Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2023

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 over the past two decades. From 2007 to 2016, more than 90% of Morro Bay's eelgrass disappeared, spurring many restoration, monitoring, and research efforts. Since 2016, eelgrass began to re-establish in areas where it had previously declined. Through restoration and natural recruitment, the past few years have been marked by significant growth. As of 2023, eelgrass acreage has reached its highest observed extent since reliable estimates have been collected, which date as far back as the 1960s.

This report summarizes the eelgrass related efforts of the Morro Bay National Estuary Program (Estuary Program) and its partners in 2023, 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 are 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 "Eelgrass" and "Technical Reports".

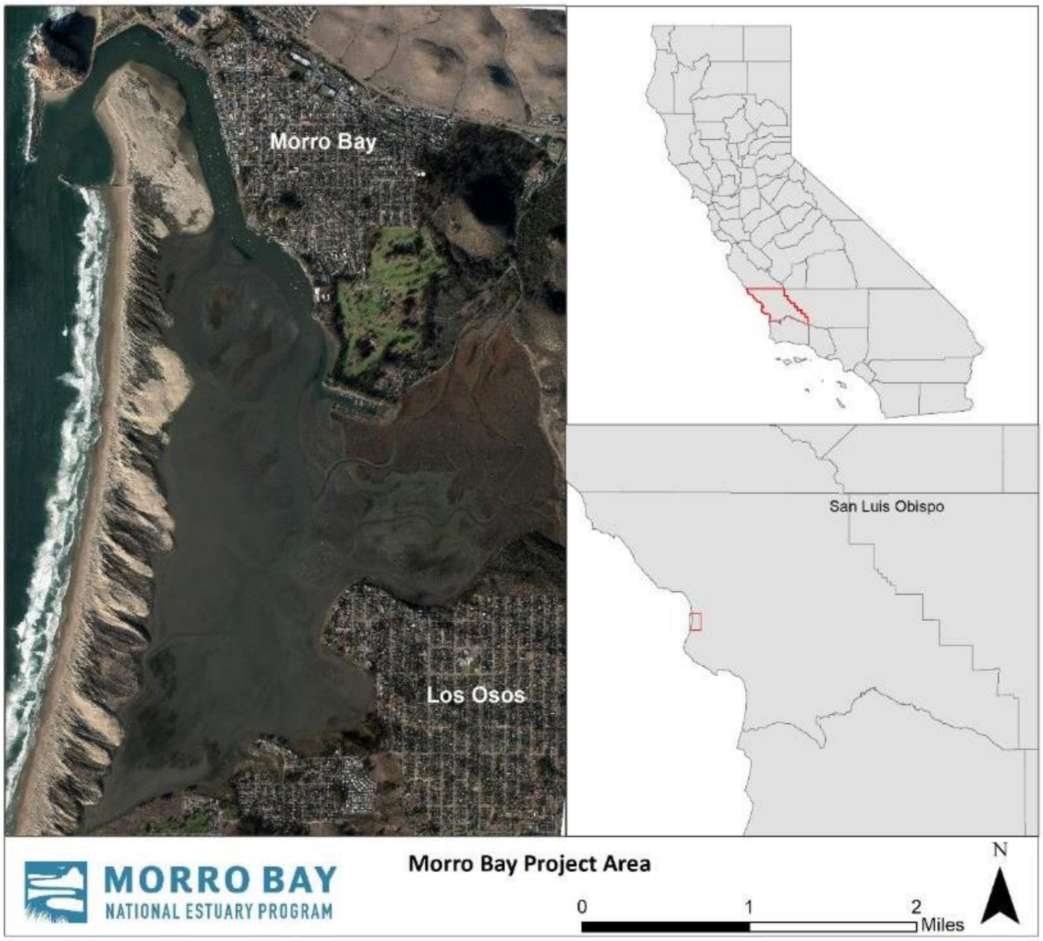

Figure 1. Morro Bay and location within San Luis Obispo County.

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 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.

