Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2021

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, water purification, and sediment accretion and stabilization (Nordlund et al. 2017). Eelgrass (*Zostera marina*), like other seagrasses, is a critical foundational habitat. Eelgrass creates habitat that leads to increased abundance and diversity of many invertebrate and fish species, and it serves as a nursery for ecologically and commercially-valuable species.

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

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

The Estuary Program has witnessed fluctuations in total eelgrass acreage for the past two decades. From 2007 to 2016, more than 90% of Morro Bay's eelgrass disappeared, spurring many recent restoration, monitoring, and research efforts. Since 2016, eelgrass began to re-establish in areas where it previously declined. Through restoration and natural recruitment, the past few years have been marked by significant growth, with eelgrass acreage now at pre-decline levels.

This report summarizes all Morro Bay National Estuary Program (Estuary Program) and partners' eelgrass-related activity in 2021, including mapping efforts, restoration, and detailed monitoring of new sites and existing eelgrass beds.

Morro Bay Project Area

Morro Bay is a shallow coastal lagoon located on California's Central Coast in San Luis Obispo County. Founded in 1870, the town of Morro Bay (population 10,861) is located in the northern extent of the estuary. The unincorporated community of Los Osos (population 14,503) 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.

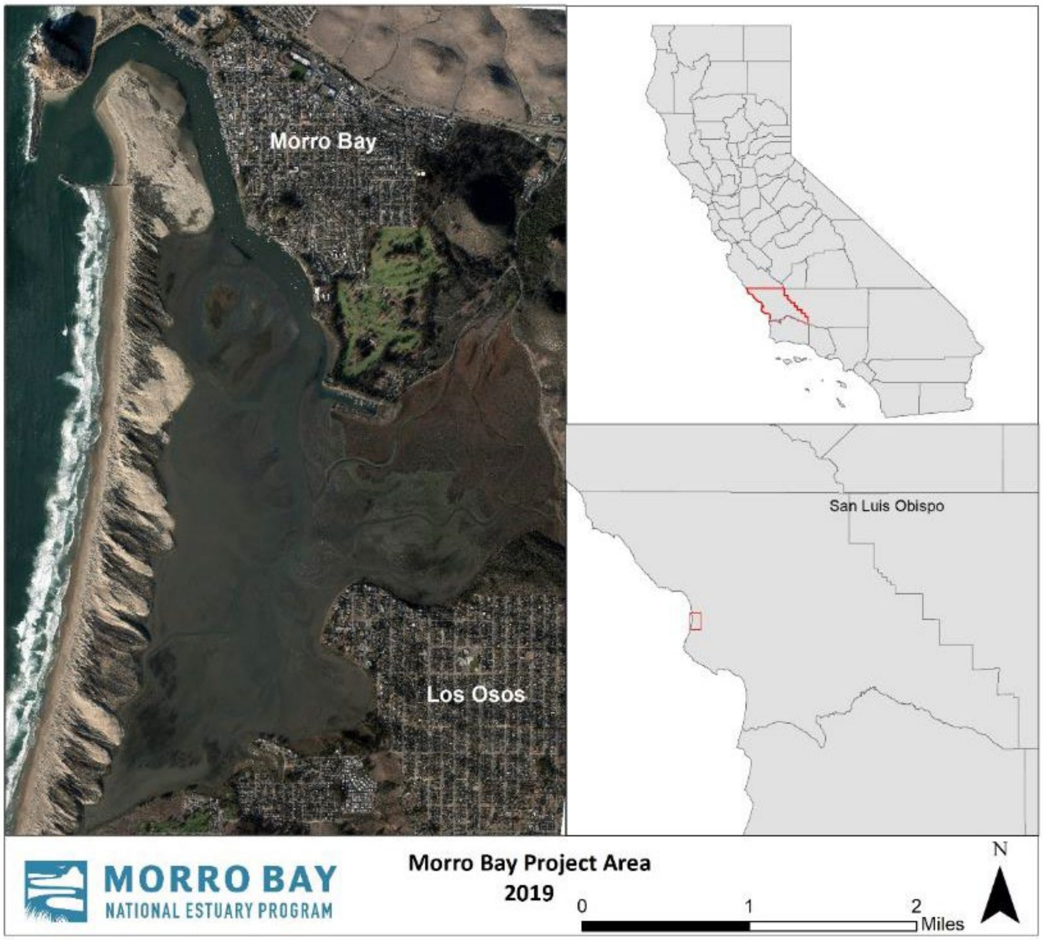

Figure 1. Morro Bay and location within San Luis Obispo County.

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 sand spit 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.

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

Eelgrass Distribution

Mapping Efforts

Morro Bay's eelgrass population has been mapped for decades, but 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 completed in later years. Between 2004 and 2013, intertidal eelgrass was mapped by multispectral aerial images. Flights were typically completed during extreme low tides in November. In 2012, the flight had to be canceled due to weather conditions and was instead completed in May 2013. Merkel & Associates (M&A) surveyed the bay in July 2013 and July 2015 using sidescan sonar, a method that targets mostly subtidal eelgrass.

In 2017, a combination of sidescan sonar and unmanned aerial vehicle (UAV) imagery were seamed together to map intertidal and subtidal eelgrass bay-wide. Multispectral aerial imagery was used to create a classification of intertidal submerged aquatic vegetation, which was groundtruthed by the Estuary Program. Multispectral imaging was collected by Ocean Imaging (OI) again in 2019 to identify eelgrass bay-wide and quantify acreage of other exposed and submerged vegetation and substrate types. Further details from this analysis can be found in the Estuary Program's 2019 Eelgrass Report.

UAV Drone Mapping

Since 2017, California Polytechnic State University, San Luis Obispo (Cal Poly) has surveyed eelgrass in Morro Bay annually using a UAV. This method of mapping is less expensive than multispectral imaging, allowing it to be collected more frequently. For each survey, a UAV technician flies a drone over the bay at a standard height of 400 feet during a series of negative tide windows. Thousands of photos are stitched together and georeferenced to create a bay-wide map. The eelgrass is then quantified in ArcGIS, a Geographic Information System (GIS) software, by manually digitizing eelgrass beds into individual polygons.

Researchers at Cal Poly mapped intertidal eelgrass throughout the entire bay in November and December 2021 using drone-based imagery (DJI Phantom 4 Pro with 20 megapixel camera). The surveys required 4-5 days of extreme low tides (approximately -1ft relative to MLLW) to expose the intertidal reaches of the bay and regions of intertidal eelgrass. In total, over 4,600 images of the bay were taken using a high-resolution camera (1.32 in/pixel) at a relatively low altitude (400 ft), resulting in very accurate imagery. These images were stitched together using Agisoft Metashape Professional to create an orthomosaic of the bay.

Estuary Program staff then manually digitized eelgrass into individual polygons in GIS. To support digitizing and verify results, staff completed extensive ground truthing of the bay from December 2021 to March 2022 using sub-meter accuracy GPS units.

Figures 2A, 2B. Resolution of photos captured with Cal Poly's UAV drone during winter of 2021. Figure 2A shows a dense eelgrass bed and monitoring of permanent plots, and Figure 2B shows how eelgrass acreage is digitized using drone imagery of the bay.

Eelgrass Acreage Data

The following table and figure present Morro Bay's eelgrass acreage over time and the method of data collection. It is important when comparing these data to keep in mind that the mapping methodology has changed over time. Between differences in mapping techniques (e.g., drone mapping, sonar) and differences in estuary conditions during mapping events (e.g., water clarity, tide height), the extent of eelgrass coverage captured can vary. Previous versions of this report are available at http://www.mbnep.org/library and include additional historical data information and sources.

Table 1. Eelgrass acreages and mapping methods, 1960 to 2021.

Year	Time of Year	Eelgrass Acreage	Method
1960	Unknown	335	Field surveys (Haydock)
1970	Unknown	452	Aerial photos (CA Fish & Game)
1988	Unknown	404	Aerial photos (Josselyn), reinterpreted (Chesnut)
1994	Late Sept to early Nov	435	Quadrat sampling (Chesnut)
1995	Late Sept to early Nov	260	Quadrat sampling (Chesnut)
1996	Late Sept to early Nov	165	Quadrat sampling (Chesnut)
1997	Late Sept to early Nov	98	Quadrat sampling (Chesnut)
1998	Unknown	125	Aerial photos (Tetra Tech)
2002	November 25, 2002	149	True color aerial images, reanalyzed (Estuary Program with Golden State Aerial and Ocean Imaging)
2003	November 21, 2003	167	True color aerial images, reanalyzed (Estuary Program with Golden State Aerial and Ocean Imaging)
2004	November 24, 2004	267	Multispectral aerial images (Estuary Program with Ocean Imaging)
2006	November 6, 2006	287	Multispectral aerial images (Estuary Program with Ocean Imaging)
2007	November 24, 2007	344	Multispectral aerial images (Estuary Program with Ocean Imaging)
2009	November 13, 2009	240	Multispectral aerial images (Estuary Program with Ocean Imaging)
2010	November 4, 2010	176	Multispectral aerial images (Estuary Program with Ocean Imaging)
2013	May 28, 2013 for multi-spectral imagery, July 2013 for sonar	15	Multispectral aerial images (Estuary Program with Ocean Imaging) and sonar (M&A)
2015	July 2015	13	Sonar (M&A)
2017	April 2017	14	Sonar and UAV (M&A)
2017	December 3, 2017	13	Multispectral aerial images (Estuary Program with Ocean Imaging)
2017	December 1 to 4, 2017	9	UAV (Cal Poly, Sea Grant)*
2018	December 6, to 8, 20 and 21, 2018	16	UAV (Cal Poly, Sea Grant)*
2019	November 26, December 11 to 13, 23 and 24, 2019, January 8, 2020	37	UAV (Cal Poly)*
2019	November 24, 2019	42	Multispectral aerial images (Estuary Program with Ocean Imaging)
2020	November 14 to 16, December 14 and 15, 2020	146	UAV (Cal Poly)*
2021	December 2, 3, and 4, 2021 January 1, 2022	500	UAV (Cal Poly)*

*Note that the UAV imagery and manual digitization process has approximately a 10% error associated with it.

