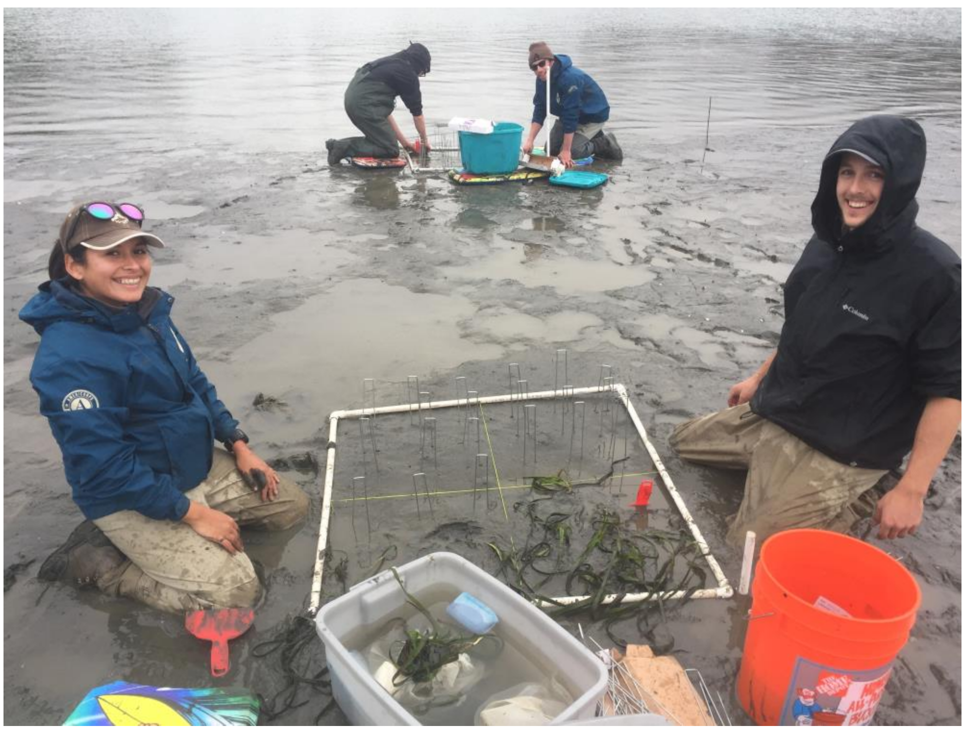
Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2018



Morro Bay National Estuary Program
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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 reasons for the decline are 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 2018. This includes small-scale experimental restoration efforts in the spring 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.

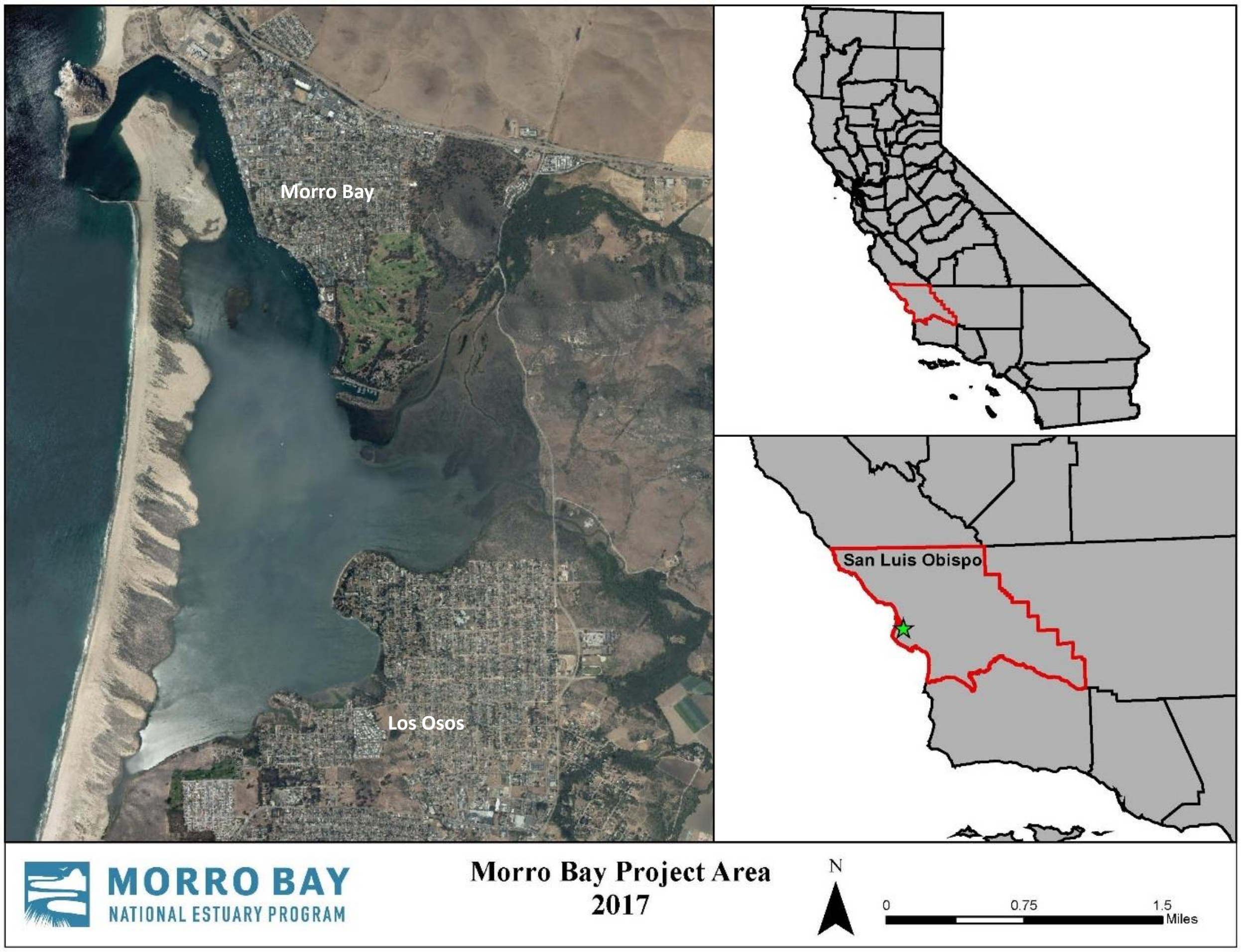


Figure 1. Morro Bay.

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 3.

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 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. In the spring, a combination of sidescan sonar and unmanned aerial vehicle (UAV) imagery were seamed together to map intertidal and subtidal eelgrass baywide. In the winter, multispectral aerial imagery was used to create a classification of intertidal submerged aquatic vegetation. The classification was groundtruthed by the Estuary Program. As no baywide mapping effort was conducted in 2018, the most recent substrate and vegetation classification results from the December 2017 effort are presented in Table 1 and Figures 2 and 3.

