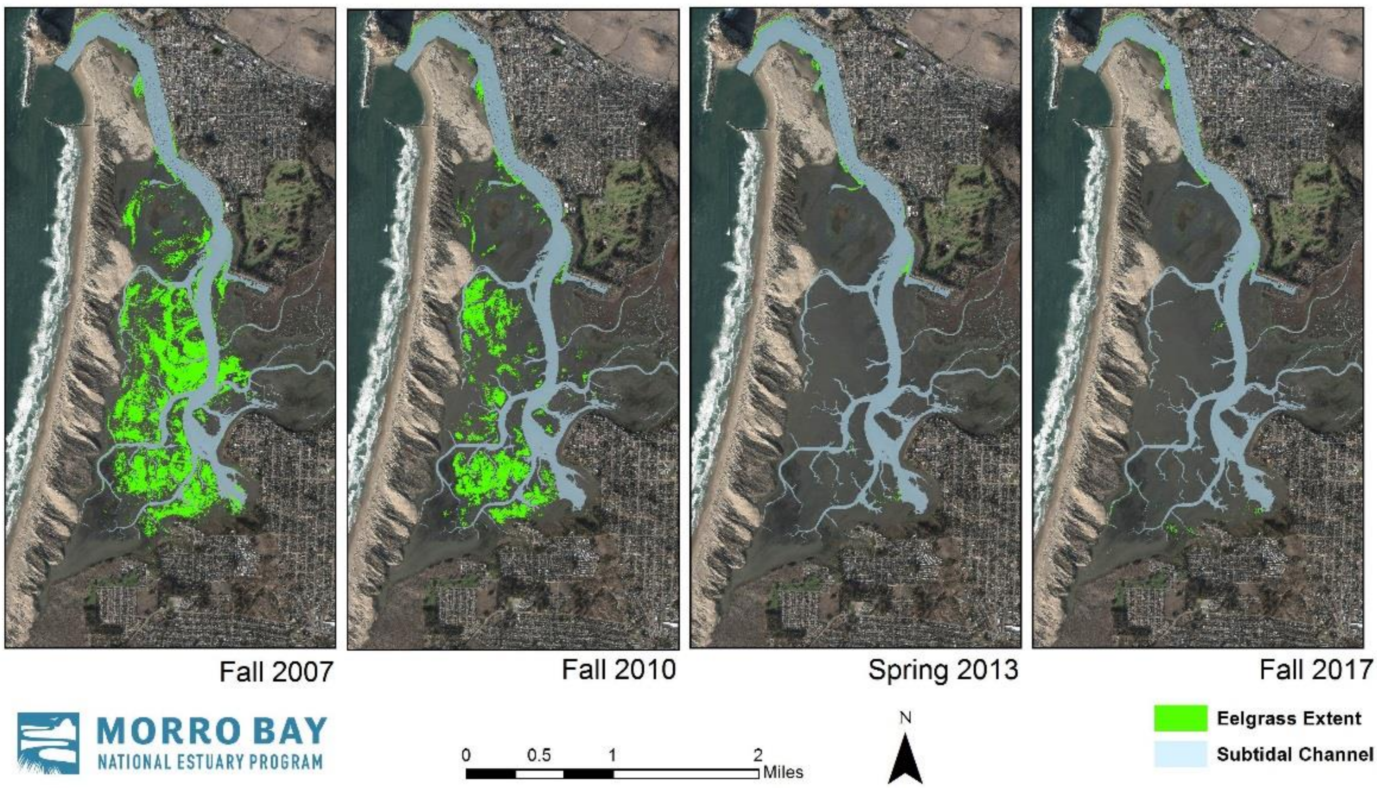


Figure 4. Loss of intertidal eelgrass in Morro Bay from 2007 to 2017.

The time series of maps in Figure 4 illustrates four multi-spectral images collected and analyzed by Ocean Imaging. The time of year was November in 2007 and 2010, May in 2013, and early December in 2017. While the front bay eelgrass appears to be relatively stable in the 2013 and 2017 maps, new patches of eelgrass appeared in the mid and backbay in the 2017 map. Although this represents a relatively small area of eelgrass, growth is occurring in areas where eelgrass has not been seen for several years.

Bathymetry Data Gap Effort

During the spring 2017 survey by M&A, bathymetry data was also collected to fill gaps in the existing composite topo-bathy of the Digital Elevation Model (DEM) for Morro Bay. The existing DEM is based on data collected between 2009 to 2011 using LiDAR and multibeam bathymetry, however, some areas were too shallow for multibeam and too deep for LiDAR. The 2017 survey was not intended for bathymetric data collection, so some of the field calibration steps needed for tight bathymetric control were not undertaken. Thus, the data should be considered to be supplemental to the previous bathymetry layers and fills in gaps that were not captured in the previous effort to create a DEM.

Figure 5 is the Morro Bay bathymetry data, including updated information from the M&A survey in April 2017.