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

Eelgrass Distribution

Mapping Efforts

Morro Bay's eelgrass population has been mapped for decades, but the method and time of year has varied. Many of the early eelgrass acreage estimates used 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 methods used in later years. Between 2004 and 2013, intertidal eelgrass was mapped with 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 in the spring. Later that winter, Ocean Imaging (OI) collected multispectral aerial imagery to create a classification of intertidal submerged aquatic vegetation, which was groundtruthed by the Estuary Program. Multispectral imaging was again collected by OI in 2019 to identify eelgrass bay-wide and quantify acreage of other exposed and submerged vegetation and substrate types. Further details of 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 surveys to be conducted 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 image. Historically, the eelgrass was then quantified in ArcGIS, a Geographic Information System (GIS) software, by manually digitizing eelgrass beds into individual polygons. However, with the expansion of eelgrass acreage in recent years, the process of manual digitization has become prohibitively time-consuming, and the use of an image segmentation machine learning model has been developed to automate this task (see "Automated Eelgrass Classification using Drone Imagery").

2023 Mapping Effort

The most recent eelgrass acreage map was assembled from a composite of low-altitude, true color aerial imagery collected by UAV and vessel-mounted interferometric sidescan sonar (ISS) conducted by M&A. UAV imagery was collected at extreme low tides in April and May to capture intertidal and shallow subtidal acreage, while ISS surveys were conducted during high tides from April to June within deeper subtidal channels. Between these two methods, 2,310 acres of the estuary were mapped in the intertidal and subtidal zones.

Upon completion of the surveys, M&A utilized a combination of spectral classification and manual digitization of the drone imagery orthomosaic and direct interpretation of hydroacoustic data to map the total eelgrass extent. All eelgrass cover was buffered by 0.5 meters in accordance with the California Eelgrass Mitigation Policy (2014) recommendations before calculating the final acreage. The inclusion of this buffer is important to note when comparing the 2023 acreage with previous years, as this method has not been used before. It is also worth noting that this survey's timing differs from most of our earlier mapping efforts, which mainly take place in late fall or winter. The seasonal difference coupled with delayed phenology stemming from atypically cold conditions resulted in a reduced eelgrass canopy that was primarily made up of rhizome mats and short shoots that were challenging to identify with UAV imagery. Fortunately, the textural pattern created by these mats was able to be differentiated from unvegetated mudflat. While this reduced canopy is accurately classified as eelgrass acreage, it also means that our final acreage is not composed entirely of dense eelgrass beds, but rather of eelgrass at varying life stages and varying levels of patchiness.

At the conclusion of their analysis, M&A reported a record-breaking 750 acres of eelgrass within the estuary in spring 2023. Approximately 704 acres were designated as intertidal, and 46 acres were designated as subtidal eelgrass, as delineated by the height of the lowest tide in 2023 (-1.7 feet Meal Lower Low Water (MLLW)). The data were ground-truthed using a combination of underwater drop video camera, low-tide surveys conducted by both M&A and the Estuary Program, and extremely low-altitude UAV imagery to get a closer look at eelgrass morphological characteristics. Comparing the ground-truthing results with the final acreage resulted in an accuracy assessment of 95%.