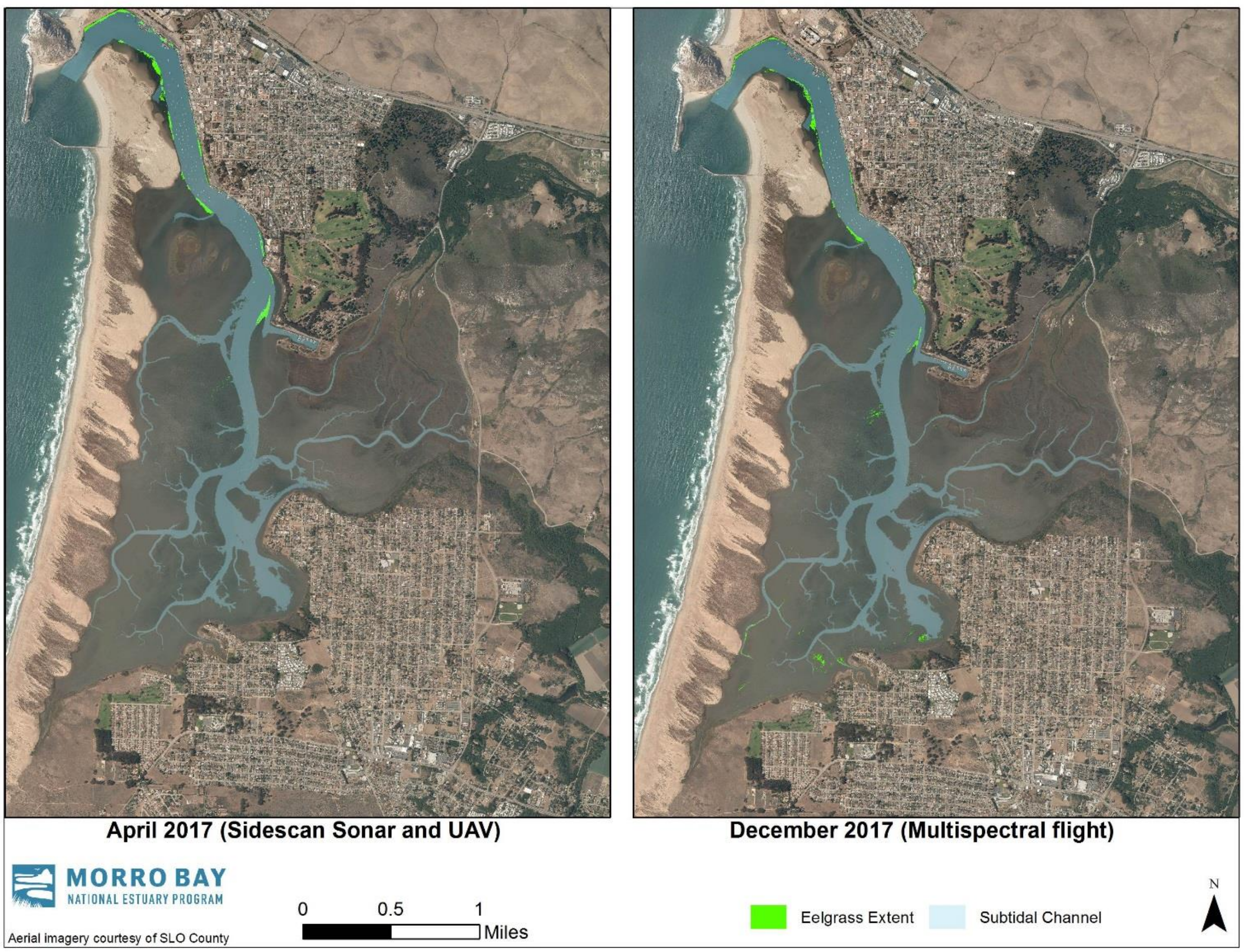


Figure 2. April 2017 map of baywide subtidal and intertidal eelgrass (left), and December 2017 map of baywide intertidal eelgrass (right).

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

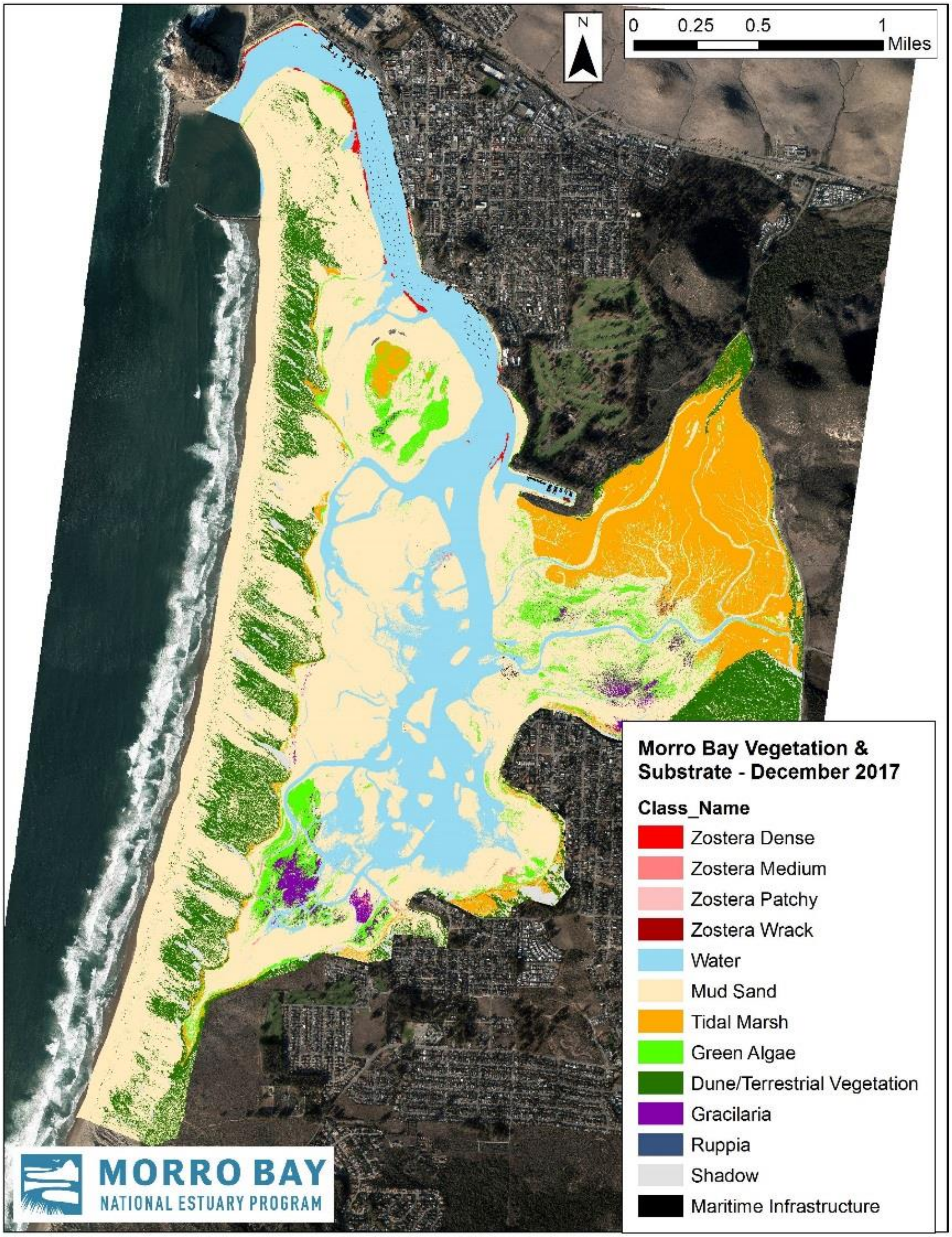


Figure 3. Morro Bay vegetation and substrate map from the December 2017 multispectral aerial imagery flight (Ocean Imaging 2018).

2017 Drone Mapping

Dr. Jennifer O'Leary was a California Sea Grant Extension Specialist and California Polytechnic State University, San Luis Obispo (Cal Poly) professor through the summer of 2018, at which point she accepted a position with The Nature Conservancy. While at Cal Poly, she received a grant from Cal Poly's Center for Coastal and Marine Studies to purchase an unmanned aerial vehicle (UAV) to develop methodologies to routinely survey eelgrass area in Morro Bay. She hired a UAV 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. 4,858 photos were taken, and 3,090 acres were surveyed from December 1 through 4, 2017. The images were stitched together and georeferenced, and then Cal Poly lecturer Maurica Fitzgibbons quantified the eelgrass in GIS using a manual classification process.

The following image shows the resolution of photos captured with the Cal Poly drone in December 2017. This image shows shellfish farm infrastructure. The dark green patches in the channel are eelgrass.

The following image is of the permanent eelgrass bed at State Park Marina, captured by the Cal Poly drone during the December 2017 flight.

The following map shows the full extent of bay-wide eelgrass from the December 2017 Cal Poly drone flight and analysis.