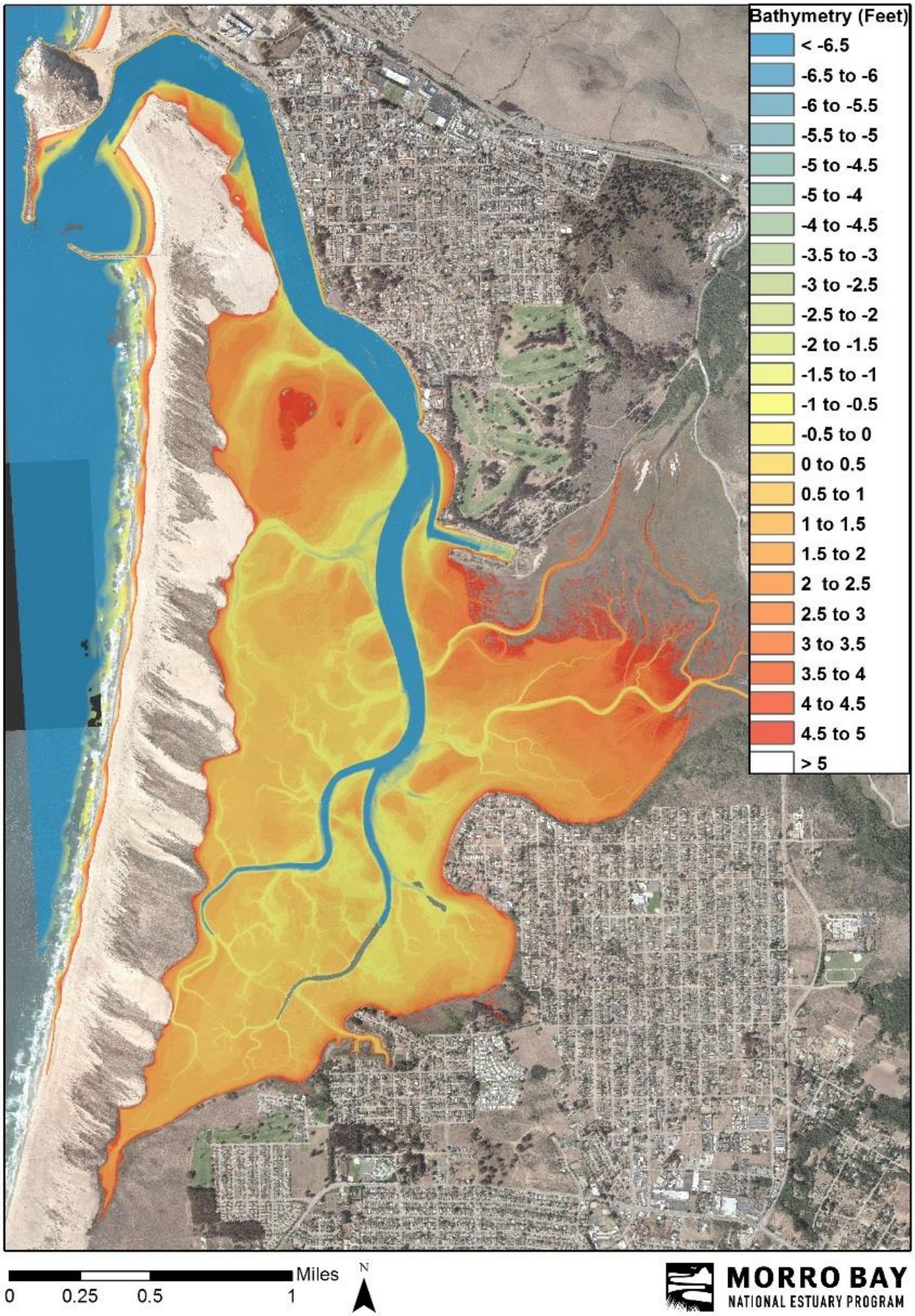


Figure 5. Bathymetry map of Morro Bay with updated data from M&A survey in April 2017.

Restoration Efforts

2012-2015: Merkel & Associates

Before 2017, there were three large eelgrass restoration efforts in Morro Bay, which were completed by the Estuary Program and M&A between 2012 and 2014. In 2012, the project was a joint effort between the Estuary Program, M&A, the U.S. Army Corps of Engineers (ACOE), and a Morro Bay community volunteer group. Eelgrass was collected from Coleman Beach, four to eight plants were bundled together into planting units, and 4,200 units were planted into 21 plots (each 3 m x 66 m) located in the intertidal and subtidal band of the mid and backbay. In August 2013, 9,775 eelgrass planting units were transplanted into 49 plots throughout the bay. Additionally, one unanchored plot of leftover eelgrass material was planted south of the State Park Marina, and five buoys with seeds in mesh bags were deployed. In 2014, eelgrass was collected from around the State Park Marina and Tidelands Park areas, and 8,949 eelgrass planting units were transplanted into 45 plots.

These large restoration plots were monitored the July following each transplant approximately 1 year after planting. In 2013 and 2014, M&A found about 45% of the plots retained eelgrass. In 2015, very little eelgrass was found, suggesting the transplants were unsuccessful. While a transplant effort had been scheduled for 2015, it was canceled.

The Estuary Program monitored all the transplant sites again in 2016 and found eelgrass present at 22 of the transplant plots (about 19% of the total planted), plus new patches of eelgrass throughout the bay. While it was possible that the eelgrass present was related to the transplant efforts, natural eelgrass may have reestablished in those same areas since the transplanting effort. It was clear that a much smaller, experimental restoration effort was necessary to determine whether transplanting was a viable option while having minimal impact to the existing eelgrass beds.

Figure 6 illustrates the eelgrass transplant locations for the 2012, 2013, and 2014 efforts, along with the eelgrass map from the Estuary Program's December 2017 intertidal eelgrass survey.