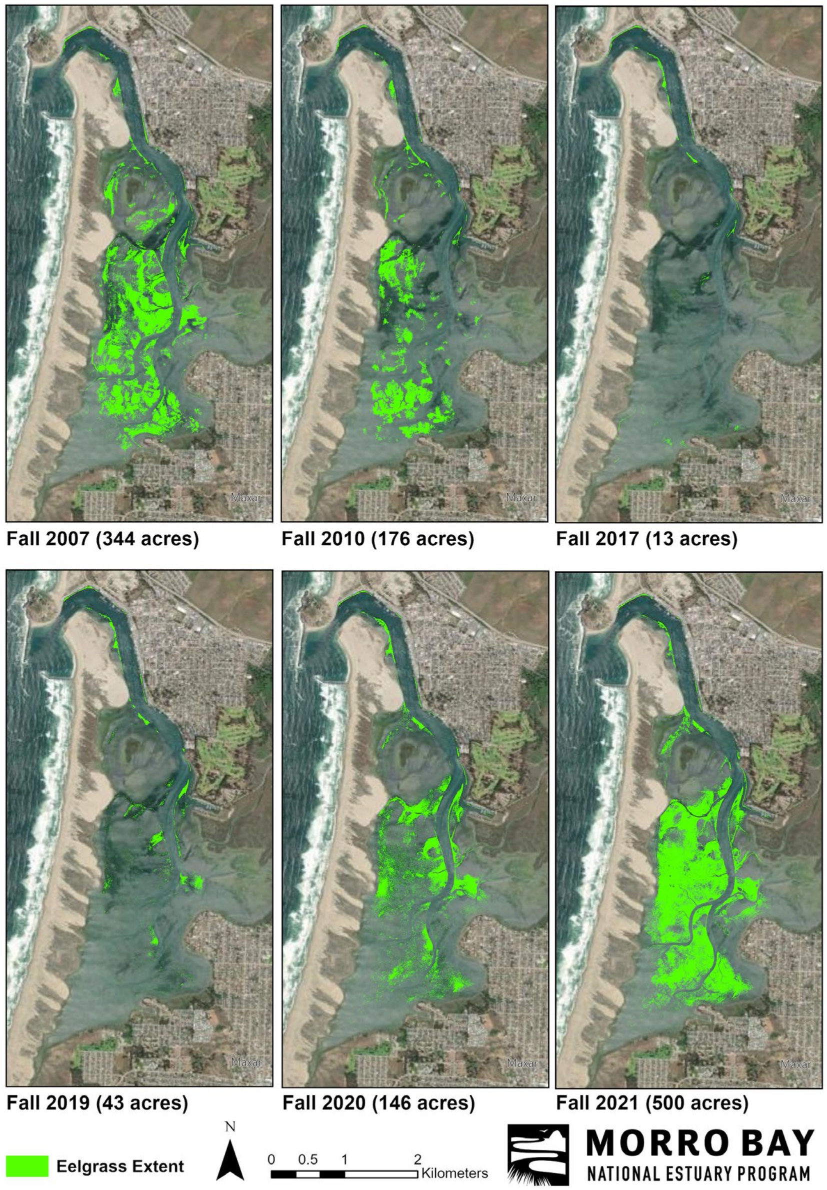

Figure 3. Changes in intertidal eelgrass density in Morro Bay from 2007 to 2021. Note that pictured here, the eelgrass extent from 2007 to 2019 was analyzed with multispectral imagery (Ocean Imaging) and extent from 2020 and 2021 was analyzed using manual quantification of drone imagery (Cal Poly).†

Given restoration efforts and significant natural establishment, there has been a major resurgence of eelgrass habitat with 500 acres mapped in December 2021. We are encouraged to see such a large expansion in eelgrass coverage throughout the bay in a short time. From 2007 to 2016, eelgrass in Morro Bay declined by more than

† Eelgrass acreage from 2020 and 2021 was analyzed using manual quantification of Cal Poly's UAV drone imagery due to the cost and labor associated with multispectral imagery analysis. Because of differences in methodology over time, exact acreages of eelgrass cannot be directly compared from year-to-year.

90% with only 13 acres mapped in 2017. Eelgrass began to re-establish in 2017 in areas where it previously declined. In 2020, 146 acres were mapped. For a subset of the bay, including some restoration sites and adjacent intertidal areas, an additional drone flyover was conducted in late April 2021 and May 2021 to help track eelgrass coverage during the spring.

Restoration Efforts

Eelgrass was harvested from healthy donor beds in Morro Bay and transplanted with the support of trained staff from Tenera Environmental, Inc. (Tenera). Transplanting occurred at 14 locations over a wide distribution of the estuary. Planting took place in February, March, and April 2021. Over these 14 sites, 3,705 eelgrass plants were transplanted. Eelgrass was planted with a combination of anchoring methods (stakes, rebar, bamboo). A California Department of Fish and Wildlife (CDFW) Scientific Collection permit was obtained prior to collection and transplanting efforts. All restoration sites are outlined in the table below. Restoration locations for 2021 are visualized spatially in relation to the 2020 eelgrass extent in Figure 4.

Table 2. Eelgrass restoration sites completed during 2021.

Site	Location	Date Planted	Approximate Elevation	Donor Bed	Planting Type
T37	35.355142, -120.850971	2/8/2021	-0.35 ft.	Coleman	3 one meter plots, 5 bamboo
T8	35.348215, -120.848548	2/10/2021	-0.16 ft.	Coleman	3 one meter plots, 4 bamboo
T33	35.353351, -120.845642	2/12/2021	-0.55 ft.	Coleman	3 one meter plots, 4 bamboo
T34	35.351355, -120.846895	2/27/2021	-0.31 ft.	N. Sandspit	3 one meter plots, 4 bamboo
T10	35.343509, -120.849259	3/26/2021	-0.31 ft.	Coleman	3 one meter plots, 4 bamboo
T32	35.336298, -120.853622	2/25/2021	-0.14 ft.	N. Sandspit	4 rebar, 4 bamboo
T22	35.335241, -120.852215	2/25/2021	-0.5 ft.	N. Sandspit	4 rebar, 4 bamboo
T23	35.337659, -120.849656	3/9/2021	-0.29 ft.	ACOE Bed	4 rebar, 4 bamboo
T24	35.336954, -120.852581	3/9/2021	-0.12 ft.	ACOE Bed	4 rebar, 4 bamboo
T25	35.334684, -120.853165	3/11/2021	-0.01 ft.	Tidelands	4 rebar, 4 bamboo
T26	35.337592, -120.852994	3/11/2021	-0.14 ft.	Tidelands	3 rebar, 5 bamboo
T27	35.337073, -120.853595	3/16/2021	-0.07 ft.	Coleman	4 rebar, 4 bamboo
T28	35.335519, -120.852948	3/16/2021	-0.06 ft.	Coleman	4 rebar, 4 bamboo
T29	35.333578, -120.851694	4/13/2021	-0.05 ft.	ACOE bed	20 bamboo
T30	35.349602, -120.846519	4/15/2021	-0.8 ft.	ACOE Bed	8 bamboo
T31	35.351806, -120.846855	4/16/2021	-0.98 ft.	ACOE Bed	7 bamboo
T35	35.329640, -120.852322	5/13/2021	-0.3 ft.	N. Sandspit	20 bamboo
T36	35.343778, -120.849299	5/18/2021	-0.98 ft.	Tidelands	19 bamboo

Figure 4. Map of eelgrass transplanting locations from 2017 to 2021, with the 2020 eelgrass extent in green.

Eelgrass Transplanting

Eelgrass rhizomes were collected from four donor beds during 2021: Coleman, Tidelands, Army Corps of Engineers (ACOE) Bed, and North Sandspit. Eelgrass was harvested on foot and by hand at low tides. No more than three rhizomes per square meter were collected, as required by the Estuary Program's scientific collection permit from CDFW. Harvesting and transplanting occurred in the spring, as previous experimental efforts showed higher success during the spring, as opposed to the summer. Pre- and post-density eelgrass counts of the donor beds were collected before and after harvesting.

Figure 5. Eelgrass collection at North Sandspit in April 2021.

Three different planting methods were used to transplant eelgrass: one-meter plots with anchoring, one-meter plots without anchoring, rebar pieces, and bamboo pieces. To transplant eelgrass within the one-meter plots, two eelgrass rhizomes were crisscrossed to form a "bundle" and secured in the sediment with a garden stake anchor. Bundles were spaced approximately 15 centimeters apart, for a total of 72 rhizomes in each one-meter plot. Small PVC poles were placed immediately outside of the plot corners to aid in relocating restoration sites.

Eelgrass was also planted using rebar and bamboo pieces as anchors. For the rebar pieces, 25 eelgrass rhizomes were anchored to smooth rebar with jute string. Each piece of rebar was three feet long, with one end bent into an "L" shape to hold the rebar in the sediment. The bamboo pieces were anchored similarly, with 25 rhizomes secured to a three-foot bamboo stake with jute string. Bamboo was then anchored to the sediment with garden stakes. Rebar and bamboo pieces were both planted off the main channel via kayaks at low tides.

Figure 6. Preparation of eelgrass bamboo pieces by Tenera staff for planting, Spring 2021.

In total, eelgrass was transplanted by Tenera at five locations along the main channel and at 13 sites off the main channel with a combination of intertidal and subtidal locations. Methods included 15 plots with anchoring, 31 rebar, and 128 bamboo plantings. Plots were a quarter-meter in size. Subtidal planting methods were similar to intertidal methods but conducted using scuba during high tides.

Figure 7. Scuba planting of eelgrass bamboo pieces, Spring 2021.

Figure 8. Eelgrass planting using scuba. Diver placing plot marker.