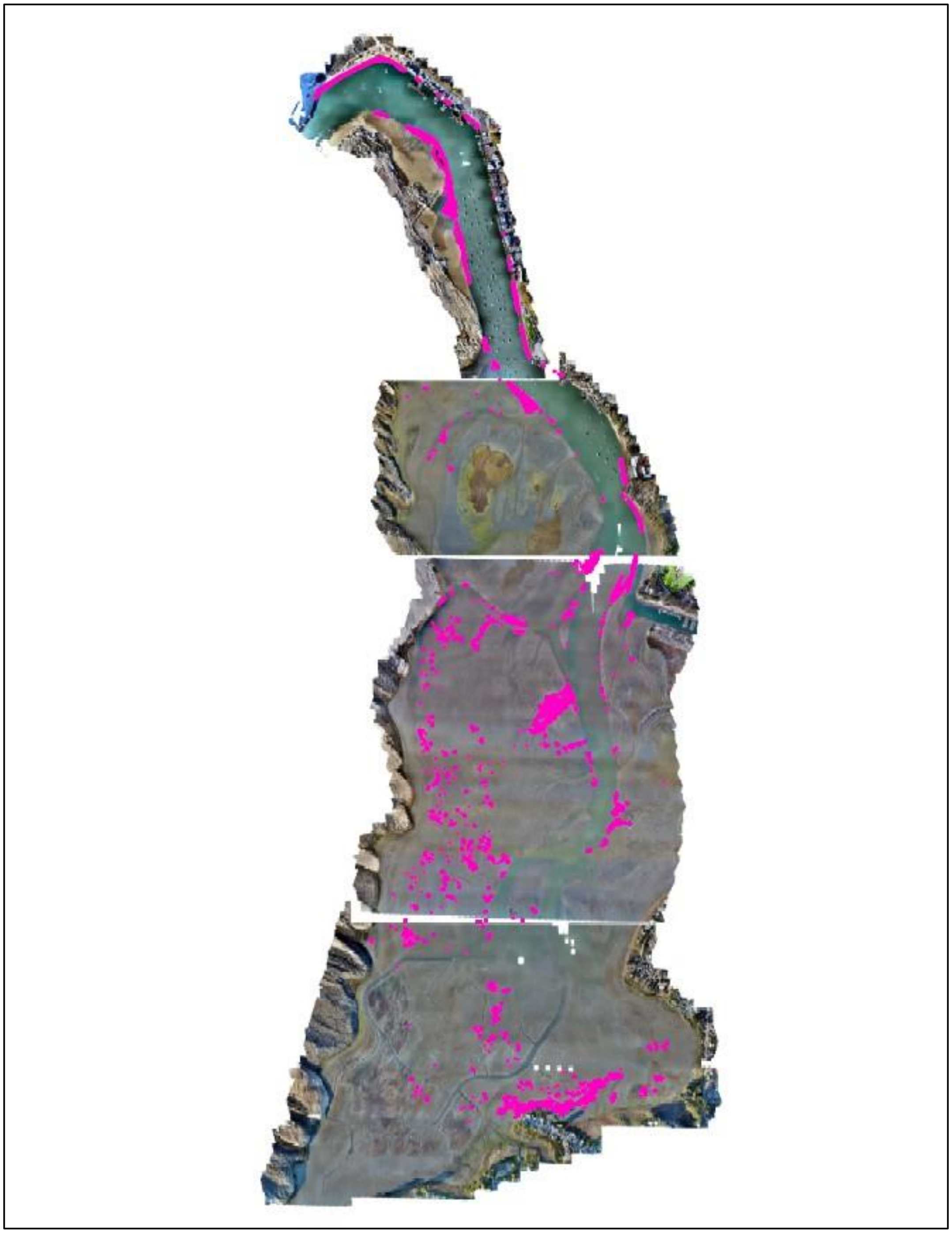


Figure 4. Baywide extent of intertidal eelgrass in December 2017, mapped via UAV.

The UAV data were compared to the December multi-spectral flight results to determine if shifting to more frequent drone surveys would be useful. Analysis determined that while the multi-spectral flight and automated classification identified 13.25 acres of intertidal eelgrass, the drone imagery with manual classification identified

9.37 acres of intertidal eelgrass. This difference in acreage is related to differences in the methodologies of collection. The drone imagery is thought to be able to more accurately capture small eelgrass patches (e.g., less than a meter in length) as compared to the multi-spectral imagery. There were also some locations where the multi-spectral imagery misidentified kelp as eelgrass and patchy areas where the multi-spectral imagery overestimated eelgrass. While the drone survey has the benefit of lower cost which allows more frequent surveying, the multi-spectral collection has been conducted consistently in the bay since the early 2000s, allowing a comparison of current eelgrass acreage to pre-decline levels.

2018 Drone Mapping

In December 2018 during the low tide windows, Cal Poly repeated their 2017 imagery collection effort via drone. This work was conducted by Dr. O'Leary of The Nature Conservancy and Dr. Ryan Walter of Cal Poly's Physics Department. The effort is part of a Sea Grant project to study bay hydrodynamics and circulation in relation to the eelgrass decline. The data is currently under review, and Maurica Fitzgibbons is processing the images to create maps of eelgrass extent and acreage numbers. The Cal Poly team is working with a professor in the Sociology Department (Geography focus) who specializes in vegetation classification schemes and is lending his expertise to the effort. The plan is to analyze the drone imagery using multiple automated classification schemes to determine which approach is optimal. Results are expected in late 2019.

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 to 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 eelgrass captured with subtidal methods and captured with intertidal methods, depending on the method and the conditions (e.g., water clarity, tide height, etc.) 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	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)

Year	Time of Year	Eelgrass Acreage	Method
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)

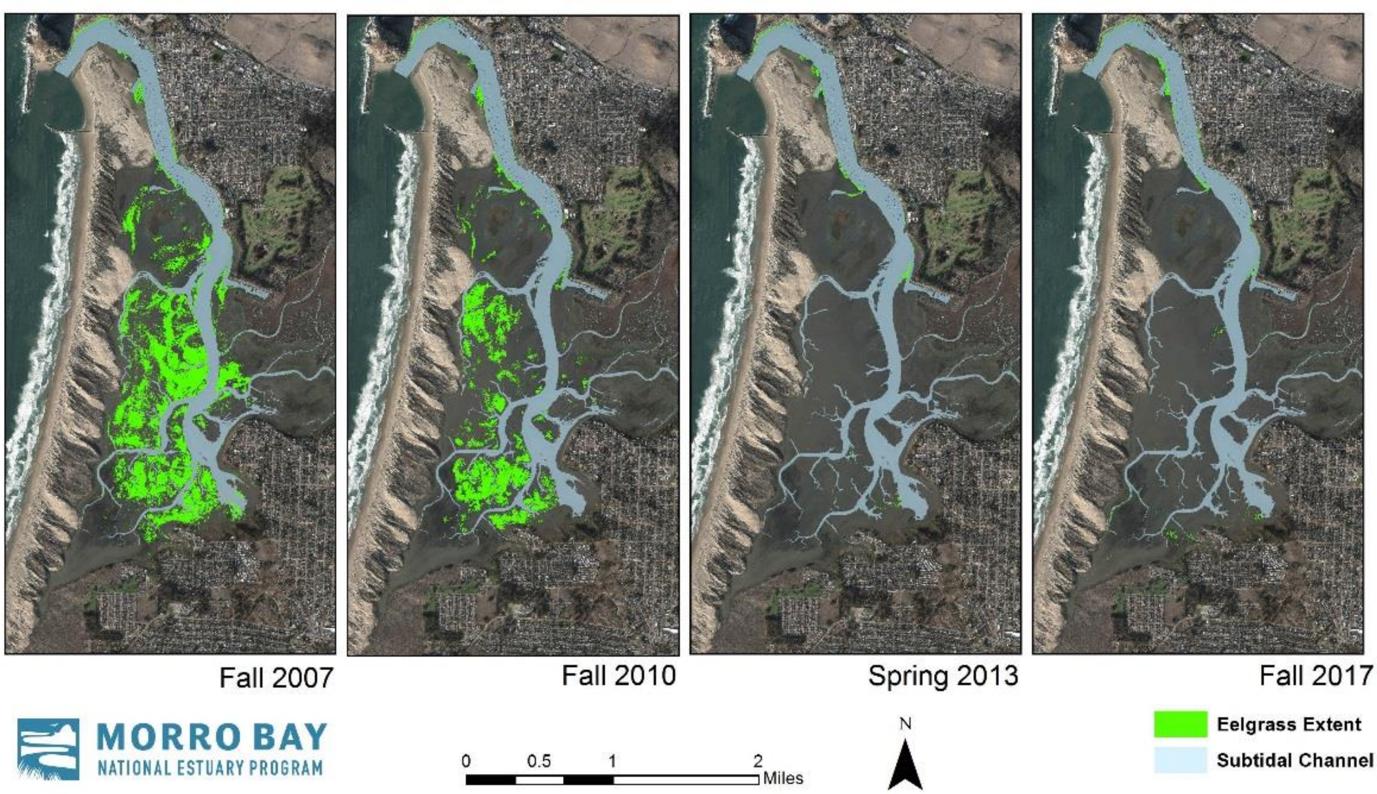


Figure 5. Loss of intertidal eelgrass in Morro Bay from 2007 to 2017.

The time series of maps in Figure 5 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. Some of the patches of eelgrass appear to be seasonal, with patches disappearing and new patching forming in areas from year to year while other areas seem to be persistent and are expanding outward from year to year.

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. M&A also deployed seed bags in a few locations to try out this restoration method.

These large restoration plots were monitored during the July following each transplant approximately one year after planting. In 2013 and 2014, M&A found about 45% of the plots retained eelgrass. In 2015, very little eelgrass was found. Based on these results, the transplant effort that had been scheduled for 2015 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.