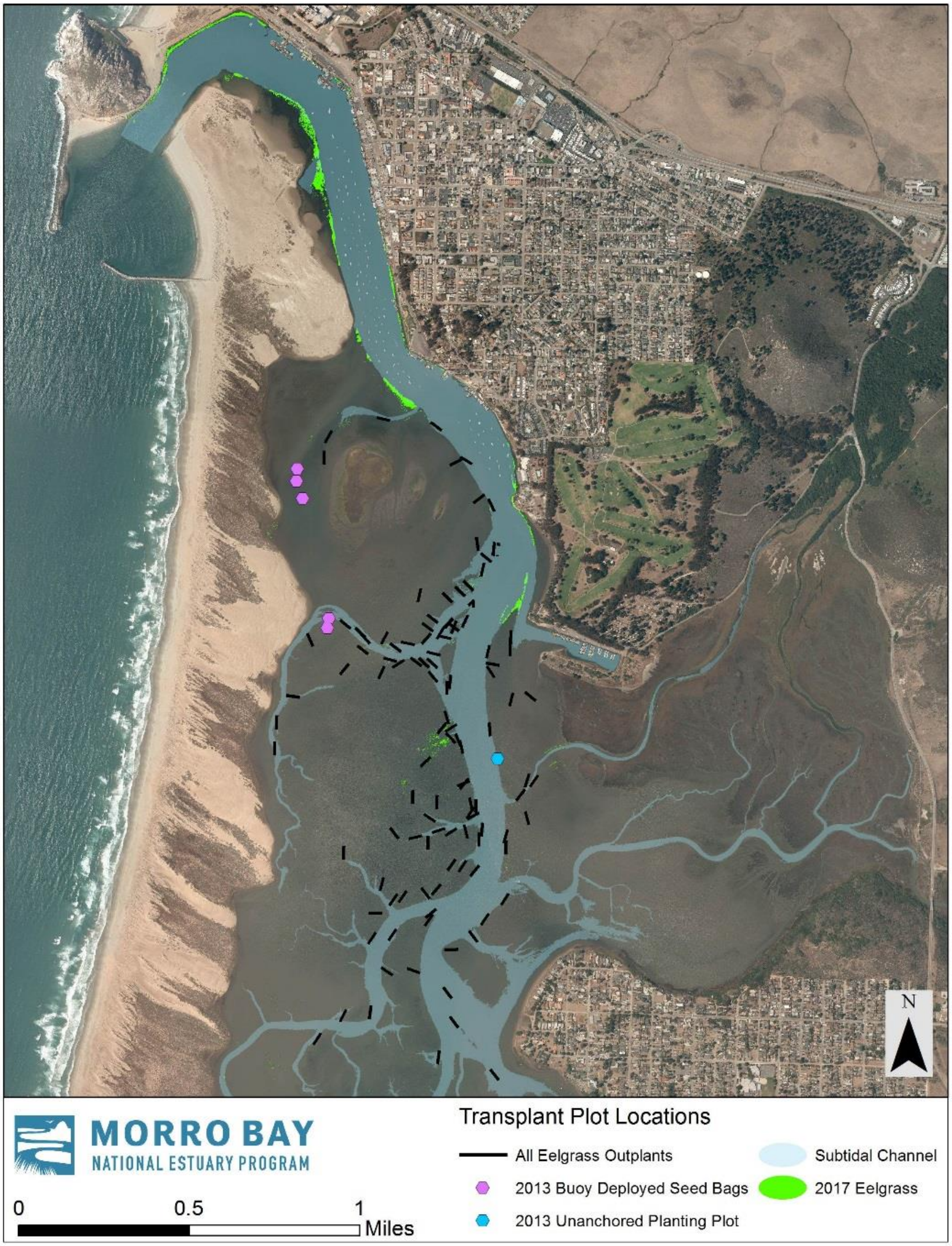


Figure 6. Transplant plots from 2012, 2013, and 2014 transplant efforts, with the eelgrass map from the December 2017 mapping effort.

Spring & Summer 2017 Transplant Efforts

Spring 2017

In March 2017, a small-scale experimental restoration effort was conducted over a three-day period. This was a combined effort between the Estuary Program, California Sea Grant, and Cal Poly, with a total of 17 people working on the project. Although planting has historically been conducted in Morro Bay during the summer months, researchers at Elkhorn Slough had recently had success planting eelgrass in the spring. Eelgrass was planted in the spring in order to become established prior to macroalgae blooms that typically occur later in the year. Macroalgae may limit light exposure and therefore survival success of eelgrass.

Spring Transplant Methods

Harvest: Eelgrass shoots were collected from the existing eelgrass bed at Coleman Beach. This site was chosen for its accessibility and large area of collectable eelgrass. A meter tape was run along the shore of the collecting area and, for each linear meter along the tape, two eelgrass plants were collected: one from a higher elevation (closer to shore/in shallower water) and one from a lower elevation (in deeper water), taking care to collect them at least one meter apart. Each day, eelgrass was collected from roughly the same area of the eelgrass bed and, over the course of the harvest, no more than 3 rhizomes per square meter were taken and no more than 10 % of the overall donor bed was collected.

Eelgrass was collected on foot and by hand in low water levels. Harvesters in waders walked in the eelgrass bed, reached into the water, used their fingers to dig the sediment away from the target shoot, and pulled the rhizome with attached shoot out of the sediment. Collected shoots were longer than 20 cm with rhizomes at least 7 to 10 cm long with 4 to 8 nodes.

Plant preparation: Immediately after collection, the eelgrass was prepared for planting. All shoots were cut to 20 cm, and longer rhizomes were cut to 10 cm for better planting success. Rhizomes with multiple shoots were adjusted so that the final plants had one to two shoots per rhizome. All the plants were then cleaned of epiphytes by gently scraping each leaf with fingers while the plants were in a bucket of estuarine water. In order to help track blade growth, some shoots were hole punched through the blades, about 8 cm above the first node.

Transplant: Two transplanting sites were chosen to test eelgrass growth in different environmental conditions where eelgrass has historically been found. At each site, four 1 m x 1 m plots were planted. Each plot had 72 plants, totaling approximately 576 transplanted eelgrass plants for this spring effort. At each site, the plots were within the intertidal or low intertidal zones, and placed at least 4 m apart at a similar elevation profile. See Figure 7 for the transplant locations.

Planting occurred just after harvesting and plant preparation, while the transplant sites were exposed. Two eelgrass rhizomes and attached shoots were crisscrossed to form a "bundle." Each plot had 36 bundles (72 plants) evenly spaced. Garden trowels were used to open a hole for the rhizomes, the bundle was planted, and a U-shaped garden stake anchored the bundle in the sediment. The shoots that had been hole-punched were planted in one quarter of each plot. A PVC marker was placed on the southwest corner to permanently mark each plot.

Summer 2017

In July 2017, a second small-scale experimental restoration effort was conducted over a four-day period. This was again a combined effort between the Estuary Program and Cal Poly, plus the help of 12 volunteers. This summer transplant was conducted at the same sites as the spring transplant to test the effect of transplanting season on restoration success (e.g., grazing pressure from brant geese).

Summer Transplant Methods

Harvest: Unlike during the spring transplant, eelgrass shoots were harvested and held overnight before transplanting due to the early morning timing of the low tides. Eelgrass shoots were again collected from the existing eelgrass bed at Coleman Beach, starting at the point where collection ended in the March effort.

Harvesting occurred on foot and by hand in low water levels, targeting shoots that were at least 20 cm long with rhizomes at least 7 to 10 cm long with 4 to 8 nodes. Over the course of the harvesting, care was again taken to collect no more than 3 rhizomes per square meter and no more than 10% overall of the donor bed.

Plant preparation: Immediately after collection, the eelgrass was prepared for planting. All shoots were cut to 20 cm and long rhizomes were cut to 10 cm. Additional processing that occurred in the spring transplant did not occur in the summer:

- Rhizomes with multiple shoots were left as they were, and a final shoot count for each plot was recorded.
- Rather than cleaning epiphytes off each blade, a subset of shoots in all quadrats were photographed to document the condition of the blades at the time of transplant.
- No holes were punched through the blades, as it proved difficult and time-intensive to monitor in the field.

A total of 753 rhizomes were collected for this summer effort. The prepared eelgrass plants were held overnight in dive bags hung from the Cal Poly boat slip in front of the Estuary Program office.