Monitoring of Restoration Sites

A sub-set of eelgrass restoration sites were monitored in May, June, August, September, and October depending on when the sites were originally planted with eelgrass. Transplanting and monitoring were completed by Tenera. The main channel sites (sites T37, T8, T33, T34, and T10) were monitored on foot at low tides and other sites (sites T32, T22, T23, T24, T25, T26, T27, and T28) were monitored off the main channel in mudflat conditions with scuba, as the substrate was too difficult to navigate on foot.

At six months post-planting, restoration sites generally showed great success. Of the five sites along the main channel, one site had died back with some eelgrass remaining. The other four sites exhibited substantial growth with many sites having a 200 to 400% increase in shoots observed. For the off-channel sites, many of the plantings grew together in the six months post-planting. In prior restoration years, it typically took 12 months post-planting to see the same level of growth. For example, site T24 with four bamboo pieces (3 feet each) grew into an eelgrass bed of 13.5 by 1.5 meters (1,448% increase) and four rebar pieces grew into a bed 12 by 2 meters (2,519% increase). Two sites were difficult to locate during the six-month monitoring as large amounts of natural eelgrass had also grown near the plots. Since eelgrass is abundant near the restoration sites, it is likely that the sites are successful and have expanded beyond their original plots. For sites that had lower growth, many were characterized by abundant *Gracilaria spp.* interspersed with eelgrass plantings. The change in eelgrass habitat and growth of macroalgae has been significant during this project period and made some of the eelgrass restoration monitoring more challenging.

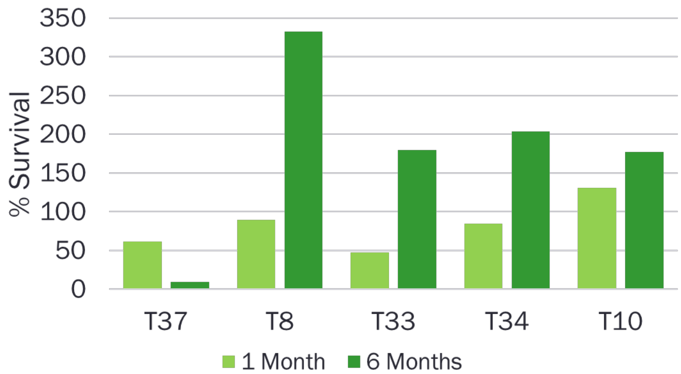

Figure 9. 2021 Intertidal restoration plots showing survival after one and six months post-planting.

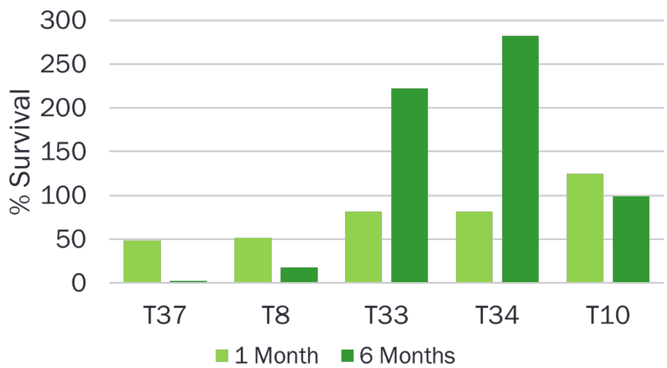

Figure 10. 2021 Intertidal restoration bamboo plantings after one and six months post-planting.

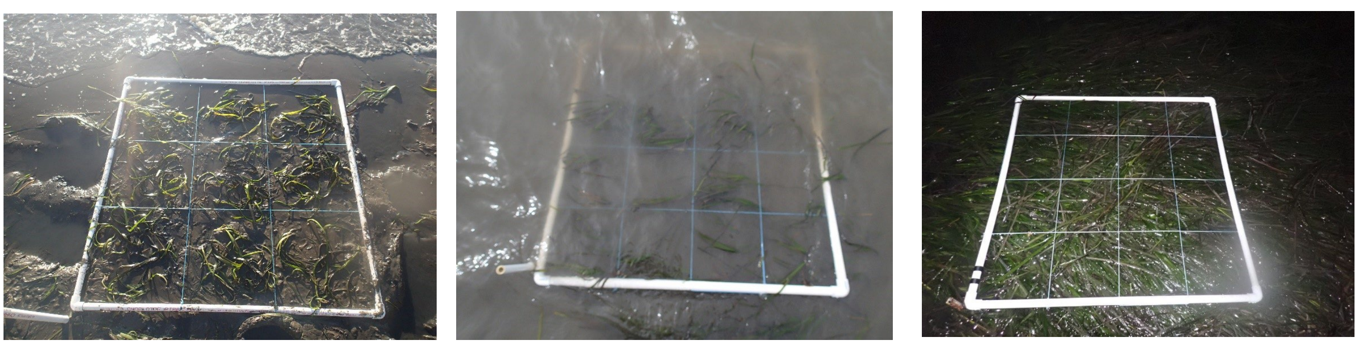

Figure 11. Midbay site (T33) showing initial planting (left), one month after (middle), and six months after (right).

Other Monitoring Efforts

In addition to monitoring the restoration plots, there have been several supplementary monitoring efforts to track eelgrass changes throughout the bay. The Estuary Program established permanent transects beginning in 2005 to measure average shoot density at sites spanning the length of the bay. California Sea Grant and Cal Poly established bed condition monitoring beginning in late 2015 to measure average density and overall condition of remaining eelgrass. Cal Poly and California Sea Grant established permanent plots in 2018, which the Estuary Program monitored in 2018, 2019, and 2021.

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. From 2012 to 2016, some sites were not surveyed due to poor weather or tide conditions. In December 2017, a new transect was established on the eastern side of the channel at Tidelands Park, called "Embarcadero." The transect now called "Reference" was originally named "Tidelands" but has since been renamed to avoid confusion.

Figure 12. The six current permanent transect monitoring locations: Coleman, Embarcadero, Reference (previously named Tidelands), Marina, Chorro, and Pasadena.

Methods

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

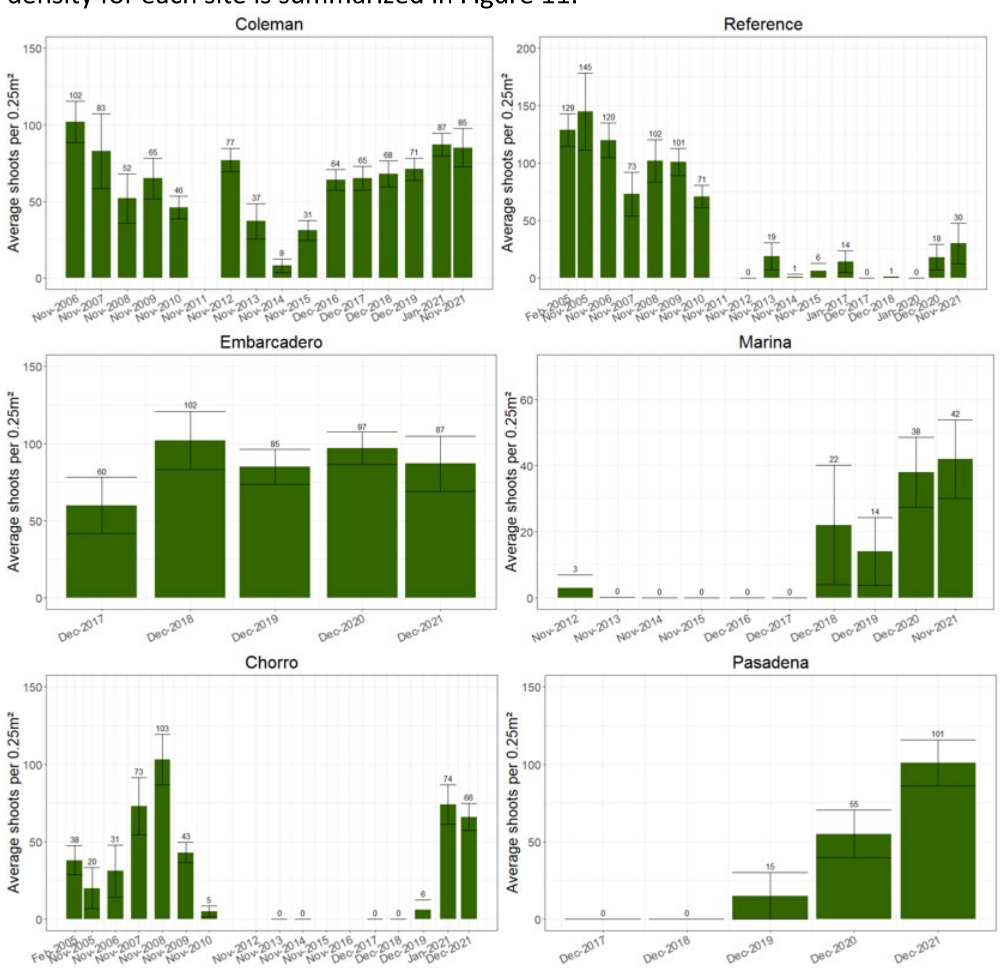

Figure 13. Average shoot density counts per year at six sites. Shoots were counted within a 0.5 m x 0.5 m quadrat. Error bars represent the 95% confidence interval.

While average shoot densities have declined since this monitoring began in the early 2000s, eelgrass does appear to be rebounding at most sites. During 2021, average densities were higher than the previous sampling effort at half of the sites, but all sites had higher densities than those recorded in 2019. For example, Chorro experienced an 11-fold increase from six shoots/0.25 m^2 in 2019 to 66 shoots/0.25 m^2 in 2021. Reference had no eelgrass present in January 2020 but had an average of 30 shoots/0.25 m^2 in 2021. The density at Pasadena also dramatically increased, jumping from 15 to 101 shoots/0.25 m^2 over the past two years. Marina follows this trend as well, exhibiting a density increase from 14 to 42 shoots/0.25 m^2 since 2019. Coleman and Embarcadero had less dramatic increases, however eelgrass density has remained fairly stable at these sites since their establishment.