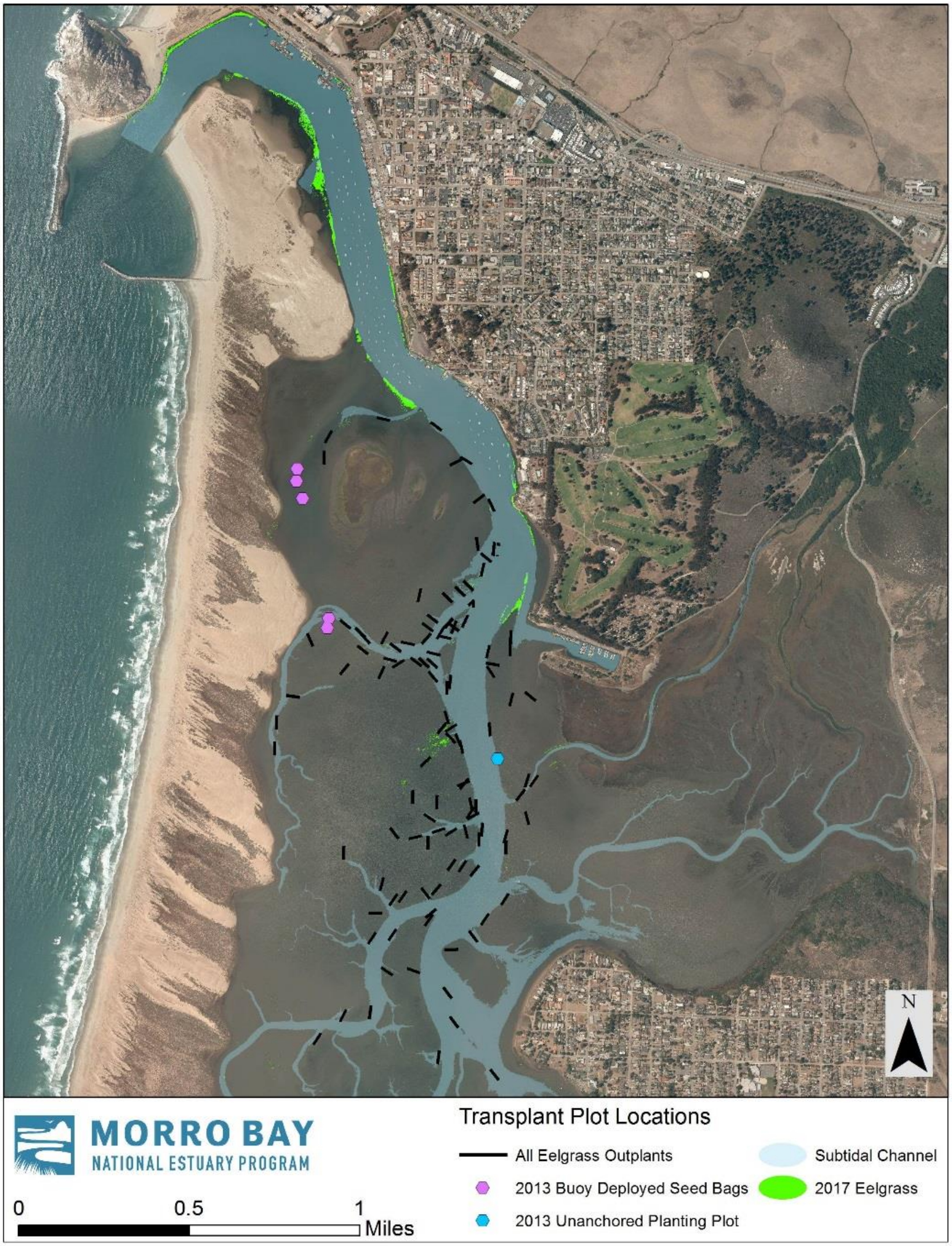


Figure 6. Transplant plots from 2012, 2013, and 2014 transplant efforts, with the eelgrass map from the December 2017 mapping effort.

2017 Estuary Program Transplant Efforts

In March 2017, a small-scale experimental restoration effort was conducted over a three-day period by the Estuary Program, California Sea Grant, and Cal Poly. The timing of the planting was selected based on spring planting efforts conducted by the Elkhorn Slough National Estuarine Research Reserve. This timing was selected to allow planted eelgrass to become established prior to the typical summer macroalgae blooms that compete with eelgrass and potentially different water quality impacts during these two seasons.

For the Morro Bay effort, eelgrass shoots were collected from the existing eelgrass bed at Coleman Beach on foot and by hand on low tides. The eelgrass was prepared for planting by trimming the shoots to 20 cm, trimming rhizomes to 10 cm, removing multiple shoots so that there were no more than two per rhizome, and gently scraping the blades clean of epiphytes.

Planting occurred just after harvesting and plant preparation, while the transplant sites were exposed. 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 with 72 plants each, totaling approximately 576 transplanted eelgrass plants for this spring effort. At each site, plot locations were within the intertidal or low intertidal zones, and placed at least 4 m apart at a similar elevation profile (approximately -0.4 ft). See Figure 7 for the transplant locations. To plant the eelgrass, two rhizomes and attached shoots were crisscrossed and a u-shaped garden stake anchored the bundle.

Figure 7. Map with eelgrass restoration locations for 2017 and 2018.

In July 2017, a second small-scale experimental restoration effort was conducted over a four-day period by the Estuary Program and Cal Poly. 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, water quality changes, etc.). Eelgrass shoots were harvested and held overnight before transplanting due to the early morning timing of the low tides. Eelgrass shoots were collected from Coleman Beach. Harvesting occurred on foot and by hand at low tides, targeting shoots that were at least 20 cm long with rhizomes at least 7 to 10 cm long or four to eight nodes. Immediately after collection, the eelgrass was prepared for planting by trimming shoots to 20 cm and rhizomes to 10 cm, if rhizomes were longer than 10 cm. No other processing of shoots occurred. A total of 753 rhizomes were collected for this summer effort. The prepared eelgrass plants were held overnight in dive bags hung from a floating dock.

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 (approximately -0.4 ft.) and placed at least 4 m apart. The same planting method from the spring was used.

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, eelgrass transplants at 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.

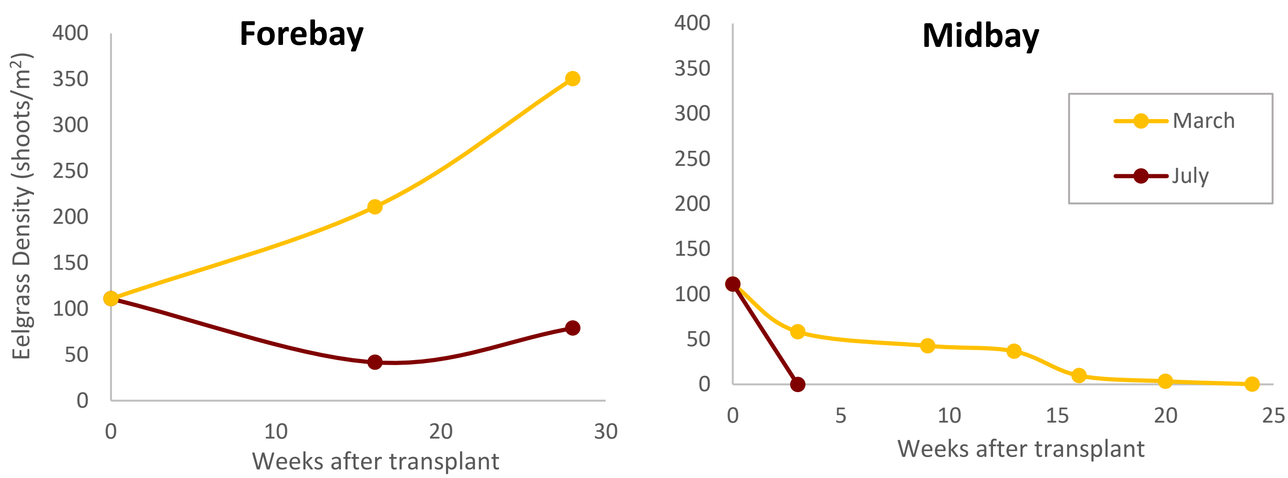


Figure 8. Eelgrass shoot densities (shoots/m^2) for the March and July transplants in the forebay and midbay (Aiello 2018).

The below photos show examples of single forebay plots that were planted in the spring and the summer and illustrate the extensive growth when planted in the spring. The forebay plots planted in the spring are about five times larger than the original area planted and have densities similar to that of the donor beds. In comparison, the forebay plots planted in the summer either did not survive or maintained about the same area as when originally transplanted.

Forebay plot (T1) after 18 months of growth. Plot was planted in spring 2017.