Transplant: A total of nine 1 m x 1 m plots were planted at the same sites used in the spring transplant: five plots were added to the forebay site and four plots were added to the midbay site. See Figure 7. At each site, the plots were within the intertidal or low intertidal zones and placed at least 4 m apart. The same planting protocol from the spring was used: two eelgrass rhizomes were crossed to form a "bundle," trowels were used to create a hole for the rhizomes, and a garden stake anchored the bundle. A PVC marker was placed in the southwest corner to permanently mark each plot. Each plot again had 72 plants, totaling approximately 648 transplanted eelgrass plants for this summer effort. Any additional plants (either leftover plants or those that did not meet planting requirements) were planted near the restoration plots in the forebay. Additionally, 28 collected rhizomes that contained flowering shoots were not used in the plots and instead kept to learn more about flowering shoots for future seed harvesting efforts.

Figure 7. Map with Eelgrass Restoration Locations for 2017.

Monitoring Results

The spring and summer transplant plots were monitored every month by Cal Poly graduate student, Erin Aiello, to measure blade length and shoot density and to take photographs. When comparing locations, the forebay site was much more successful than the midbay site (Figure 8). When comparing seasonality, there was overall more success in March compared to July.

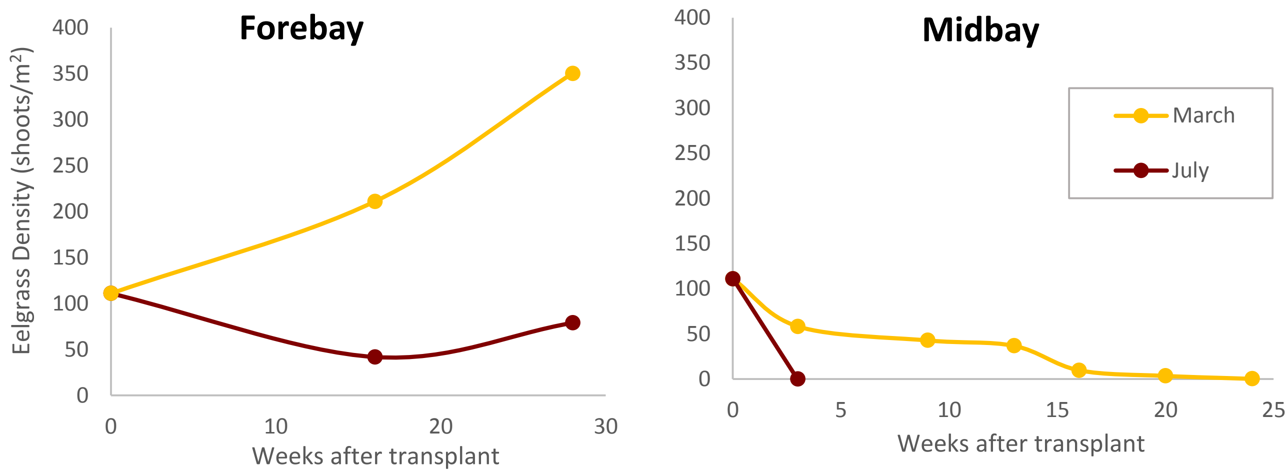


Figure 8. Eelgrass shoot densities (shoots/m^2) for the March and July transplants in the forebay and midbay (Aiello, in preparation).

Monitoring in August of the July planting at the midbay site indicated only six eelgrass shoots remaining among the four plots that had been planted in July. The remaining shoots were short and did not show signs of growth. Some rhizomes were still found in the substrate buried under the garden stakes, but eelgrass shoots were not present. At the forebay site, the average number of remaining shoots from the July planting in the five plots was 58%, 53%, 56%, 53%, and 74%, and there were signs of growth at the forebay plots. A few blade length measurements were collected, and from all five plots, some blades had doubled in length. *Bulla gouldiana* and their eggs were also found in high numbers at the forebay plots.

The March 2017 planting monitoring was conducted by Erin Aiello, and the results will be available upon presentation of her thesis in 2018. Additional monitoring of the July 2017 transplants will be conducted in 2018 by the Estuary Program. Photos are currently being analyzed by Cal Poly to quantify plant health.

Fall 2017 Seed Restoration

The Estuary Program explored eelgrass restoration using seeds. Transplanting eelgrass seeds, rather than adult plants, has been successful in a number of studies and restoration efforts (e.g., Pickerell et al. 2005; Pei-Dong et al. 2015). There are two primary methods used for planting seeds. The first is a buoy method, which consists of a bag of flowering shoots attached to a buoy on one end and an anchor on the other, such that the bag floats in the water column and the seeds drop as they mature. The second method is a burlap bag technique, where a bag of seeds is staked down into the sediment. Eelgrass plants are able to grow through spaces in the burlap, and the burlap helps to protect against seed predation.

In Morro Bay, eelgrass seeds have rarely been used in restoration efforts. In the 2013 M&A transplant effort, five seed bag buoys were deployed but with no intensive follow-up monitoring. In fall 2015, the Estuary Program planned a seed bag buoy restoration effort but the necessary permits from the California Department of Fish and Wildlife (CDFW) did not come through. While seeds were never deployed, the Estuary Program tested this method with empty bags and found some serious challenges with the buoy method. The buoys would snag macroalgae, which could shade out seedlings. Strong tides would also drag a buoy and its anchor over great distances, which would prevent accurate monitoring of method success. In 2017, the Estuary Program moved forward with a new seed restoration effort using the burlap bag method.

Seed Availability

Eelgrass beds were checked periodically for seed development and availability in 2015 and 2016. While it was once thought that Morro Bay eelgrass beds flowered in July and August because this is the case in other estuaries, some beds were found to have flowering shoots with a range of developmental stages in September and October. More observations were necessary to understand the exact flowering timeframe.

In June 2017, the Estuary Program began monitoring eelgrass beds for flowers every other week. Standup paddleboards were used to access the majority of the forebay beds during mid to high tide windows. Total flowering shoot counts were recorded in a 1 m x 1 m quadrat and the various stages of each flowering shoot were recorded (Figure 9). Anecdotal evidence from Erin Aiello suggests that some beds began flowering as early as May, but densities of flowering shoots were approximately 1 to 5% of the beds monitored. Beds began flowering in higher densities in early July and into August and, of those flowering shoots, most contained seeds in stages 2 or 3. Each flowering shoot often had multiple blades containing seeds, and though they occurred on the same shoot, many blades were in various stages of seeding.