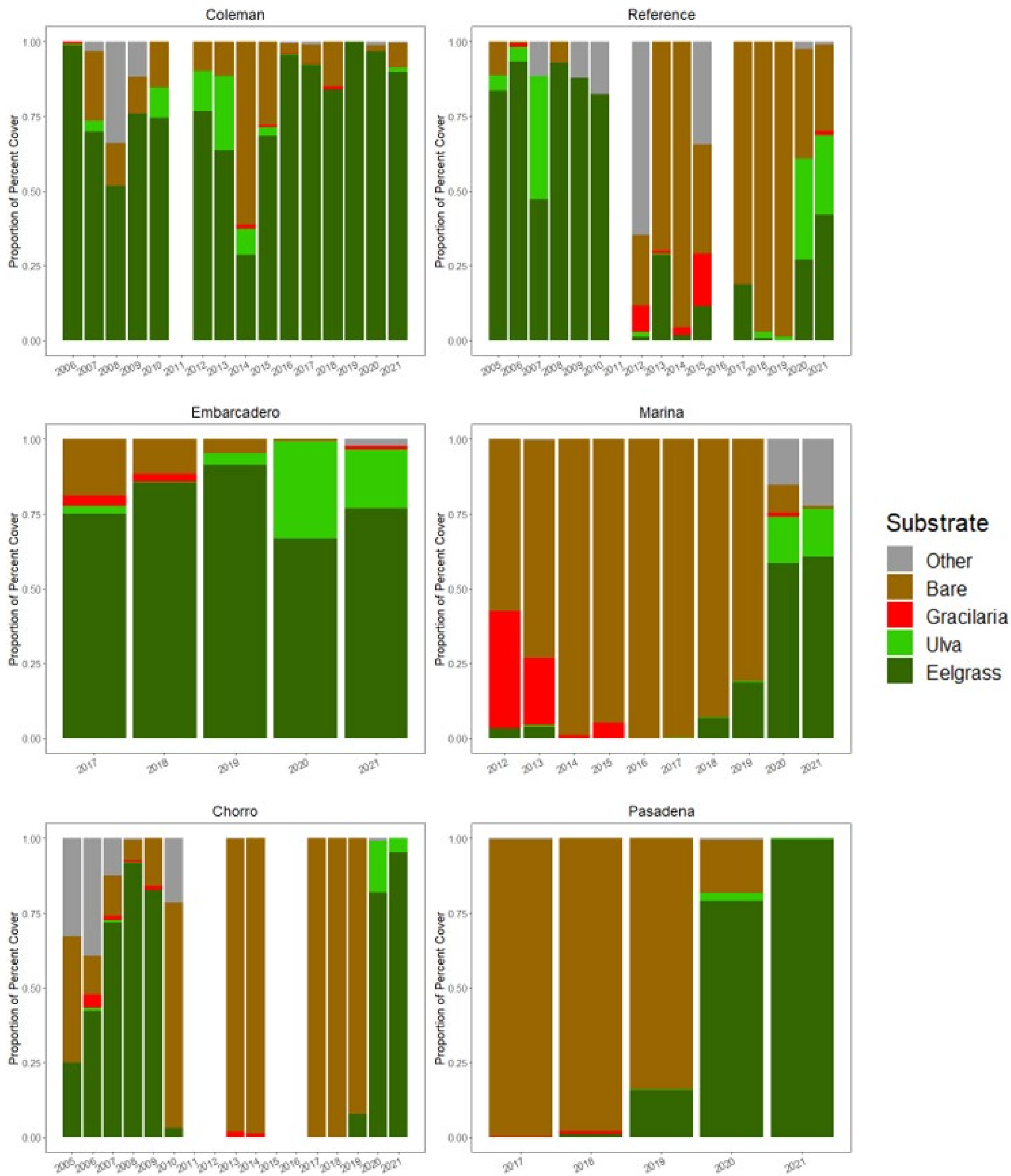

Figure 14. Proportional compositions of the primary recorded percent coverage types, averaged over all quadrats for a given year. Each vertical bar represents one year's sampling efforts.

Proportional compositions are summarized in Figure 14. The percent cover of eelgrass (dark green bars) observed at all sites closely follows the fluctuations in density seen in Figure 13. However, these plots show how additional macroalgae taxa fluctuated in abundance as well. Four out of the six sites have experienced a notable increase in *Ulva* coverage over the past two years. Fortunately, the appearance of *Ulva* does not seem to be stifling eelgrass growth, as both organisms are currently experiencing increases in coverage. Of note, Pasadena has reached nearly 100% eelgrass percent cover after being nearly 100% bare in 2017 and 2018.

Permanent Transect Photos and Observations

Photo monitoring documents site conditions, although they have not been taken every year.

Coleman Transect

Average eelgrass density slightly decreased at this transect since 2020 but is still over ten times the density observed in 2014. Current shoot density is comparable to pre-decline levels seen in 2007.

Figure 15. Permanent transect monitoring at Coleman Transect, 2016 to 2021.

Reference Transect

Eelgrass is beginning to make a comeback at this transect after having been virtually absent since 2017. Small patches of eelgrass began appearing in 2019 at higher elevations than previously observed and have transformed the landscape to consist of eelgrass "islands" separated by small channels. Shoot density currently sits at less than a third of pre-decline levels surveyed before 2010.

Figure 16. Permanent transect monitoring at Reference Transect (previously "Tidelands"), 2017 to 2021.

Embarcadero Transect

This transect was established in 2017 and is the newest of the six permanent transect monitoring sites. Eelgrass density has remained mostly continuous and has not experienced any notable declines since monitoring began. The Embarcadero transect has been a harvest site for restoration efforts for multiple years.

Figure 17. Permanent transect monitoring at Embarcadero Transect, 2017 to 2021.

Marina Transect

After the establishment of this transect in 2012, no eelgrass was present from 2013 to 2017. Patchy eelgrass began appearing in 2018 and 2019 and is now forming into one continuous bed. The shoot density observed in 2021 is the highest recorded after a decade of monitoring.

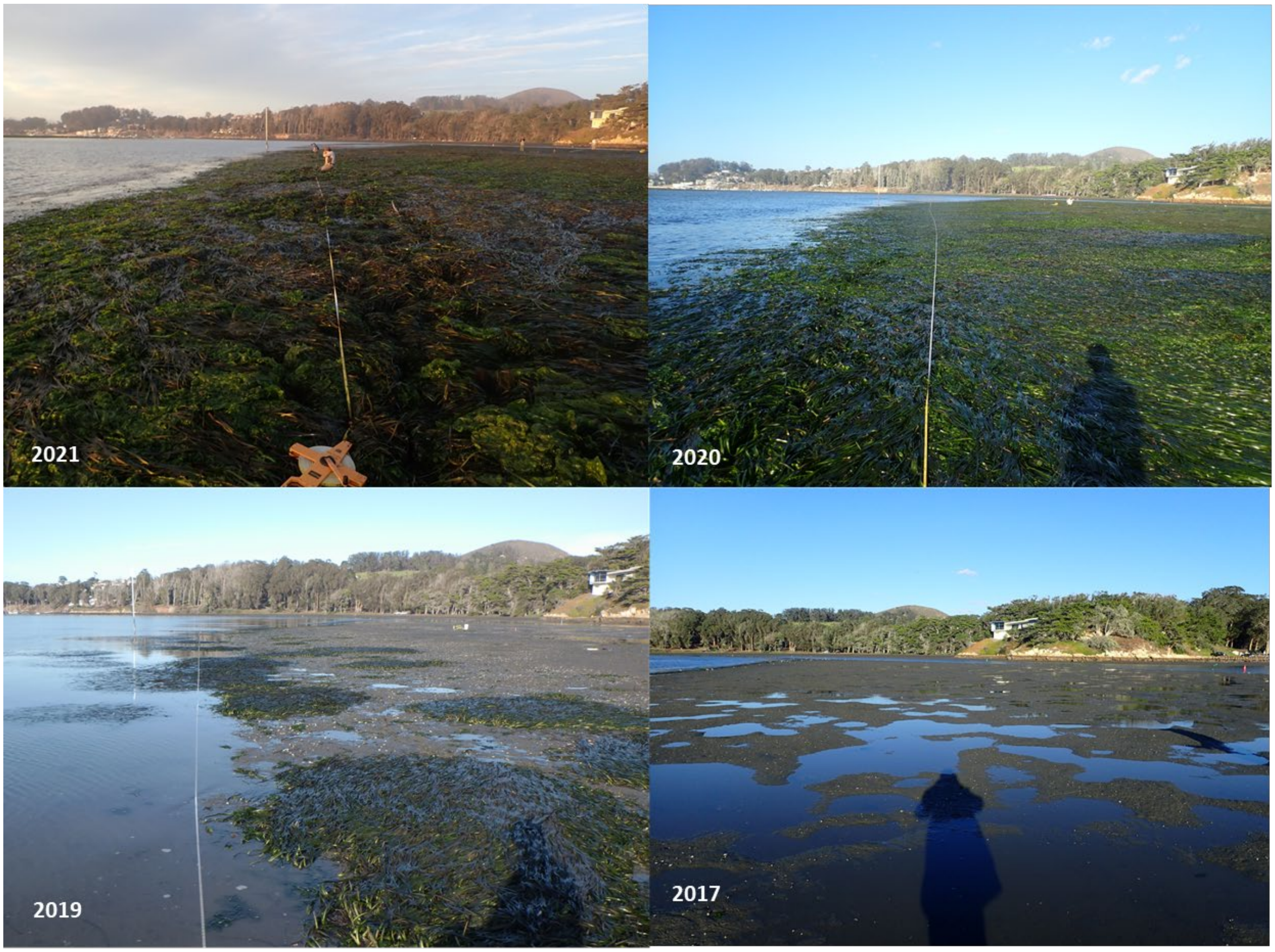

Figure 18. Permanent transect monitoring at Marina Transect, 2017 to 2021.