Forebay plot (T1) after 13 months of growth. Plot was planted in summer 2017.

Spring 2018 Restoration Efforts

The MBNEP completed small-scale transplanting efforts in February and March 2018. The five transplant locations represented a range of conditions throughout the extent of the estuary including sites in the forebay, midbay, and backbay. Collection and transplanting occurred in the spring, as previous experimental efforts in 2017 showed that planting in March had a higher success than planting in July.

Eelgrass rhizomes were collected primarily from eelgrass beds near Coleman Beach (1,659 total rhizomes collected) with a smaller portion collected at Tidelands (283 total rhizomes collected) (Figure 7). The total allowed eelgrass collection for transplanting was 2,250 rhizomes. Eelgrass mitigation beds and areas used for long-term monitoring were avoided. Eelgrass was collected on foot and by hand at low tides, taking care to not collect more than three rhizomes per square meter, which was the allowed amount in the scientific collection permit. Harvesting only occurred in each location of the bed one time. In the planting from February 25 to 28, harvesting days had low tides between -0.5 and -1.4 ft and for the March 26 to 28 effort, low tides were between -0.6 to -0.8 ft. Eelgrass was collected just before the lowest daily tide during both months. Pre-harvesting density counts near Coleman Beach ranged from 168 to 388 shoots/m^2 with an average of 336 shoots/m^2. Average post-harvesting density counts at Coleman Beach were 420 shoots/m^2, keeping within the allowed 10% take of eelgrass per square meter. Pre-harvesting density counts at Tidelands ranged from 264 to 420 shoots/m^2 with an average density of 347 shoots/m^2. Post-harvesting density counts at Tidelands were 392 shoots/m^2.

Once eelgrass was collected, no processing of the blades was conducted (e.g., removal of epiphytes, trimming of blades, etc.). Longer rhizomes (greater than 10 cm) were left at the length they were harvested at and planted horizontally leaving the full length of the rhizome intact. All plants were counted and placed in large plastic transport containers filled with 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 outside of the transplant quadrats. Care was taken to keep the plants in fresh, cool estuarine water, covered, and shaded. All rhizomes were mixed between collection buckets at a donor location to maximize diversity among the transplant plots. Harvested eelgrass from Coleman Beach was not mixed with eelgrass from Tidelands. Harvested eelgrass was placed in dive bags and held overnight off of a floating dock in the forebay about halfway between Coleman Beach and Tidelands.

Eelgrass was transplanted at one forebay, three midbay, and one backbay location within Morro Bay (Figure 7). The forebay plot location (T1) extended immediately north from the planting site that was planted there in 2017. At the forebay site, three plots each were planted at three different depths for a total of nine plots at the site. The middle depth was planted at approximately -0.4 ft and represented the same elevation where eelgrass was planted in 2017. The three shallower plots were planted at approximately -0.1 ft and the deeper plots at approximately -0.7 ft. For the three midbay locations (T3, T4, T5), three plots were planted at roughly the same elevation (-0.5 ft) at each location.

The backbay site (T6) had four plots planted at the same elevation (1.4 feet). The elevation at the backbay site was much higher than the other sites but had eelgrass present nearby. For the 22 plots planted in spring 2018, the total rhizomes transplanted totaled 1,584. Some individual rhizomes had more than one shoot present and were counted before planting for future monitoring.

The 2018 eelgrass transplant locations were as follows:

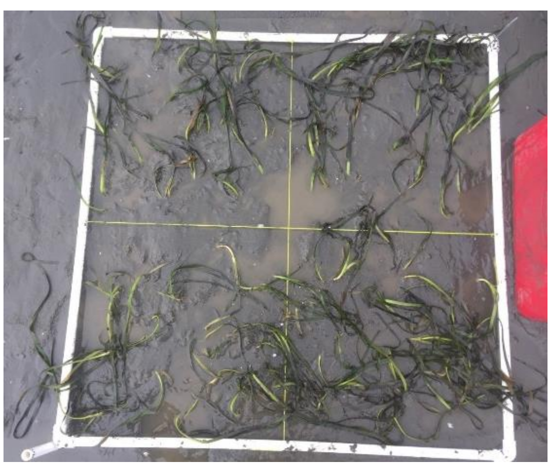
- Forebay T1 (north of 2017 restoration plots): 35.35462, -120.84970
- Midbay T3 (near State Park Marina): 35.34464, -120.84673
- Midbay T4 (near Grassy Bar Oyster Co.): 35.34290, -120.84887
- Midbay T5 (near Grassy Bar Oyster Co.): 35.33845, -120.84721
- Backbay T6 (near Doris Ave.): 35.32239, -12084675

To transplant eelgrass within plots at all locations, two eelgrass rhizomes were crisscrossed to form a "bundle" and secured in the sediment with a two-sided metal garden stake, similar to the 2017 transplanting effort. A plastic putty scraper was used to create a shallow slot for placing rhizomes horizontally just below the sediment surface. Bundles were spaced approximately 15 cm apart for a total of 36 bundles or 72 rhizomes in each plot. Small PVC poles (20 cm above substrate) were also placed immediately outside of the plot corner to aid in relocating restoration sites. Coleman Beach supplied donor eelgrass for sites T1, T4, T5, and T6. Tidelands donor bed supplied eelgrass for the State Park Marina site (T3).

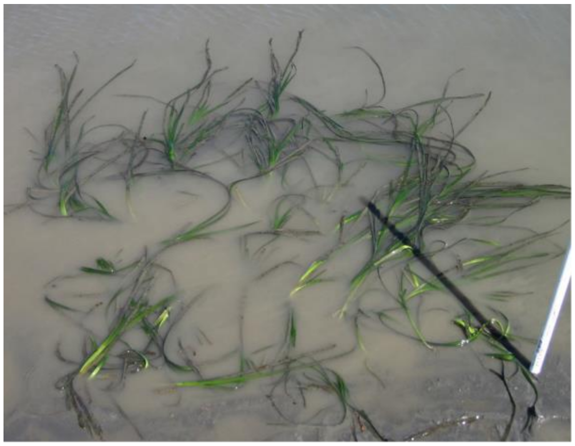
At the two midbay sites (T4 & T5) and the backbay site (T6), eelgrass was also planted with a different anchoring method. Rather than garden stakes, eelgrass was tied with jute string to 3/16-inch smooth rebar that was three feet long with one end bent to hold the rebar into the sediment. Twenty-five rhizomes were tied to each rebar piece. There were three rebar pieces at each of the three sites (T4, T5, T6), totaling nine rebar pieces. The rebar plantings were placed at approximately the same depth as the plots at each site. Rebar plantings were spaced one meter apart from each other and marked with small PVC poles (20 cm above substrate) to aid future monitoring. The total eelgrass collected for the rebar method was 225 rhizomes.

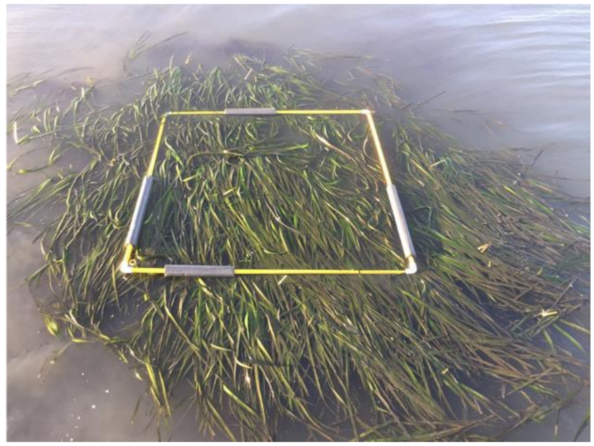
Monitoring of the plots and rebar plantings have shown a large increase in both shoot density and expansion beyond the original one-meter plots. The forebay and midbay sites began spreading directly after planting. The backbay site did not demonstrate success until monitoring in early November 2018. Overall, all plots and rebar plantings were growing. The following photos and charts (Figures 9 and 10) illustrate the substantial growth of the plots at all sites. At the forebay site, all three depths (-0.1, -0.4, -0.7 ft) were also growing well.

Forebay site- middle depth (T1). Immediately after planting (left). Nine months of growth (right).



State Park Marina site (T3). Immediately after planting (left). Nine months of growth (right).





Midbay site (T4). Immediately after planting (left). Eight months of growth (right).

Backbay site (T6). Immediately after planting (left). Eight months of growth (right).