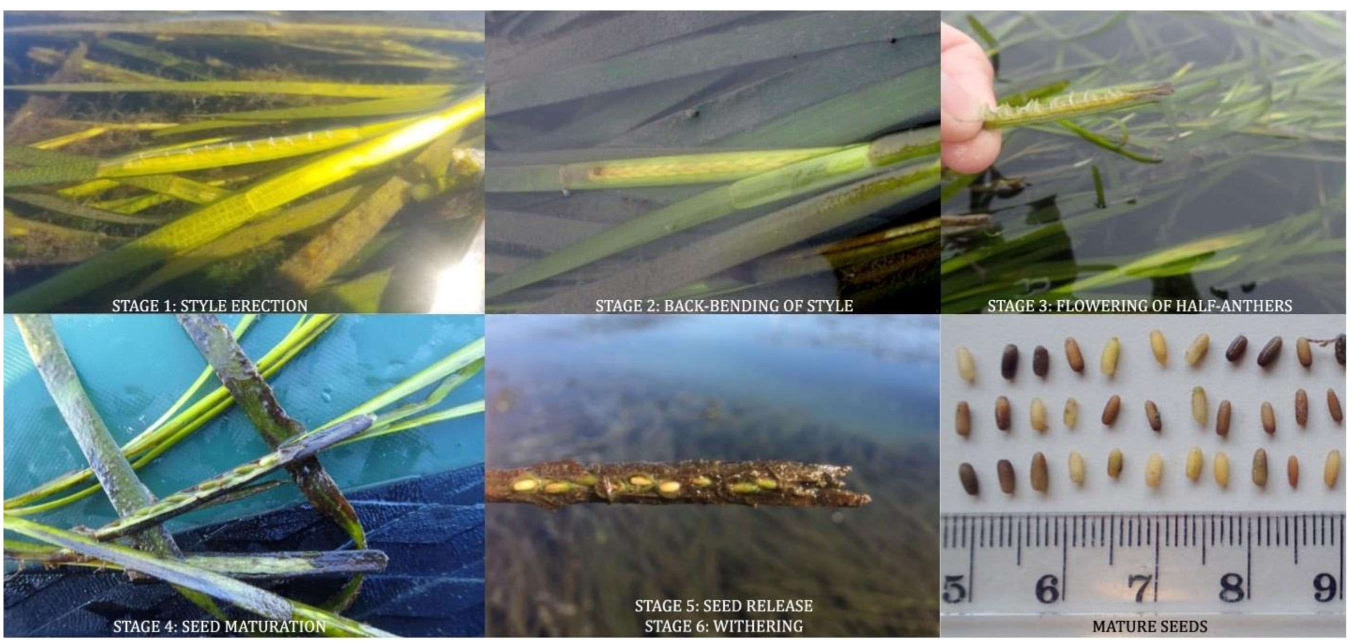


Figure 9. Stages of eelgrass flowers and seed production in Morro Bay (Adapted from materials by M&A).

Seed Collection & Deployment

Based on the challenges presented by the buoy deployment tests in 2015, the Estuary Program chose to instead use the burlap seed bag method for the restoration effort. This technique allows the number of seeds going into the exact planting area to be controlled and successful growth more precisely tracked. Because the bags are placed flush with the sediment, there should be little interference from macroalgae, and seeds are protected from predation (e.g., Harwell and Orth 1999; Pei-Dong et al. 2015).

Collection

Seed collection began in September after flowering shoot densities increased and seeds began to reach maturity stages 4 and 5. The permit allowed for the collection of 300 blades from each of these locations: Coleman Beach, North Sandspit, and Windy Cove. After monitoring these beds for roughly two months, Estuary Program staff decided the Windy Cove eelgrass bed did not flower at high enough densities to allow for collection. The allowable number of blades allocated for both Coleman Beach and North Sandspit was harvested, for a total of 600 flowering blades. These blades were pinched off from the eelgrass shoot if they were in stages 4 or 5. Harvested blades were placed in small mesh paint-straining bags and labeled with the location and date of collection.

These bags were placed in a mesh dive bag floating in the bay, attached to the boat docks near the Estuary Program office. The blades were kept for approximately one month until the seeds were in the final stage of development and were released from the ovary sack. Once all seeds had been released from the blades, the seeds were then separated from debris. Studies have found that seeds are viable as long as they are firm, have an intact seed coat, and sink rapidly in salt water (Marion and Orth 2010). Each seed was tested in estuarine water, and only those that sank rapidly were used.

Deployment

Small 2” burlap packets were created with a 1” border to be used for staking the packet to the sediment with garden staples. Using tweezers, ten seeds were inserted into each burlap packet and then the bag was stapled shut. Seed bags were planted at each of the following locations: the forebay north of the 2017 restoration plots, State Park Marina, and the backbay off Mitchell Drive. See Figure 7 for locations. At the three planting locations, fifteen burlap packets were staked into the sediment evenly spaced within a 1 m x 2 m plot. Plots were marked with small PVC poles at all four corners. Additionally, some extra seeds were scattered directly into the sediment (2 to 3 cm deep) by hand in a plot in the backbay.

Flowering shoots floating at water’s surface

Seeds in a collected blade


The flowering shoots held in mesh bags Eelgrass seeds



Seeds put into burlap packets Burlap packets prepared for deployment




Bags deployed at forebay (left), State Park Marina (center), and backbay near Mitchell Drive (right).

Seeding Monitoring
The seeding restoration will be monitored throughout the winter and into 2018. Results will be available in the Estuary Program's 2018 Eelgrass Report.

Other Monitoring Efforts
In addition to monitoring the restoration plots, there are several supplementary monitoring efforts to track eelgrass changes throughout the bay. Permanent transects were established beginning in early 2005 to measure average shoot density at sites located throughout the bay. Bed condition monitoring was established with California Sea Grant and Cal Poly beginning in late 2015 to measure average density and overall condition of remaining eelgrass.

Permanent Transects
History
Permanent transects were established 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, Pasadena) were monitored annually from 2006 to 2010. 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 ("Embarcadero"). Note the transect now called "Reference" was originally named "Tidelands" and has been changed to avoid confusion.

Figure 10. The six current permanent transect monitoring locations.

Methods
Fieldwork was usually conducted during extreme low tides (-0.4' 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 the 50 m transect. A 0.5 m x 0.5 m 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 were counted to determine density.