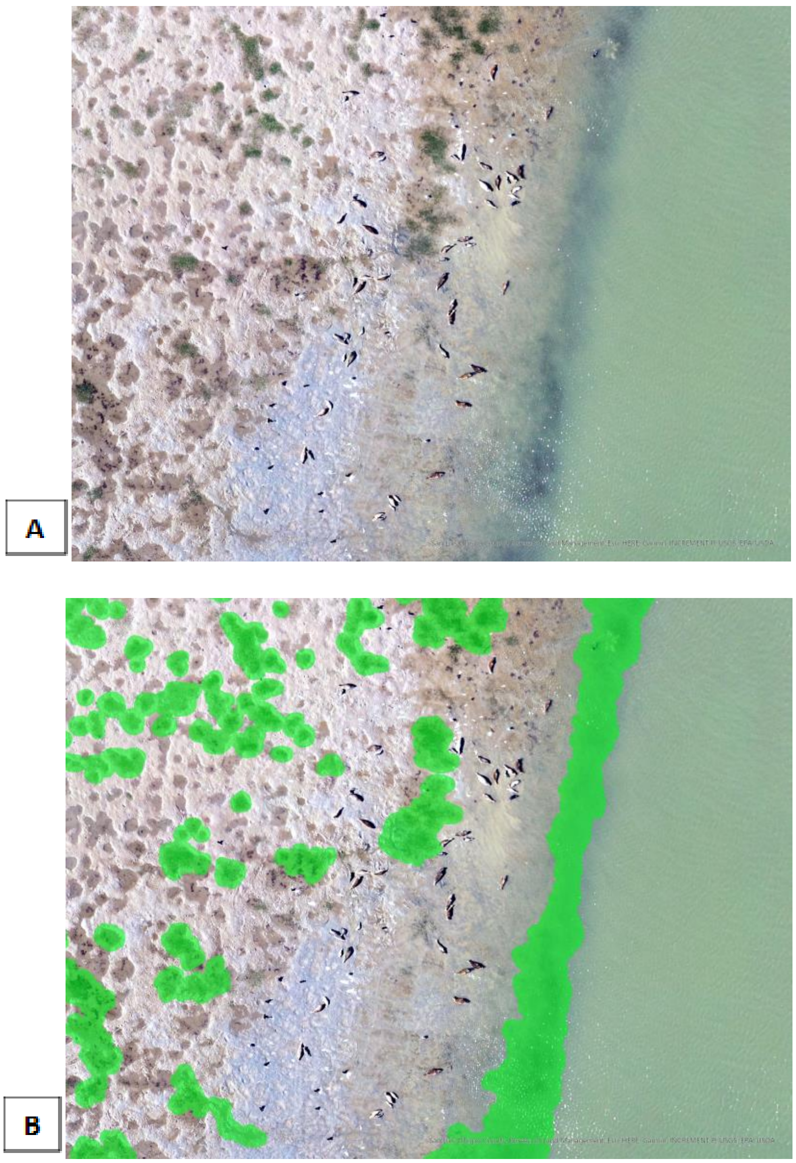

Figure 2A, 2B. Resolution of photos captured with M&A's UAV drone during spring of 2023. Figure 2A shows sea lions relaxing by the main channel near Pasadena Point, and Figure 2B shows the same image with the eelgrass layer overlaid to demonstrate how submerged eelgrass beds and small patches of eelgrass are detected with this method.

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 information and sources.

Table 1. Eelgrass acreages and mapping methods, 1960 to 2023.

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)*
2023	April 14 to 18, May 9 to 11, and June 16 to 17, 2023	750	Sonar and UAV (M&A)

*Note that the UAV imagery and manual digitization process has an approximate error of 10% associated with it.