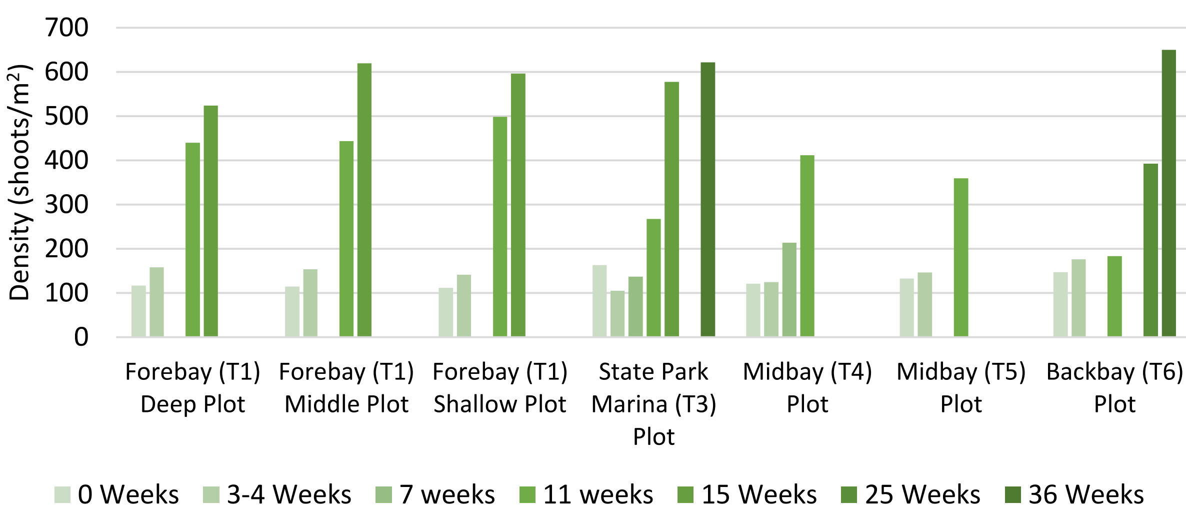


Figure 9. Change in average eelgrass plot density over time. Plots were monitored at different intervals, but all 2018 plots have increased in density and expanded from the original plots.

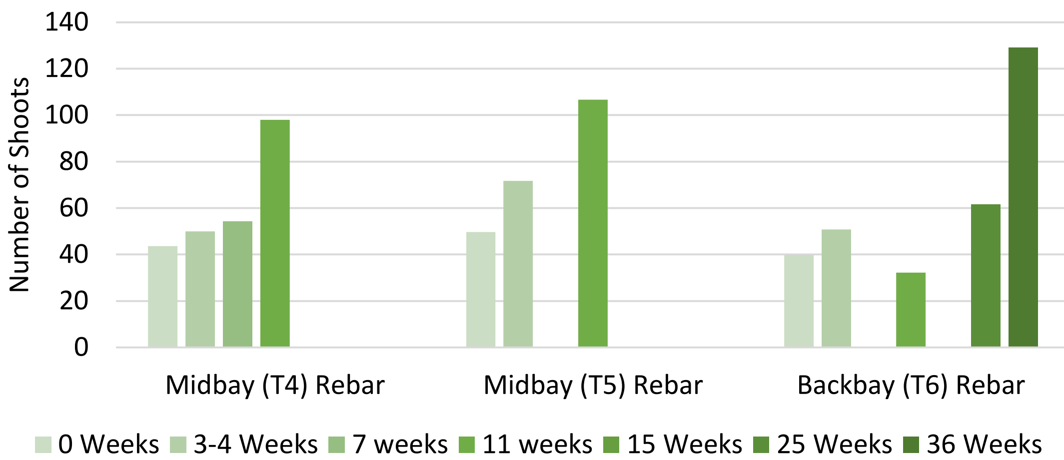


Figure 10. Number of eelgrass shoots per rebar planting. Shoot numbers averaged for multiple rebar pieces. All three sites where the rebar method was used showed an increase in shoots.

Fall 2017 Seed Restoration Results

The Estuary Program completed a small-scale effort to monitor, collect, and transplant eelgrass seeds for re-establishment in the Morro Bay estuary. Eelgrass flowering blades were collected over a range of dates and locations. Any areas that were used for long-term monitoring or eelgrass mitigation beds were avoided. The collection permit allowed for collection of 300 blades each from Windy Point, Coleman Beach, and North Sandspit eelgrass beds. The initial intention was to collect seeds from each of these beds; however, Windy Point did not flower at high enough densities to allow for collection. Therefore, harvesting occurred for the full amount allowed by the permit from both Coleman Beach and North Sandspit, totaling 600 flowering blades.

Seeds were collected by hand on paddle boards by pinching off the flowering blades from the shoot. Each flowering shoot had many blades (approximately 5 to 15 flowering blades/shoot), and each blade collected had anywhere between two to ten seeds. Seeds were collected at stage 4 and 5. Seeds were placed in dive bags off of the boat docks near the Estuary Program's office in Morro Bay until seeds were in the final stage of development and were released from the ovary sack.

Seeds were then placed in two-inch burlap packets (with edge for staking). Each burlap packet contained ten seeds. Fifteen burlap sacks were placed within a one-by-two meter plot and staked down. Packets were checked to ensure approximately 2 to 3 cm of sediment were covering the seeds. Plots were marked with small PVC markers on all four corners of the plot. One plot was planted at each of these three locations (Figure 7).

- Forebay (north of 2017 restoration plots): 35.35516, -120.85084
- State Park Marina (off main trail): 35.34543, -120.84506
- South Bay (off Ramona Dr.): 35.322219, -120.85517

The State Park Marina site was planted on November 1, 2017, the Forebay on November 2, 2017, and the South Bay site on November 17, 2017. The depth of the Forebay and the State Park Marina sites was 0 to -1 ft. The site in the South Bay was planted at a higher elevation (~0.5 to 1 ft) but naturally established eelgrass was growing close by at a shallower depth. Additionally, some seeds were placed directly into the sediment (2 to 3 cm depth) by hand without being placed in a burlap packet.

Monitoring of the seeds was conducted in winter and spring of 2018. As of March 2018, the State Park Marina site had three seedlings (from loose seeds, not placed within seed bags), and the Forebay site had no germination. The Mitchell Drive site germinated earlier than expected, with 15 seedlings in mid-January. There were 20 in the beginning of February, but dropped down to five seedlings as of late March (all grown within seed bags). As of November 2018, there were no seedlings at the Forebay or State Park Marina. The Mitchell Drive site in the backbay did have seedlings. Some of them were within the plot but not necessarily within the burlap sacks, so a final count is uncertain at this location.

Due to the level of effort and the limited success, the Estuary Program opted to not conduct additional seed harvesting and planting in 2018. The effort may be revisited in the future.

Other Monitoring Efforts

In addition to monitoring the restoration plots, there were 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 plots were established by Cal Poly and California Sea Grant in 2018.

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 11. The six current permanent transect monitoring locations.

Methods

Fieldwork was usually 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 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 12.