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 run 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. However, as eelgrass declined, it became too damaging to collect samples, and the biomass study was stopped.

Results
Average shoot density for each site is summarized in Figure 11.

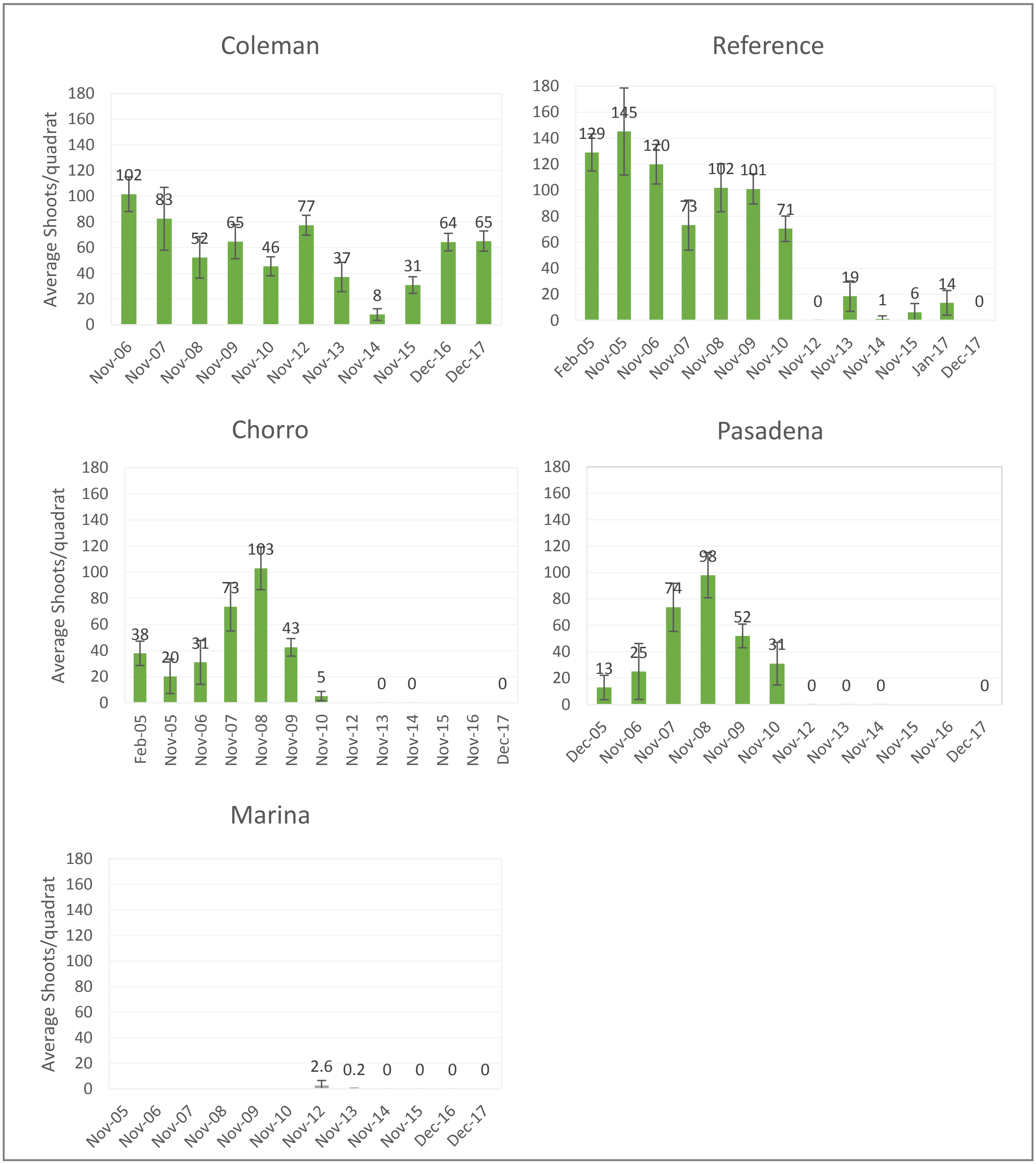


Figure 11. Average shoot density counts per year at five sites. Shoots were counted within a 0.5 m x 0.5 m quadrat. Error bars represent the 95% confidence interval.

Average shoot densities have clearly declined at each site, and Coleman Beach appears to be the only site where densities have bounced back. While the new Embarcadero transect has no historic data to compare to, it had an average of 60 ± 18 shoots per 0.5 m x 0.5 m quadrat, which is about the same density currently seen at Coleman.

The permanent transects were established to track eelgrass density, however the overall decline has prevented this from being the most useful method of monitoring eelgrass. Once a site has no eelgrass to measure, the transect no longer provides valuable data. Most transects are not permanently marked, which makes it a challenge to return to the exact spot each year. There were 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. Therefore, a different method was needed to more fully capture the health of existing eelgrass.

Permanent Transect Photos and Observations

Photos were taken to document site conditions. Site photos from multiple years and general observations are provided.

Coleman Transect

The 2017 shoot density counts were almost identical to the 2016 counts.


Nov 4, 2010


Dec 14, 2016

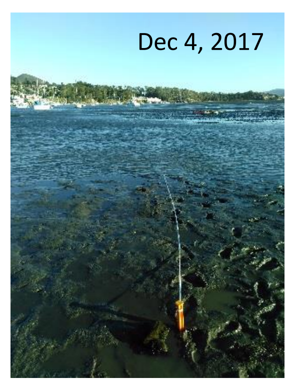

Dec 1, 2017

Reference Transect

Previously known as “Tidelands.” While there was no eelgrass on the completed transect, a large eelgrass bed was located within several meters. A PVC stake in the bed, presumably marking the main transect, was very deep and likely measuring subtidal eelgrass instead of intertidal. Due to site conditions, this deeper transect was not monitored.


Nov 6, 2010

Nov 16, 2013


Dec 4, 2017

Embarcadero Transect

This site was established in 2017. It was on the eastern side of the channel at Tidelands Park, at the south end of the dock. The eelgrass looked in good condition, and the bed was mostly continuous.


Dec 4, 2017

Marina Transect

While there were numerous eelgrass patches observed in the area in 2016, no eelgrass was found in the 26 m x 50 m area in 2017 (all three transects were completed).