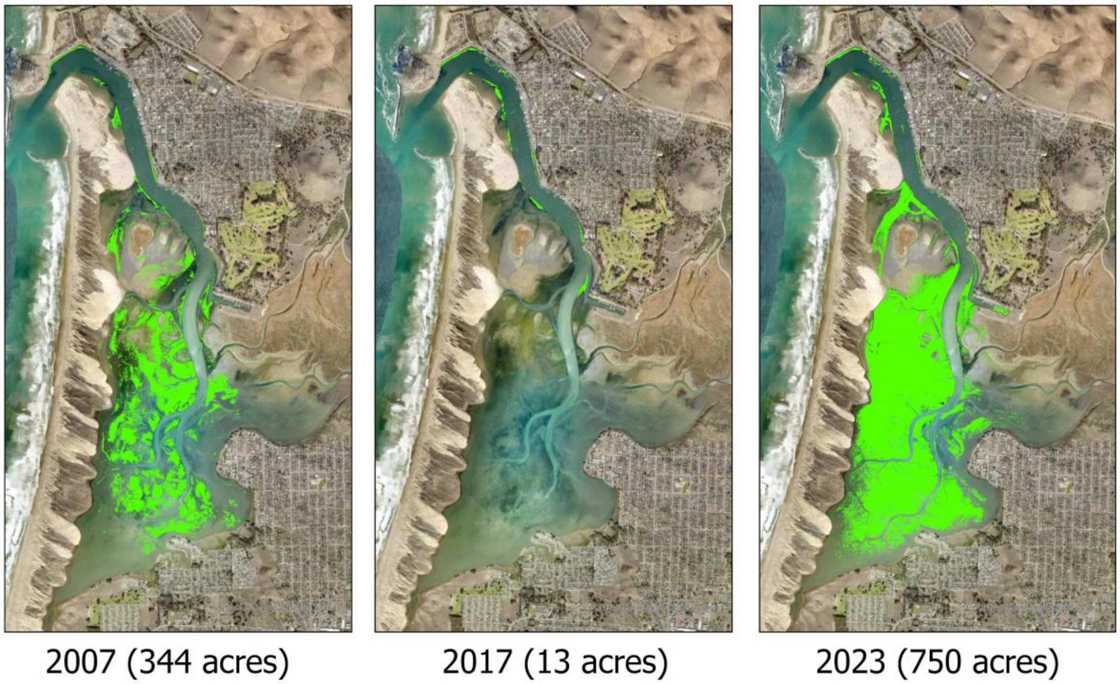

Figure 3. Changes in eelgrass acreage in Morro Bay from 2007 to 2023. Note that the intertidal eelgrass extent from 2007 and 2017 was analyzed with multispectral imagery (Ocean Imaging) and both the intertidal and subtidal extent from 2023 was analyzed using a combination of drone imagery and sidescan sonar (M&A).†

Given restoration efforts and significant natural establishment, there has been a major resurgence of eelgrass habitat with 500 acres mapped in 2021 and 750 acres mapped in 2023. While we are encouraged to see such a large expansion in eelgrass coverage throughout the bay in a short time, we are anticipating a reduction in acreage in the near future. M&A conducted a depth analysis using the digital elevation model (DEM) from a 2019 topo bathymetric LiDAR survey and compared it with the 2023 eelgrass inventory. They found that over 70% of the estuarine area falling between a depth of +0.5 and -0.5 feet MLLW was supporting eelgrass during the survey, indicating that eelgrass is nearing its maximum spatial extent. In addition, colder-than-average water temperatures for the past several years has likely contributed to acreage expansion, and this is likely to change in the coming years. Given these conditions, a reduction in acreage to a more sustainable extent is likely. Continued monitoring will be essential for tracking acreage fluctuations and enacting restorative measures in a timely manner if needed.

Restoration Efforts

Eelgrass restoration was initiated in 2017 as a response to the precipitous decline in acreage that began in 2007 and had reached alarmingly low levels by 2013. A variety of different restoration methods were attempted, with the most successful stemming from transplanting. Transplanting consisted of collecting eelgrass plants from healthy donor beds and planting them at sites where eelgrass had been lost. To keep the plants from being uprooted by small-scale erosion or tidal movement, they were anchored into the sand with garden stakes, bamboo shoots, or rebar. Trained staff from Tenera Environmental, Inc. (Tenera) played a major role in this effort and continued to monitor the newly-planted restoration plots to test the effectiveness of these methods.

† Because of differences in eelgrass mapping methodology over time, acreages of eelgrass cannot be directly compared from year-to-year.