Chorro Transect

Shoot density at the Chorro transect has returned to pre-decline levels, although it did experience a small decrease this year after a remarkable twelve-fold increase from 2019 to 2020. Prior to 2019, eelgrass had not been recorded at this site since 2010. Surveys were not conducted at this transect in 2011-2012 and 2015-2016 due to staffing limitations and time constraints.

Figure 19. Permanent transect monitoring at Chorro Transect, 2017 to 2021.

Pasadena Transect

The Pasadena transect had the highest observed shoot density of 2021, after having had the fourth highest density in 2020. The photos below show the dramatic transformation that took place at this site over the past four years. In this relatively short time frame, eelgrass density has increased from 0 shoots/0.25 m^2 to 101 shoots/0.25 m^2. The Pasadena transect was established in 2005, however the original transect location was lost and it had to be re-established at new coordinates in 2017. Due to the uncertainty of its original location, only data collected at Pasadena since 2017 has been included in the report.

Figure 20. Permanent transect monitoring at Pasadena Transect, 2018 to 2021.

Permanent transects were initially established to track eelgrass density from sites throughout the bay. While density data at permanent sites can provide insight into the coverage of eelgrass at a particular location, it is not always the optimal method of monitoring eelgrass health. For example, there are often instances of eelgrass near the site (even within just a few meters), but because it was not on the transect, it is not captured in the data collection. Most transects are also not permanently marked or are difficult to permanently mark, which makes it a challenge to return to the exact location each year. Due to challenges with this methodology, a different method of monitoring 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. However, permanent transect monitoring has continued, as it is the longest running eelgrass dataset for Morro Bay. This dataset helps to document pre- and post-decline conditions.

Bed Condition

History

Bed condition monitoring was established as a joint effort between Dr. Jennifer O'Leary of California Sea Grant and the Estuary Program in late 2015. This method measures eelgrass conditions in terms of density, blade length, evidence of necrotic tissue, and competition with algae and other organisms.

Monitoring occurs at four significant beds in Morro Bay along a 150-meter, seven-quadrat survey. Historically, both intertidal and subtidal eelgrass beds were surveyed, and monitoring occurred twice per year, once in late fall and again in the spring. Due to tidal constraints, the fall monitoring and subtidal monitoring have been halted. Since 2019, only the spring intertidal sampling has been conducted.

Methods

While in the field, eelgrass health is assessed using a combination of methods. Within each quadrat, stipe counts are conducted to determine eelgrass density, and plant and algae material are identified using the point-intercept method at 25 points. Between quadrats, eelgrass presence/absence is recorded along every meter of the transect to estimate the patchiness of the eelgrass bed.

An integral component of the Bed Condition protocol involves taking pictures of eelgrass plants and using photo processing to aid in the determination of blade health. At each site, five stipes are chosen from distinct locations within every quadrat. Each stipe is photographed with all the blades spread out against a whiteboard, so the full area of each blade is visible. These photos are then used to calculate percent cover estimates using ImageJ software.

Figure 21. Bed condition monitoring sites at Coleman Beach, North Sandspit, Reference Bed, and Windy Cove.

Results

The Estuary Program conducted spring 2021 monitoring at Coleman Beach, Reference Bed, and Windy Cove sites. North Sandspit was a site monitored from 2015 to 2017 but has not been monitored since 2019 due to lack of adequate low tides. The figure below displays the results of some preliminary data analysis, using only the spring intertidal data from 2016 to 2021, and excluding sites that lacked adequate replication over several years.

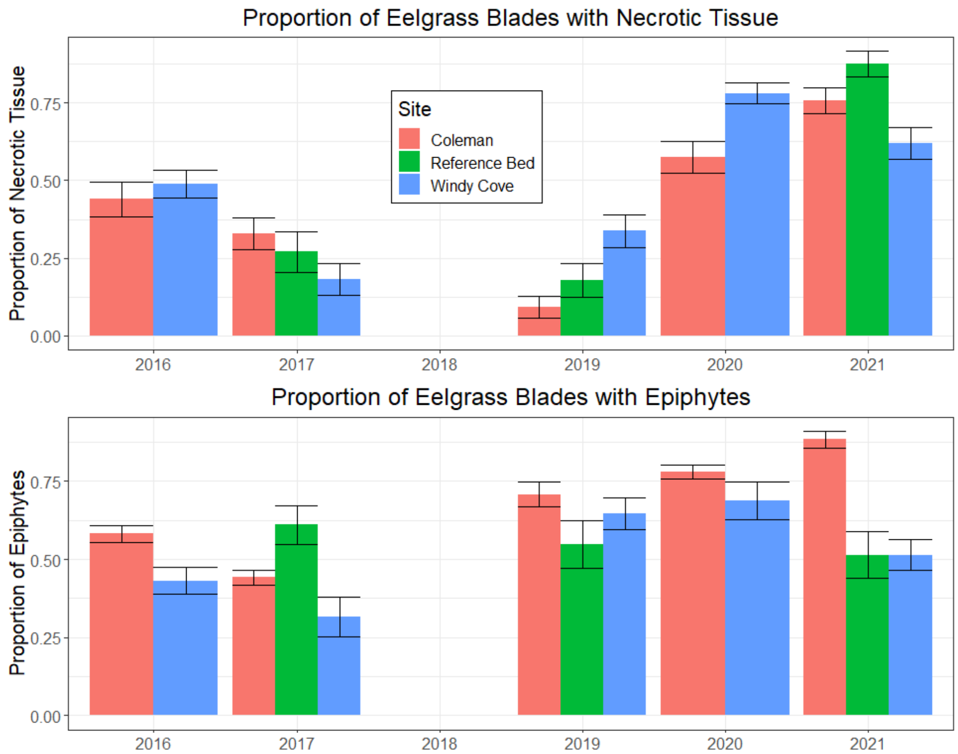

Figure 22. Blade condition results from spring intertidal sampling events. No sampling was conducted in 2018. Reference Bed was not sampled in years where a green bar is absent. Error bars represent the standard error.

The preliminary results show that the proportion of eelgrass blades with necrotic tissue was especially low in 2017 and 2019, staying below 50% at all sites. Due to the lack of data in 2018, it is difficult to determine whether these incidences of low necrotic tissue were isolated events, or signs of a more significant trend. Since 2019, the proportion of necrotic blades has increased, coinciding with increasing blade length. The three sites in the figure above each experienced a mean blade length increase of over 160 millimeter between 2019 and 2021. The trends displayed by these two indicators generally represent opposing health conditions, however it is possible that the proportion of necrotic blades is confounded with increasing blade length, given that there is more eelgrass tissue present overall.

The presence of epiphytes is variable between sites and years but has shown a general increasing trend at Coleman Beach since 2017 and has been consistently over 50% at Windy Cove since 2019. Some of the most common types of epiphytes observed are microalgae and the red algae *Smithora naiadum*.

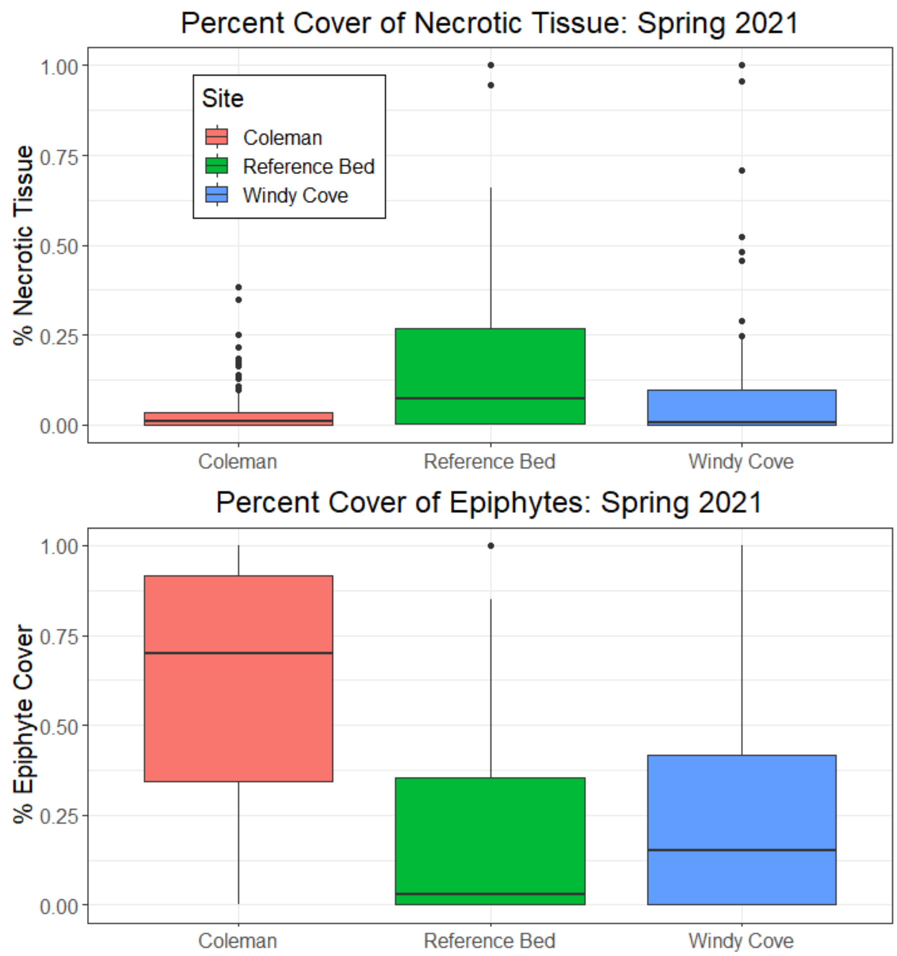

Figure 23. Results from processing pictures of eelgrass taken during the Spring 2021 monitoring.