Nov 15, 2013

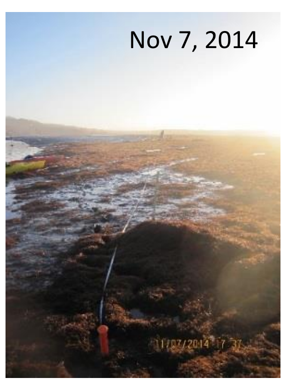

Dec 13, 2016


Dec 3, 2017

Pasadena Transect

There was some confusion over the location of the transect as the area had not been surveyed since 2014. One transect was monitored based on the markers in the field, and two were identified using maps from 2014. None of the transects had eelgrass, but some small patches ranging in size from 0.0625 m^2 to 0.25 m^2 were found higher on the mudflat.


Nov 5, 2010


Nov 7, 2014


Dec 2, 2017

Chorro Transect

The area was last surveyed in 2014 and no eelgrass, either intertidal or subtidal, was found. In 2017, no eelgrass was found on the transect, but two small patches were found in the area.

Bed Condition Monitoring

As eelgrass declined, a new method of monitoring the remaining eelgrass beds was needed to supplement the permanent transects. Bed condition monitoring was established as a joint effort between Dr. Jennifer O'Leary and the Estuary Program in late 2015. This method measures eelgrass condition in terms of density, blade length, evidence of necrotic tissue, and competition with other algae and organisms. Monitoring occurs at five significant beds in Morro Bay along a 150-meter, 7-quadrat survey. Both intertidal and subtidal eelgrass are surveyed, as so much of the intertidal eelgrass is gone. Monitoring has occurred twice per year since 2015, once in late fall and again in the spring. The plan is to continue this monitoring in future years. This work is being supported by California Sea Grant and by a grant from the Pacific States Marine Fisheries Commission (PSMFC).

Data are currently being analyzed by Cal Poly and will be included in a future report.

Figure 12. Bed condition monitoring sites: Coleman Beach, North Sandspit, Reference Bed, Windy Cove, and State Park Marina.

Permanent Plots

In addition to bed condition monitoring, Dr. O'Leary is coordinating the establishment of small permanent plots at six sites throughout Morro Bay. These plots would be monitored throughout the year to track seasonal changes in eelgrass condition. So far, they have been installed at Coleman Beach, North Sandspit, Windy Point, and Grassy Bar Oyster Farm and will be added at Reference bed and near Cuesta Inlet in Los Osos. This work is supported by a grant from PSMFC.

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 ft.

In 2017, the ACOE issued two separate dredging contracts. ACOE contracted with the Portland District hopper dredge, Yaquina, to dredge portions of the Entrance Channel, Transition Area, and Main Channel. Dredging began on May 1 and was completed on May 28. No eelgrass was lost in this dredge event. ACOE also contracted Ahtna Design-Build, Inc. to conduct suction cutterhead pipeline dredging within portions of the Navy Channel, Morro Channel, and the Sand Trap. The pipeline dredging began in February and ended in July, pausing operations while the Yaquina dredged in May. The pipeline dredging resulted in a net loss of 22 m^2 of eelgrass around the Coast Guard T Pier. Due to the relatively small amount of eelgrass impacted, it was recommended that the ACOE defer mitigation or participate in other eelgrass recovery projects (M&A 2017).

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. Between 2008 and January 2017, 23 surveys were completed over the course of seven construction projects. The surveys identified about 1,150 m^2 of eelgrass and more than 900 m^2 of possible habitat that could potentially be impacted by the projects. While the seven projects are all at various stages of completion, no eelgrass has yet been significantly affected.

There was one new survey completed in 2017. In October 2017, the final post-construction survey was completed for the Morro Bay Landing Phase 1b dock replacement project. In November 2015, the single floating dock between the two Morro Bay municipal T-piers was replaced with a shorter dock and new dock fingers. Three of the 13 new piles directly hit eelgrass, possibly impacting an estimated 40 stems of eelgrass (0.4 m^2). The results from the final survey show that the eelgrass area was not significantly reduced by the project. In fact, in contrast to the bay-wide decline, eelgrass in this surveyed region has increased by more than twice the area compared to the first survey done in 2006 (Tenera 2017).

Morro Bay Science Explorations with the Estuary Program

The Estuary Program began its science talk series with a presentation on the eelgrass of Morro Bay to increase public awareness. The talk, "Eelgrass and the Estuary," was held on October 12 and was open to the public. Three speakers presented different aspects to the eelgrass project: Carolyn Geraghty, Estuary Program Restoration Projects Manager; Erin Aiello, Master's Candidate at Cal Poly; and John Roser, local Brant goose expert. Around 50 guests attended.

Partnerships

The Estuary Program is continuing their partnership with Cal Poly and California Sea Grant in order to support eelgrass research efforts. The effort also involves CDFW and NOAA partners. These partnerships promote sharing of data and expert opinions to help guide eelgrass activity.

Research Efforts

Genetic Diversity of Eelgrass

Dr. Jenn Yost, plant biologist and professor at Cal Poly, together with graduate student Julia Harenčár and a team of students, spearheaded a genetic study of Morro Bay eelgrass. Genetic diversity has been shown to be an important factor in eelgrass bed health and was thought to be a potential factor in the struggling Morro Bay population. However, the team found that Morro Bay eelgrass has relatively high genetic diversity. The diversity is comparable to other Pacific Coast bays, suggesting that the Morro Bay eelgrass is not experiencing negative genetic consequences since the population decline. All of the remaining eelgrass beds in Morro Bay are genetically homogeneous, as are eelgrass shoots at different depths in the bay. The team also compared Morro Bay eelgrass with Bodega Bay eelgrass and, as expected, found the populations are genetically distinct. This, along with a previous study from 2014, indicates that Morro Bay eelgrass is genetically distinct from both southern and northern populations. Furthermore, some historic eelgrass samples from prior to the decline were compared to the current samples, and no differences were found. This study has important restoration implications: there is no need to bring eelgrass in from other bays to increase genetic diversity (it may actually be detrimental to do so), and if transplanting, eelgrass can be collected from any part of the bay. Julia Harenčár presented this data as her master's thesis in June 2017 (Harenčár 2017).

Fish Biodiversity

Dr. Jennifer O'Leary, with a grant from Cal Poly, carried out bay-wide evaluations of fish populations to compare with surveys conducted prior to the eelgrass decline. She is currently preparing a report on changes in abundance and species composition of fish in Morro Bay and how fish populations differ between areas with and without eelgrass.