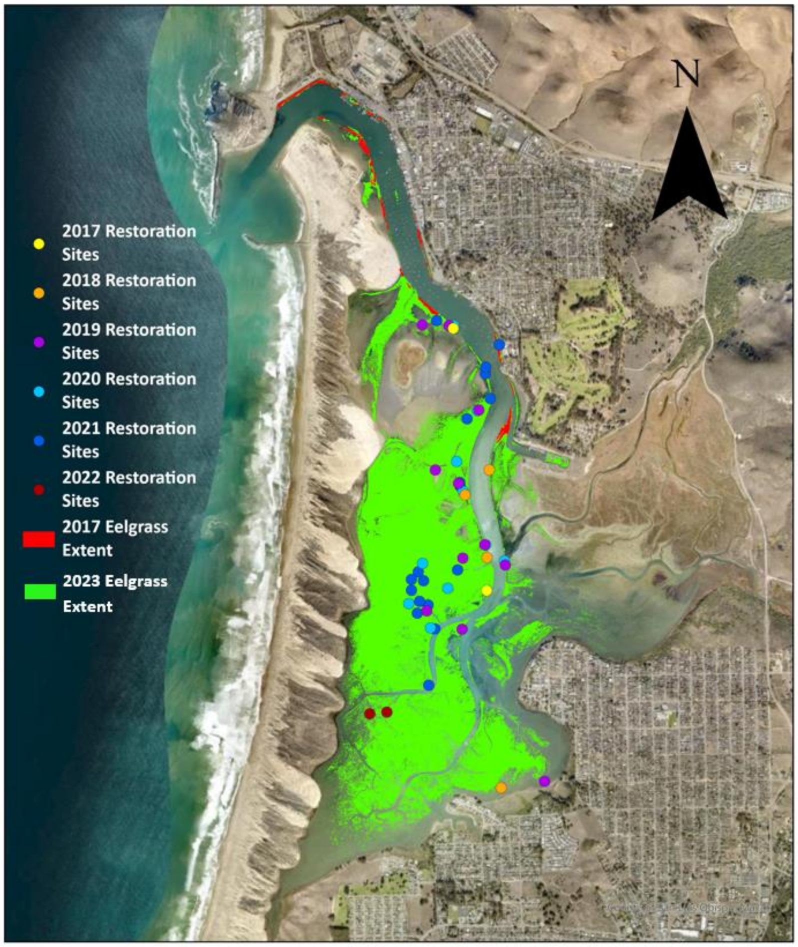

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Figure 4. Map of eelgrass transplanting locations from 2017 to 2022, with the 2017 eelgrass extent in red and the 2023 eelgrass extent in green.

By 2022, the recovery of eelgrass to pre-decline acreage marked the end of the five-year restoration effort. Since the start of the project, over 15,000 eelgrass plants had been transplanted across 39 restoration sites. While the resurgence of eelgrass acreage cannot be fully attributed to restoration, the effort likely had an important impact by reintroducing eelgrass to areas where it had been lost and contributing to seed dispersal throughout the estuary.

Monitoring Efforts

The Estuary Program has implemented several supplementary monitoring efforts to track eelgrass changes throughout the bay, including the establishment of permanent transects 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 until 2022, after which this effort was discontinued. The Oyster Bed site from the permanent plot effort was instead incorporated into the Estuary Program's annual Bed Condition monitoring.

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 5. 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 tide 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 running parallel to each other to measure eelgrass at various depths. Note that for analysis, 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 halted.

Results

Average shoot density for each site is summarized in Figure 6.