The figure above (Figure 23) displays the percent cover of necrotic tissue and epiphyte coverage for all photos processed from Spring 2021. Photos that were blurry, dark, or had low resolution were excluded from the final dataset, however these photos made up less than a quarter of the total image library. The results corroborate those seen in Figure 22, in which Reference Bed had the highest incidence of necrotic tissue and Coleman had the highest epiphyte coverage in 2021. It is important to note that while necrotic tissue was present on the majority of blades at all sites during the Spring 2021 monitoring, the actual percent cover of necrotic tissue typically made up less than a quarter of the total blade area. This is just one example of how photo processing provides a more complete picture of eelgrass health when used in conjunction with the field data.

Observations indicate that eelgrass beds closer to the mouth of the Bay, like Coleman, typically have higher epiphyte coverage. It is believed that a higher rate of grazing in the back bay keeps epiphyte coverage down in those beds, while the lack of regular grazing in the front bay allows for epiphytes to grow continuously. It is also possible that water clarity and light penetration play a role in epiphyte distribution, as the presence of epiphytes can be linked to higher rates of primary productivity.

Permanent Plots

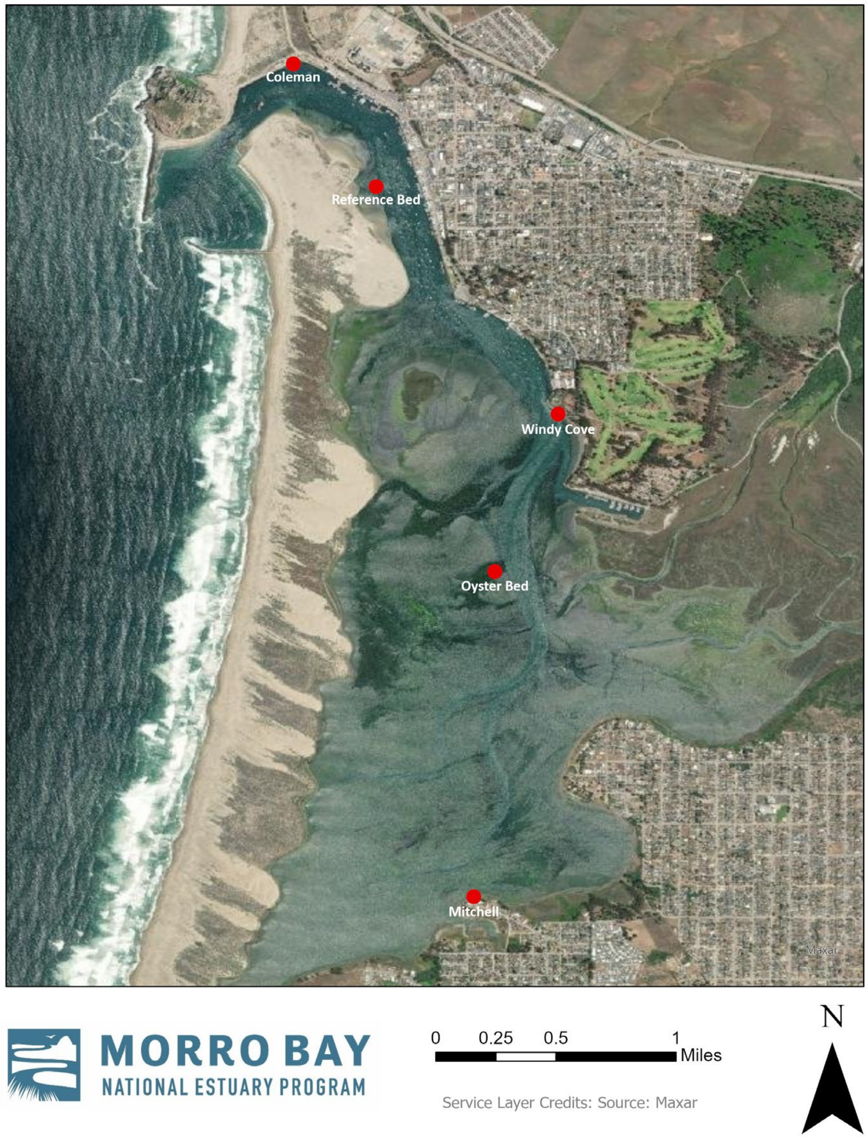

Figure 24. Eelgrass permanent plot monitoring locations.

History

In response to the decline of eelgrass in Morro Bay, permanent plots were installed in 2018 at five sites ranging from the front bay to the back bay (Figure 24). Three of these sites (Coleman, Reference Bed, and Windy Cove) are sites that had persistent eelgrass coverage through the period of recent eelgrass decline (2007 to 2016), while Oyster Bed and Mitchell represent areas where eelgrass coverage was lost.

Based on hydrological studies, there is a gradient of water quality parameters across the Morro Bay estuary. The area from the bay mouth to Windy Cove is largely influenced by oceanic water, and the water south of Windy Cove is less frequently exchanged with oceanic water and is notably warmer and saltier in the dry seasons (Walter et al. 2018). The five sites were established across this gradient of conditions to offer insight into the spatial variability of eelgrass health.

Methods
Three plots were installed at each site by driving PVC markers into the sediment with anchor-screws, marking the corners where a one-meter by one-meter quadrat is placed. These markers remain permanently at each site, allowing the same plot of eelgrass to be monitored over time. The plots were monitored seasonally during 2018 and 2019, and once during spring 2021.

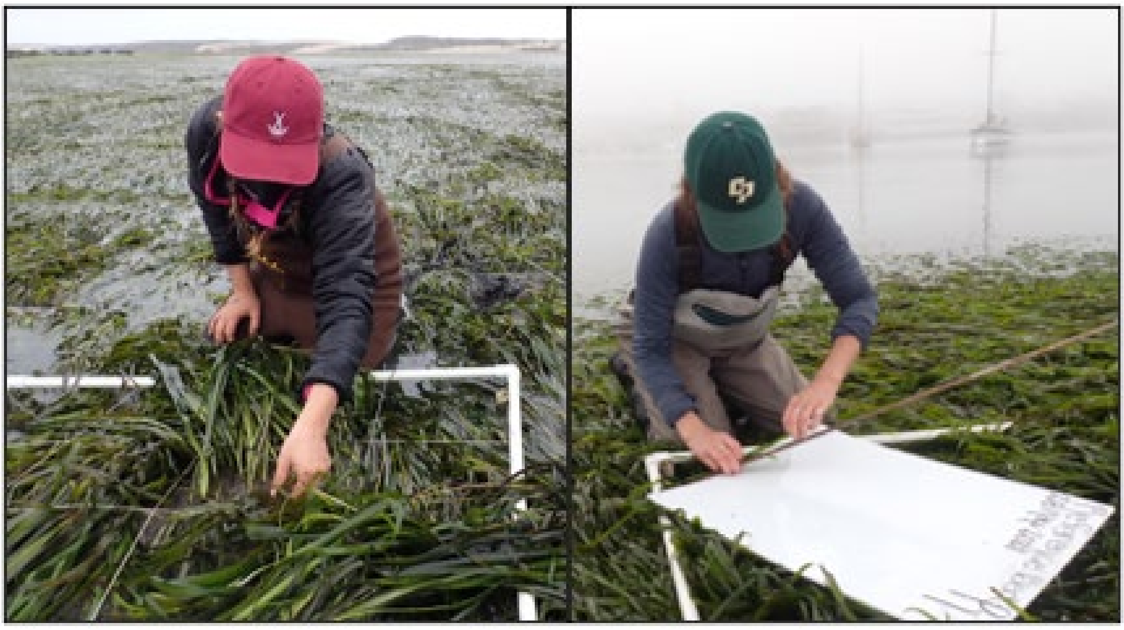

Figure 25. Density counts and blade length measurements. Stipes are counted in the center four quadrat squares, pictured at Oyster Bed in spring 2021 (left photo). The longest blade for each stipe is measured with a meter stick, pictured at Reference Bed in spring 2021 (right photo).

Monitoring the permanent plots provides an opportunity to assess the health and condition of eelgrass over time. When monitoring the permanent plots, there are a variety of indicators that are being assessed. These indicators include eelgrass density, blade length, presence of necrotic tissue, tissue erosion, evidence of grazing, an account of what fauna and flora are within each plot, and the percent cover of epifauna and epiphytes living on the eelgrass blades.

Results

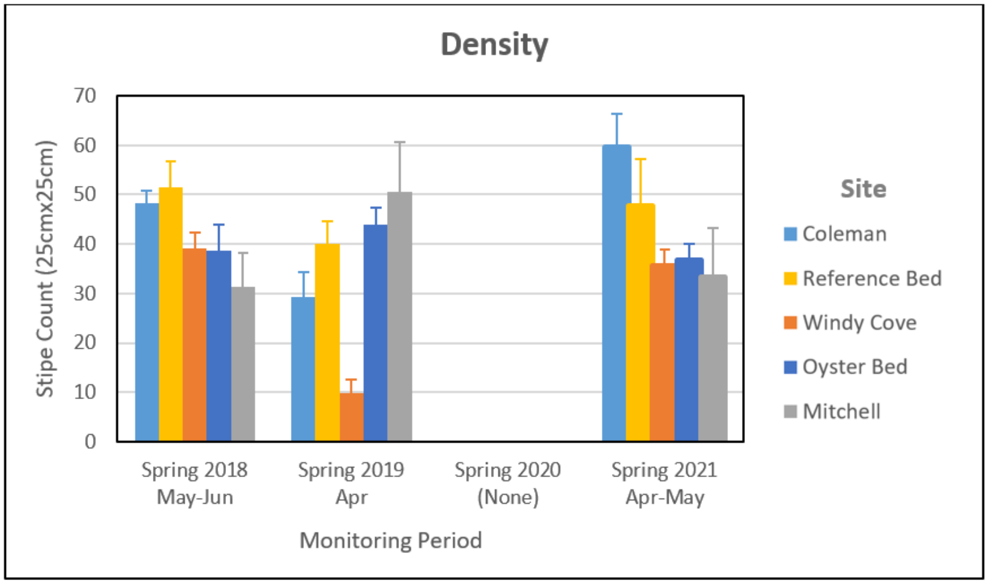

Figure 26. Average stipe count from 2018 to 2021, within a 25 cm x 25 cm quadrat.