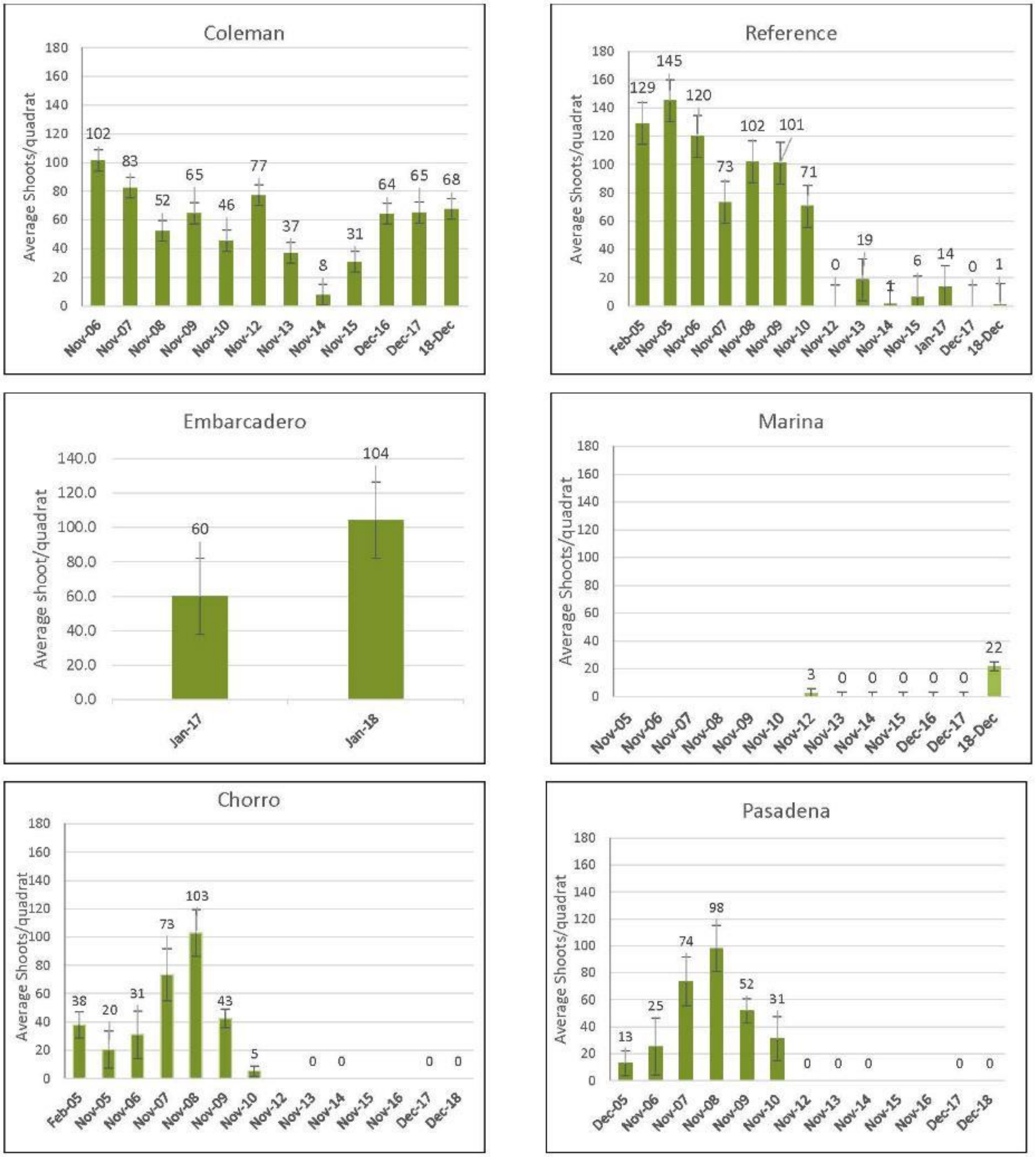


Figure 12. Average shoot density counts per year at six sites. Shoots were counted within a 0.5 m x 0.5 m quadrat. Error bars represent the 95% confidence interval.

Average shoot densities have clearly declined at each site, and Coleman Beach appears to be the only site where densities have recovered. Densities at Colman have remained stable since 2015. While the new Embarcadero transect has no historic data to compare to, 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 2018, it had an average of 104 ± 23 shoots, which makes it the densest bed of all the permanent transect locations.

The permanent transects were established to track eelgrass density, however the overall decline has prevented this from being the optimal 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. The Estuary Program collaborated with Cal Poly and Sea Grant to develop a new monitoring protocol called Bed Condition Monitoring.

Permanent Transect Photos and Observations

Photos were taken to document site conditions.

Coleman Transect

The 2017 shoot density counts were almost identical to the 2016 counts. In 2018, eelgrass at the Coleman transect was less dense than at the Embarcadero site.


Nov 4, 2010


Dec 14, 2016

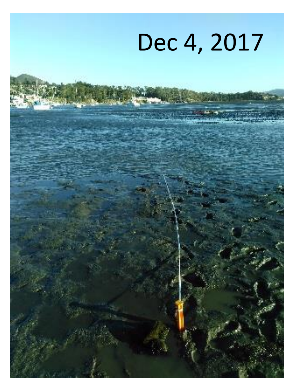

Dec 7, 2018

Reference Transect

Previously known as "Tidelands." While there was no eelgrass on the completed transect, a small patch of ten shoots was present. Unable to survey the deeper transect due to water, and photos were not taken due to water. Monitored on December 20, 2018.


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. In 2018, eelgrass appeared healthy and dense, without a lot of epiphytes.


Dec 4, 2017


Dec 6, 2018

Marina Transect
Patchy eelgrass was present in the area in 2016 but not in 2017. In 2018, patchy eelgrass was present along all three transects, as well as nearby.


Nov 15, 2013


Dec 13, 2016


Dec 5, 2018

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. As in 2017, there were small patches of eelgrass ranging in size from 0.0625 m^2 to 0.25 m^2.

Chorro Transect

The area was surveyed in 2014, and there was no eelgrass present. It was not surveyed in 2015 or 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.

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, seven-quadrat survey. Both intertidal and subtidal eelgrass are surveyed, as much of the intertidal eelgrass has died. 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 continue only with the spring monitoring and halt the fall monitoring. Thus, in 2018, monitoring was conducted by Cal Poly in the spring and monitoring was not conducted in the fall. The Estuary Program plans to continue this monitoring each spring in future years, with analysis to be conducted by Cal Poly.

Cal Poly's spring 2018 monitoring effort was conducted at Coleman Beach, North Sand Spit, Reference Bed, and Windy Cove sites. The photos have been evaluated but the data analysis is not yet complete.

Figure 13. Bed condition monitoring sites at Coleman Beach, North Sandspit, Reference Bed, and Windy Cove.

Permanent Plots

In addition to bed condition monitoring, Dr. O'Leary established small permanent plots throughout Morro Bay during 2018. These sites are identified as Mitchell, Oyster Bed, Windy Point, Reference, and Coleman Beach. These plots are monitored approximately quarterly throughout the year to track seasonal changes in eelgrass condition. Data management and analysis are currently underway. This data is support by a Sea Grant project which will conclude in 2020.

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.

A pre-dredge survey occurred on April 19 and 20, 2018 to assess eelgrass presence in the area of potential effect (APE). The ACOE assumed that areas within 50 ft of the dredging area would not be impacted. The pre-dredge survey did not identify any eelgrass within the APE or within 50 ft of the area. The survey mapped 11.9 acres of eelgrass in the forebay area. Eelgrass condition was assessed at three reference locations in the bay, and the results were that the eelgrass was healthy. The survey assessed the area known as the Morro Channel where there was concern that dredging during the previous year might result in bank slumping and eelgrass loss. The survey determined that additional slumping did not occur. The scarp partially healed and an expansion of eelgrass in two areas was noted, resulting in an increase of approximately 2 m^2 of eelgrass. However, the toe of the slumped terrace that extended into the channel in 2017 lost a band of eelgrass, resulting in a loss of 13 m^2 of eelgrass. Thus, this bed experienced a net loss of 11 m^2 of eelgrass. While the reason for the loss is not clear, the survey determined that additional losses are unlikely (M&A 2018).

In 2018, the ACOE issued a dredging contract with the Portland District hopper dredge, Yaquina, to dredge portions of the Harbor Entrance Channel, Transition Area, and Main Channel up to Channel Marker 8. Dredging was conducted from May 1 to 18. The ACOE concluded that there were no impacts to eelgrass, thus a post-dredge survey was not conducted (M&A 2018).

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 2018, surveys were conducted to support three construction projects on the Embarcadero. The conclusions of the pre-construction surveys were as follows:

- A survey for a walkway construction project noted two small patches of eelgrass, but the report concluded that neither the construction nor the completed walkway structure would impact the eelgrass.
- A survey for a project to conduct dock work and a seawall repair identified two very small patches of eelgrass. Past surveys have indicated small patches that have not persisted. The survey report concluded that removing the docks to clear the area to repair the seawall and the seawall repair itself should not impact eelgrass.

- A survey for a project to replace and add docks estimated that 9 to 10 m^2 of eelgrass could be permanently shaded by the project. To help offset these impacts, in June a floating dock was removed permanently to reduce shading and improve habitat. A section of dock was relocated to its original location where no eelgrass occurs, and grated panels were incorporated into the dock and access ramp to allow light to reach the seabed. Given the unusual conditions of this specific project, ACOE allowed a one-time out-of-kind mitigation fee to be dedicated to eelgrass mapping and research. The Estuary Program was selected as the non-regulatory recipient of this fee (which was received in 2019) and will utilize the funding within two years.

While the projects are all at various stages of completion, no eelgrass has yet been significantly affected.

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

Various research efforts are underway related to Morro Bay eelgrass. They are briefly summarized, including an estimate of when results will be available.

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. Generally, the study found that fish numbers and biomass in Morro Bay have not changed since the eelgrass die-off.

Water Quality Monitoring

Dr. Ryan Walter from 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. In the summer of 2018, Walter deployed two sensor array locations for a month to track water quality conditions in the bay during the dry season. This data will be compared to a sensor deployment in the winter of 2019, and results will be available in early 2020. This work is funded by a Sea Grant award.