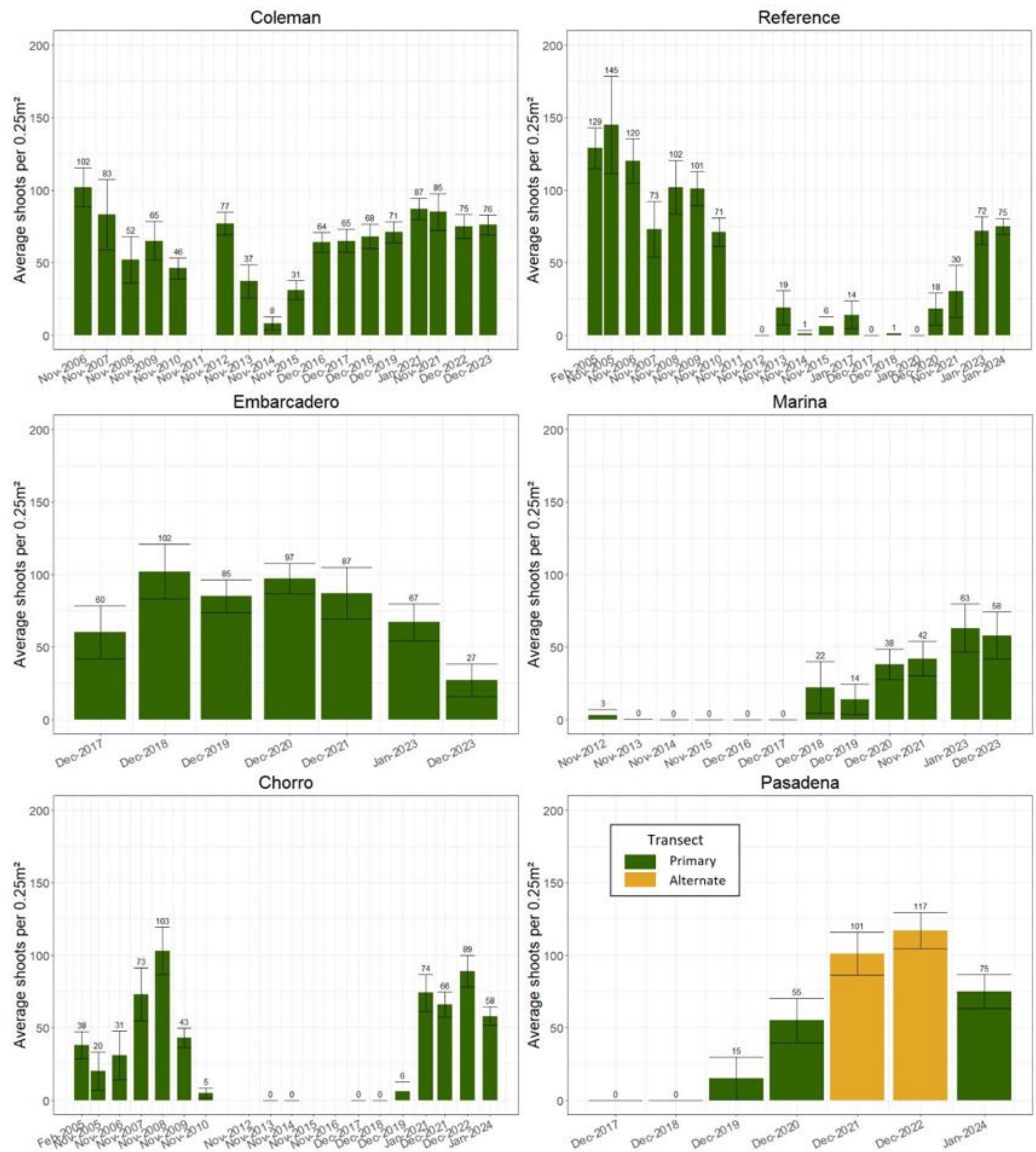

Figure 6. Average shoot density counts per year at six sites. Shoots were counted within a 0.5 m x 0.5 m quadrat. Error bars represent the 95% confidence interval. The yellow bars in the Pasadena plot indicate the years when an alternate transect was sampled at this site.

Eelgrass density has rebounded to pre-decline levels at Coleman, Reference, and Chorro, the three sites where surveys were conducted before 2007. In 2023, average densities were slightly higher than the 2022 sampling effort at two out of six sites. However, all sites except for Embarcadero had higher densities than those recorded in 2017, which was the lowest point of the eelgrass decline. Eelgrass density experienced a minimal decrease at Marina, and notable decreases at Embarcadero, Chorro, and Pasadena. The especially dramatic drop in density at Embarcadero to levels below those observed in 2017 appears to be driven by active erosion occurring at the site.