Density is the primary parameter used to determine the abundance of eelgrass at a site and is a commonly used indicator of eelgrass condition. Over the course of the study, density was variable across all sites and ranged from approximately 10 to 60 stipes/0.25 m^2 (Figure 26). The steep decline in density observed at Windy Cove in spring 2019 was likely due to erosion within one of the plots, skewing the data from that year's survey. Mitchell, the site furthest back in the bay, had a relatively high density of eelgrass during this same time period. Sites with the highest density changed each year, and given the range of sites and conditions in the bay, density does not appear to be a very sensitive indicator of eelgrass condition.

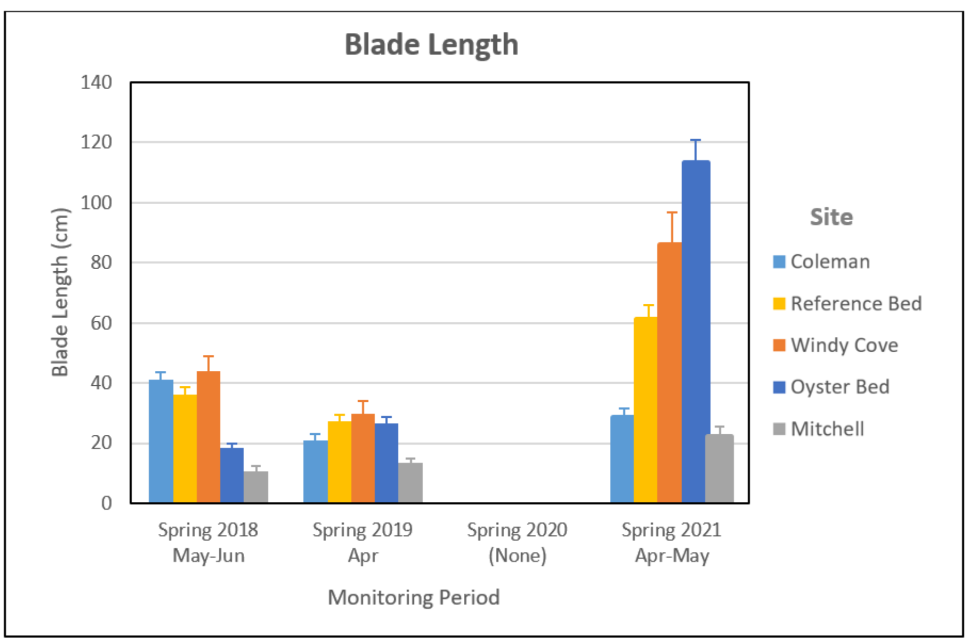

Figure 27. Average lengths of eelgrass blades from 2018 to 2021, within a 25 cm x 25 cm quadrat.

Blade length, another indicator of eelgrass health, notably increased at three sites between the spring of 2019 and spring of 2021 (Figure 27). This could be indicative of more favorable conditions for eelgrass, as the timing corresponds with the expansion of eelgrass acreage. Coleman, the site closest to the mouth of the bay, had persistent eelgrass cover throughout the period of decline and did not experience an increase in blade length. Eelgrass at the Mitchell site consistently had the shortest blade lengths.

Algal coverage results from this monitoring effort are consistent with observations from Permanent Transect monitoring. All Permanent Plot sites had very low algal cover in 2018 and 2019 (<5%) but experienced a notable increase during the Spring 2021 monitoring, with cover reaching over 40% at Reference Bed and Mitchell.

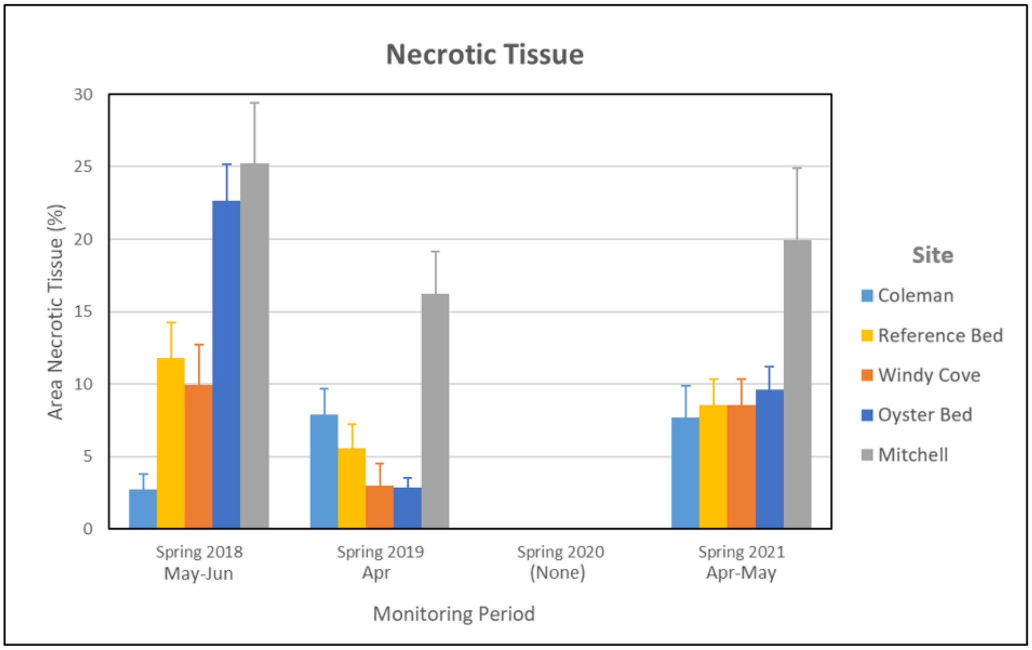

Figure 28. Average percent of eelgrass blade area covered with necrotic tissue from 2018 to 2021, within a 25 cm x 25 cm quadrat.

Additional indicators of eelgrass health, including epiphyte coverage and presence of necrotic tissue, display variability along the gradient of the bay. As seen in the Bed Condition results, epiphyte coverage is higher in the front bay and lower in the back bay. Coleman typically has the highest epiphyte coverage while Mitchell has the lowest. Conversely, Mitchell had the highest incidence of necrotic blades, which typically indicate poor health since necrotic blades are brittle, eroded, and likely are not actively photosynthesizing (Figure 28).

Figure 29. Stipe from Mitchell during the Spring 2021 monitoring. The majority of the blades at the site were covered in brown, necrotic tissue.

Considering the indicators evaluated, several factors indicate that the location of the Mitchell site is less hospitable to eelgrass growth and recovery. This site has higher necrotic tissue and shorter blade lengths than other sites, indicating poor quality eelgrass. Through the permanent plot monitoring, we have found that eelgrass is able to grow across a range of conditions, and thus shows potential for high resilience.

Additional Activity

Dredging Operations

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

ACOE began their annual dredging in Morro Bay on May 8, 2021 and the project was completed on June 2, 2021. During active dredging, ACOE contracted Merkel & Associates (M&A) to conduct weekly water sampling efforts upstream and downstream of the dredge footprint as well as at the disposal location. Water quality parameters included dissolved oxygen, light transmittance, turbidity, pH, temperature, and salinity. Action levels for all parameters were defined as a 20 percent or greater change between upstream and downstream locations, and dissolved oxygen levels were maintained at a minimum of 5 mg/L. In addition, two one-liter water samples were collected at all sampling locations once during the cycle. These samples were then analyzed for total suspended solids (TSS) and total chlordane.

According to a post-project report, no water quality exceedances were encountered during dredging activities. Adequate dissolved oxygen was maintained throughout the project, ranging between 6.9 mg/L to 8.9 mg/L. TSS values ranged from 1.0 mg/L to 6.5 mg/L, which falls within typical non-rainy season values for Morro Bay. The pesticide Chlordane was not detected at any station during sampling (M&A, 2021).

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 using scuba divers and/or sonar before, during, and after construction projects. Between summer of 2020 and 2021, two surveys were conducted to support construction projects on the Embarcadero. The conclusions of the surveys were as follows:

- A survey for the continuation of a permit to complete pile and dock work near 571 Embarcadero. Recent work completed under this permit includes improvements to public walkways and a full dock replacement following damage from King Tide events. Seven solitary eelgrass plants were found and deemed to be new recruits. This was the first time eelgrass had been found at this site after five previous surveys from 2009 to 2016. This is likely due to increased sunlight in the absence of boats and the general trend in eelgrass expansion observed throughout the bay.
- A pre-construction survey completed for a project to remove an old dock and replace it with a public walkway extending to a new floating dock near 833 Embarcadero. The survey found three small eelgrass plants, however no negative impacts to eelgrass are expected. The project location is rocky and does not contain eelgrass-suitable habitat. In addition, the plants are out of the way of the new construction.

Partnerships

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

Research Efforts

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

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 back bay. Funding for these stations are provided by the Central and Northern California Ocean Observing System (CeNCOOS) and the Estuary Program. A real-time data stream is available here: https://www.cencoos.org/data/shore/morro. Additionally, Dr. Walter maintains temperature sensors at the mouth of the bay and back of the bay.

Dr. Emily Bockmon of Cal Poly's Chemistry Department oversaw numerous ocean acidification monitoring and carbonate chemistry sampling efforts. In 2020, two autonomous pH sensors were deployed, one at the bay mouth T-Pier and the other at a water quality sensor array in the back bay. Data is automatically uploaded from the sensor to the web and can be viewed here: https://data.cencoos.org/#metadata/100050/station. Calibration samples were collected on seven occasions in 2021 for quality control purposes. Data calibration, processing, and sensor maintenance are ongoing.