Dr. Walter conducted a series of three cruises in the summer of 2018 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. At the same time, Dr. Emily Bockmon of Cal Poly's Chemistry Department conducted measurements of estuarine water carbonate chemistry. Analysis and reporting is currently underway.

Dr. Bockmon is also working with a graduate student to collect weekly samples at six shoreline locations throughout the bay from August to December. The water is being analyzed for pH, dissolved inorganic carbon, and total alkalinity. Data will serve as a baseline understanding of the chemistry conditions of the water in the bay. Early results indicate an elevation carbon dioxide concentrations and total alkalinity of the water of the back bay, such that the estuary likely acts as a source of carbon dioxide to the ocean and the atmosphere.

Graduate Research

The thesis work of Erin Aiello of Cal Poly focused on the spatial and temporal effects on eelgrass restoration success. Her work also touched on other factors that impact eelgrass success. These factors and a brief summary of her findings are as follows:

- Salinity: Measurements in spring 2017 indicated wide swings in salinity in the midbay (5 at low tide versus 33 at high tide). Research in other areas indicate eelgrass is negatively impacted by salinities 7.5 below ambient levels. These low saline conditions were caused by freshwater loading during rain events. In the forebay, the mean salinity was 32.9 while the minimum was 30.1.
- Epiphytic Loading: While other studies found this to be an important factor in eelgrass restoration success (lower epiphytic growth on eelgrass blades having greater success), it does not appear to be the case in Aiello's study. The forebay transplants had slightly higher epiphytic load than the mid-bay transplants, but this did not hinder the success of the forebay transplants.
- Water Temperature: During the time period of the study, forebay water temperatures remained below 20°C, except during a few brief anomalous periods in July, August, and September. Waters in the midbay reached higher than 20°C at least once each month from May 2017 to September 2017. Elevated water temperatures in the midbay may have contributed to reduced restoration success in 2017 plantings.
- Sediment: The clay percent was higher at the midbay site than what is thought to be optimal for eelgrass. Previous research indicates silt with 0 to 12% clay provides better substrate for eelgrass. Aiello's work found a clay percent of 13.7% in the midbay. At the forebay transplant site, the substrate was 10% clay. Other areas in Morro Bay which still sustain eelgrass exhibit lower levels of clay: 10% at Windy Cove and 3% at Coleman Beach.
- Carbon and Nitrogen in Sediment: Sediment was analyzed for carbon and nitrogen content. Collection was conducted in the summers of 2016 and 2017. Carbon content and the carbon to nitrogen ratio are higher in the back bay and decrease closer to the bay mouth.

Drone Mapping of Eelgrass

As part of the Sea Grant project, Cal Poly is conducting annual drone flights to map eelgrass baywide. The first map was created in December 2017, and the operation was repeated in December 2018. The 2018 images are currently being processed, and the eelgrass is being hand digitized. Initial analysis indicates quite a few small patches in new locations from 2017. The work is expected to be completed by the summer of 2019.

Sediment Substrate Mapping

Dr. Walter collected sediment samples from 18 different sites throughout the bay in the subtidal and intertidal depths using grab samples from a boat and sediment cores. Samples were analyzed for grain-size composition, and data analysis is underway.

Crab Biodiversity and Otter Indirect Effects

Dr. Lisa Needles from Cal Poly's Biology Department has been conducting lab and field trials to determine crab impact on eelgrass. She is looking at three different species of crab. Preliminary results in both field and lab trials show a statistically significant impact from crabs on eelgrass. Whether this is a biologically significant impact in the field is yet to be determined. The next phase of the project is to install cages that will allow natural populations of crabs to have access to recovering eelgrass.

Summer 2018 Eelgrass Wasting Disease Research

Eelgrass blade sampling was completed in Morro Bay during May 31 through June 2, 2018 by Cuesta College professors Drs. Laurie McConnico and Silvio Favoreto, Estuary Program staff, and biology students at Cuesta College. Individual blades were collected as a part of the sampling protocol to examine for the presence of *Labyrinthula spp.* on eelgrass (*Zostera marina*) within the estuary. A total of 92 blades were collected from the outside of plants, by hand picking blades at the base of their attachment points. Whole plants were not collected. On May 31, a total of 24 blades were collected from the backbay near the Doris Avenue public access trail in Los Osos. On June 1, 24 blades were collected at Coleman Beach access point and 22 blades were collected from the mid channel of the Morro Bay estuary. Finally, on June 2, 22 blades were collected from Windy Cove. Individual blades are being processed for culture of *Labyrinthula spp*. and future DNA extraction and qPCR. These samples are housed at Cuesta College in San Luis Obispo. Results of this effort are expected in fall 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 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 14 for brant numbers seen in Morro Bay over the past 20 years (Roser 2019). Roser's data for the 2018 to 2019 season should be available in spring 2019.

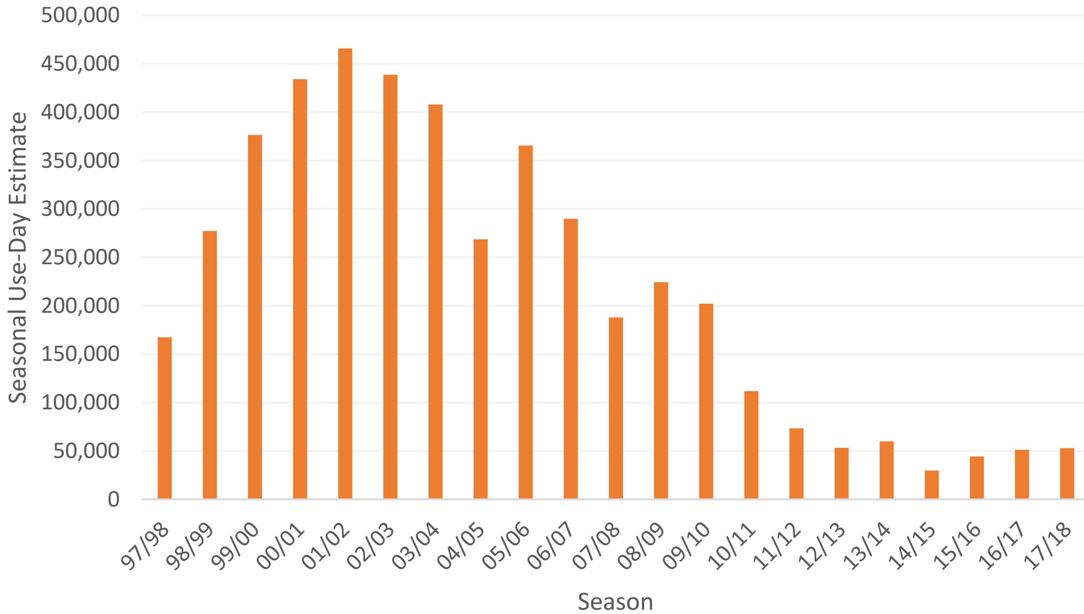


Figure 14. Brant seasonal use-day estimates in Morro Bay from 1997 to 2018 (data adapted from Roser 2019).

Cal Poly graduate student Dakota Osborne is studying the impacts of brant grazing on eelgrass. He installed brant exclosure cages, which are fairly open cages which the brant will not enter and thus prevent them from feeding on eelgrass. He is installing them in eelgrass beds and then taking measurements in the beds to determine brant grazing effects in caged area as compared to uncaged areas. Observations were taken in December 2018 and will be repeated weekly until the Brant leave the area in the spring. The results are expected to be available in late 2019 or early 2020.

Upcoming Projects in 2019

Bathymetry Mapping

Funding has been secured to conduct a complete bay-wide bathymetry map utilizing sonar and LiDAR. The effort also includes deployment of tide height stations. The effort 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. The project is being run through NOAA's Office for Coastal Management. Data acquisition is expected in the spring of 2019 with completed data available in the summer.

Baywide Eelgrass Map

Plans are underway for the Estuary Program to contract for a baywide aerial survey and mapping effort in December 2019. This work involves classification of submerged aquatic vegetation, including eelgrass.

Restoration

Restoration was conducted in February and March of 2019. Monitoring will continue for the 2019 transplants as well as restoration conducted in 2017 and 2018. These results will be available in the Estuary Program's 2019 Eelgrass Report.

Other Monitoring

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

Additional Research 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. Cal Poly is planning on another round of drone flights in December 2019 to map eelgrass baywide. They will also continue their bed condition monitoring protocol in 2019. Cuesta College will continue its research on wasting disease and its impacts on Morro Bay eelgrass, which is expected to be concluded in the fall of 2019.

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 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 the April 2017 and the December 2017 mapping efforts. 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 are growing and expanding, such as our 2018 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 2019, 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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