Water Quality Monitoring

Dr. Ryan Walter, professor in Cal Poly's physics department, continues to maintain and run a water quality instrument package at the mouth of the bay and a weather station in the backbay. 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, he maintains temperature sensors at the mouth of the bay and back of the bay. In 2017, he added a midbay site to the long-term measurements. He also recently recovered instruments deployed for a full year to examine seasonal changes in conjunction with eelgrass experimental transplants. These data will be downloaded and analyzed in the coming months. Support for this work comes from the PSMFC.

Crab Biodiversity and Otter Indirect Effects

Dr. Lisa Needles from Cal Poly's Biological Sciences Department has been quantifying the diversity, size, and abundance of crabs inside and outside eelgrass beds and in different areas of Morro Bay. Preliminary findings from trapping efforts in 2015 and 2016 suggest that there are more abundant crab populations and larger crabs towards the back of the bay both inside and outside of eelgrass beds. In 2017, undergraduate students studied the preference of crabs for certain prey items. The goal was to understand direct impacts of crabs to eelgrass via clipping of the blades, bioturbation, and disturbance of shoots. Through a coast-wide collaboration with researchers at several other institutions including University of California, Santa Cruz, the indirect effect of the Southern sea otter on eelgrass (e.g., through the consumption of crabs) was also being assessed (Lisa Needles, personal communication, June 2017). Reports on the research are still being developed.

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 brant occupy Morro Bay (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. See Figure 13 for brant numbers seen in Morro Bay over the past 20 years (Roser 2018).

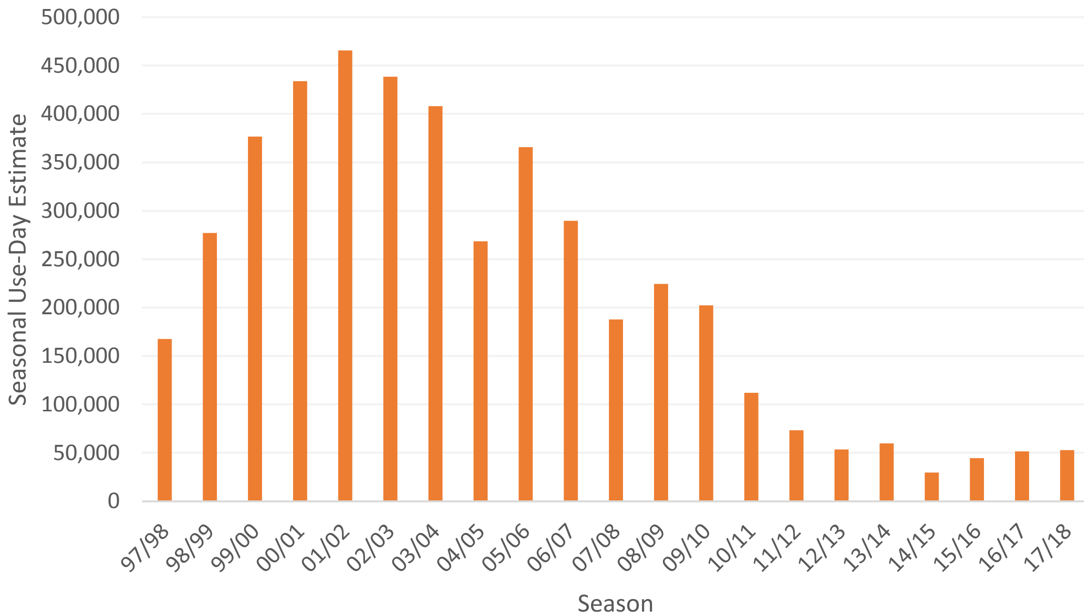


Figure 13. Brant seasonal use-day estimates in Morro Bay from 1997 to 2018 (data adapted from Roser 2018).

Several Cal Poly students have studied brant foraging behavior over the past few years. In 2016, Cal Poly student Robert Heim studied brant and their foraging locations during a season of extremely limited eelgrass availability. He conducted weekly observations from late-January to mid-March 2016 and found brant only in the saltmarsh and never in or around eelgrass. In 2017, Cal Poly student Amy Yoger repeated Heim's project and found the opposite results: brant were often seen in the eelgrass beds and never seen in the saltmarsh. Cal Poly master's student Dakota Osborn will be evaluating how brant grazing affects eelgrass density and health. The work will occur from December 2018 to December 2019 and is supported through Cal Poly.

Upcoming Projects in 2018

Mapping

Funding has been secured to conduct a complete bay-wide bathymetry map utilizing sonar and LiDAR. The survey serves multiple purposes: 1) Provides input for a circulation and hydrodynamic model under development as part of a Sea Grant project, 2) Provides elevation data which supports eelgrass restoration efforts, and 3) Provides data for a tidal prism calculation for comparison to historical data.

Restoration

Additional transplants will be planted throughout the estuary in 2018 to test additional planting locations and depths, as well as a new anchoring method.

Other monitoring
Permanent transect and bed condition monitoring will continue in addition to monitoring of the new permanent plots.

Additional Activity
Cal Poly and California Sea Grant research projects will continue to collect data to further our understanding of suitable conditions for eelgrass in the bay. Sediment loading and transport is 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. The exact cause of the decline may never be known as eelgrass is sensitive to a suite of factors, all of which may have complex interactions. Natural factors that may have negatively impacted eelgrass include salinity, wave velocity, increased turbidity due to sediment or phytoplankton blooms, pathogens, grazing, and eelgrass wasting disease. Human activity also potentially negatively impacts the eelgrass environment through dredging, propeller scarring, shading, introducing invasive species, and non-point source loading of nutrients, herbicides, and sediment.

One encouraging sign is the presence of eelgrass in the back bay beginning in fall 2016, in areas where eelgrass has not been seen for several years. Anecdotally, it appears that 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 the April 2017 and the December 2017 mapping efforts.

The drastic decline of eelgrass in Morro Bay has driven many recent restoration and research efforts. Eelgrass was mapped using two different methods in 2017. Monitoring of the eelgrass beds has continued to track changes in the population. Experimental small-scale transplanting efforts were completed in the spring and summer and monitored closely to show that eelgrass was more successful when planted during the spring. A third effort in the fall used eelgrass seeds rather than adult plants to explore this additional restoration method.

In 2018, 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.

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