Figure 30. Dr. Emily Bockmon collects nutrient samples during one of the bay-wide boat transects, investigating how water chemistry changes along the main channel.

Dr. Bockmon and her students also conduct monthly carbonate chemistry sampling at seven shore locations, one of which was added this past year. Nutrient sampling was added at three of the shore sampling locations starting in July 2021.

In addition to these ongoing projects, researchers completed several short-term monitoring efforts, including a two-week experiment monitoring pH at the Grassy Bar Oyster Farm and two bay-wide boat transects characterizing the chemical and physical environment of the bay in July and December. Another two-week study, conducted with Dr. Ryan Walter, focused on ocean acidification and hypoxia inside and outside of eelgrass beds. The work was funded by a Restore America's Estuaries Coastal Watersheds Grant, and results are expected in 2022.

Eelgrass Wasting Disease Research

Students and faculty from Cuesta College have been studying the occurrence of the slime mold *Labyrinthula spp.* on eelgrass in Morro Bay since 2018. This project is focused on the distribution of *Labyrinthula spp.* throughout the estuary and understanding its role in eelgrass wasting disease.

Eelgrass blade sampling is conducted annually in Morro Bay by Cuesta College students under the guidance of Cuesta College professors Dr. Laurie McConnico and Dr. Silvio Favoreto. Approximately 20 to 25 individual blades are collected from the mouth, mid-bay, and back bay. Students process and culture fragments of each blade to detect the presence of *Labyrinthula spp*. and a separate portion of each eelgrass blade is dried and preserved for subsequent sequencing and DNA quantification.

Although data analysis for this project is still underway, the past four years of data indicate that *Labyrinthula spp.* behaves as an opportunistic organism in the Morro Bay estuary, rather than a primary pathogen. Opportunistic microbes take advantage of a weakened state to promote disease but are unable to establish infection in healthy hosts. In 2021, 40 DNA samples were processed to investigate the eelgrass microbiome in association with wasting disease. Preliminary results show that blades with necrotic spots harbor twice the number of microbial species as healthy blades and the microbial community changes depending on where the eelgrass samples were collected in the bay.

In addition to studying *Labyrinthula spp.*, Dr. McConnico and Dr. Favoreto further refined the Excess Green Index (EGI) method, designed to compare the health of eelgrass samples using non-invasive, quantitative, image-based analysis. The method is based on RGB deconstruction and analysis of high-definition images obtained from cultured blade fragments. This past year, they found that EGI is negatively correlated with the visual necrosis score and can be used as an indicator for a sample's photosynthetic capabilities. EGI eliminates the guesswork of visual scores but is more time consuming since measures are performed every two to three centimeters along the blade.

Further sampling and analyses are expected to take place during 2022. Once completed, results from 2018 to 2022 will be compared and used to assess temporal changes in the slime mold. These long-term data sets will be critical to better understanding the role *Labyrinthula spp*. and other microbes play in eelgrass health within the Morro Bay estuary.

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. The brant populations in Morro Bay have historically been associated with eelgrass availability and were likely impacted by the eelgrass decline. However, the recent increase in eelgrass acreage has not yet resulted in a brant increase of similar magnitude.

John Roser, a local biologist, has been counting brant in Morro Bay for nearly 25 years. To estimate the presence of brant in the bay, mid-winter counts are conducted each January and can be compared to historic counts as far back as 1931. Counts from the 1930s through the 1960s averaged between 6,000 to 7,000 brant, with some counts reaching as high as 12,000 brant. The more recent counts, displayed in Figure 31, are all below these historic averages. Brant numbers in Morro Bay experienced a significant decline from the early 2000s until 2015 but have started a modest recovery.

We hope to see brant return in larger numbers if eelgrass continues to thrive, however the changing climate has altered the number of brant that choose to migrate from Alaska. Warmer temperatures in Alaska allow for adequate food availability throughout the year, causing proportionally less brant to make the 3,000-mile migration. While the number of brant stopping by Morro Bay is fairly low, it is worth noting that their overall population numbers across the Pacific Flyway are stable.

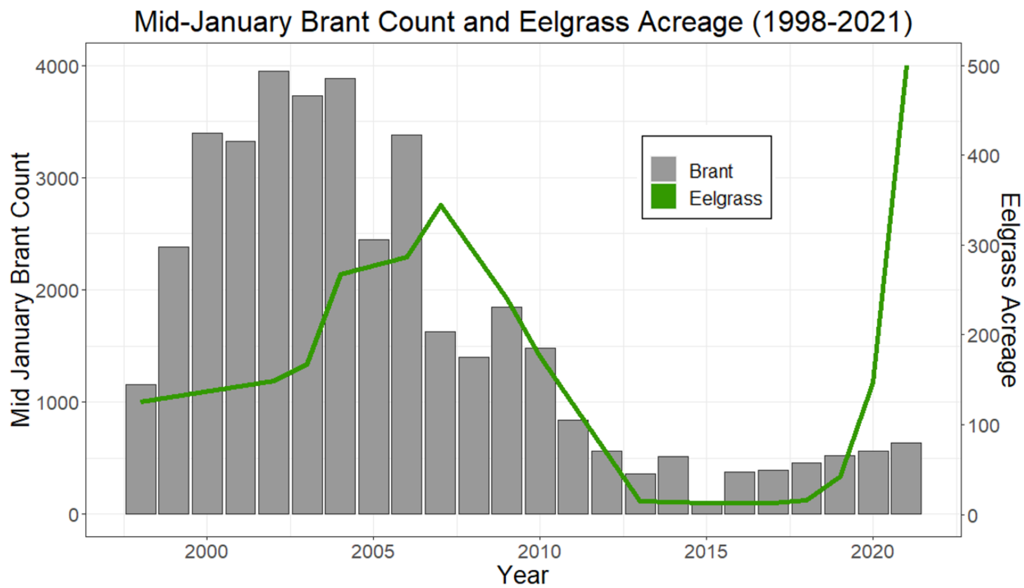

Figure 31. Results of the Mid-January Brant count from 1998 to 2021 compared with eelgrass acreage.

Several Cal Poly students have also studied brant foraging behavior over the past few years. In 2018, Cal Poly graduate student Dakota Osborne began studying the impacts of brant grazing on eelgrass. He installed eelgrass enclosure cages, which are open cages that the brant will not enter, thus preventing them from feeding on eelgrass. He has installed these cages in eelgrass beds and has been recording measurements to determine brant grazing effects in caged areas as compared to uncaged areas. Results from this research are expected in 2022.

Upcoming Projects

Drone Mapping

The Estuary Program will partner with Cal Poly for a bay-wide UAV drone survey during fall 2022. Although high resolution imagery will be acquired, the full manual quantification of eelgrass coverage in GIS is not expected to take place. The imagery will support Cal Poly's machine learning project, which seeks to develop algorithms to automate the classification of eelgrass from the drone imagery.

Topo Bathymetrtric LiDAR Survey

The Estuary Program will contract with NOAA's Office of Coastal Management in 2022 to conduct a light detection and ranging (lidar) survey throughout the bay. Previous surveys from 2010 and 2019 were used to generate Digital Elevation Models (DEM) to assess the rates of elevation change following eelgrass decline. A study led by Dr. Ryan Walter found that eelgrass loss had contributed to erosion at 90% of sites that had previously supported eelgrass beds, with a mean elevation loss of 0.1 m (Walter et al. 2020). In contrast, sites near the mouth of the bay that had retained eelgrass during the decline had experienced a mean elevation increase of 0.32 m. This is consistent with findings from a number of studies that have shown that seagrasses support sediment retention. The new DEM produced by the upcoming survey will explore if recent eelgrass expansion has changed, or potentially reversed, the trend in erosion that dominated the decline.

Restoration and Monitoring

In 2022, the Estuary Program plans to conduct monitoring of restoration sites, permanent transects, bed condition locations, and permanent plots. Due to the increased prevalence of macroalgae, an algae-focused monitoring project is currently in development and will likely begin in 2023.

Additional Research Activity

Dr. Ryan Walter of Cal Poly will continue to maintain the water quality instrument package at the mouth of the bay and in the back bay throughout 2022. Dr. Bockmon of Cal Poly will also continue to oversee the operation of the autonomous pH sensors at the mouth and back bay locations. Her team also intends to collect monthly shoreline carbonate chemistry samples and nutrient samples until the summer of 2022.

Additional research efforts by Cal Poly, Cuesta College, and others will continue to collect data to further our understanding of suitable conditions for eelgrass in the bay.

Conclusions

Eelgrass plays a vital role in the health of the Morro Bay ecosystem. While the acreage of eelgrass in Morro Bay has fluctuated in the past, the last decade has included the most precipitous decline and recovery on record. While there is no clear explanation for the recovery, factors such as shifts in elevation and water quality, natural recruitment, and restoration efforts have each played a role. The Estuary Program plans to continue monitoring eelgrass health and acreage to further develop our understanding of eelgrass bay-wide and to assess how specific eelgrass beds are faring over time.

The past several years have marked a major transitionary period in Morro Bay's eelgrass beds, and the Estuary Program is in the process of investigating the impacts of this transition. Eelgrass coverage has climbed to record highs, yet broader changes in climate could be modifying conditions within the estuary. Data indicates that migratory patterns are changing, sedimentation and erosion continue to modify estuarine bathymetry, and macroalgae abundance has significantly increased. While eelgrass and algae appear to be coexisting at the moment, these two primary producers have similar requirements for survival and may be in direct competition with one another if conditions take an unfavorable turn. Consistent monitoring will be key in adapting to and addressing future changes.

In 2022 and beyond, we will build upon our existing knowledge of eelgrass and its complex relationships with macroalgae proliferation, sedimentation, wasting disease, and more. Restoration will continue through 2022 with funding from Restore America's Estuaries and USFWS. The Estuary Program and its many partners will continue to work towards a better understanding of the estuary as a whole and apply that understanding to supporting a sustainable eelgrass population in Morro Bay.

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