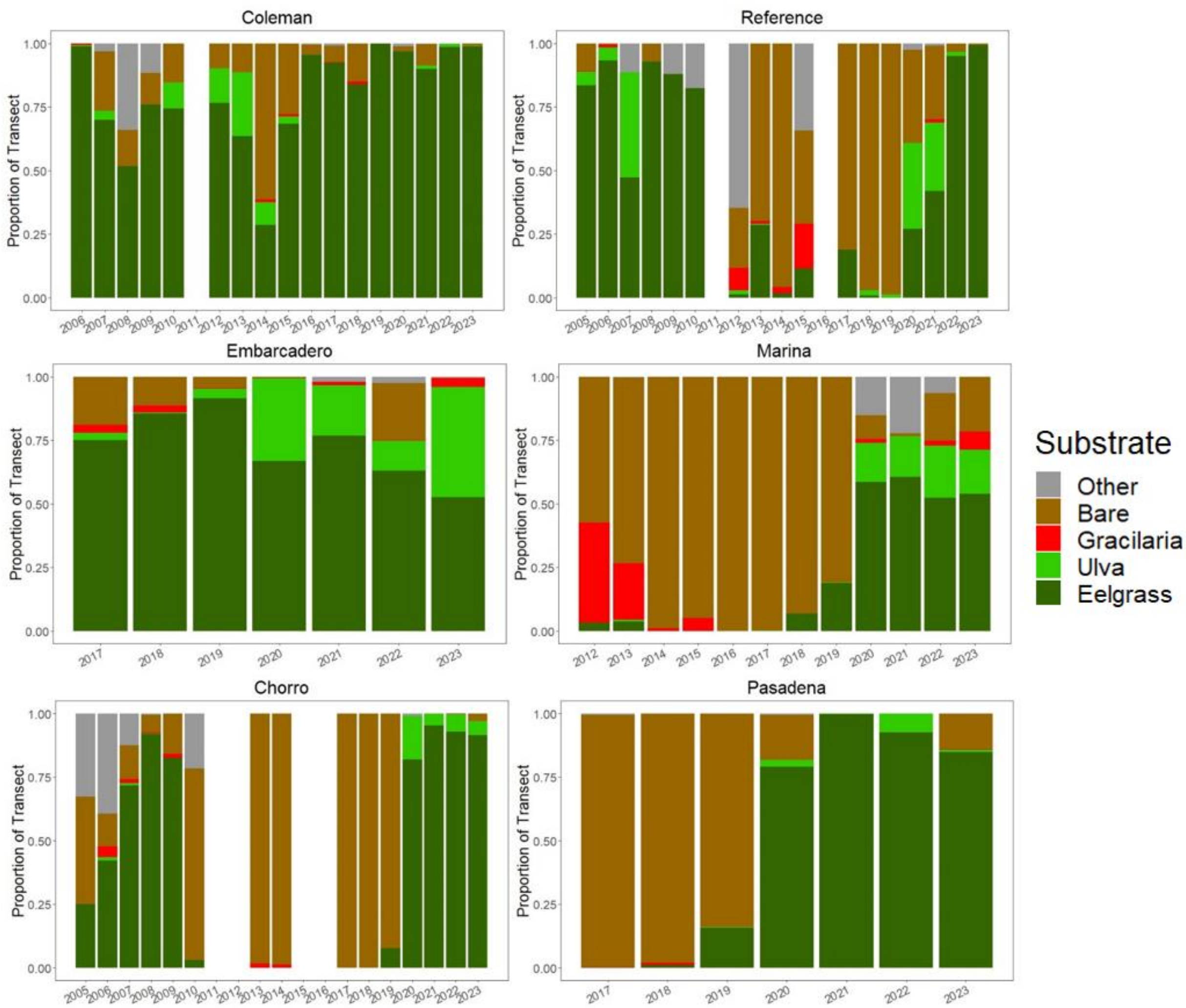

Figure 7. Proportional compositions of the primary recorded percent coverage types, averaged over all quadrats for a given year. Each vertical bar represents one year's sampling efforts.

Proportional compositions are summarized in Figure 7. The percent cover of eelgrass (dark green bars) observed at all sites closely follows the fluctuations in density seen in Figure 6. However, these plots show how additional macroalgae taxa fluctuated in abundance as well. The percent cover of *Ulva* (light green bars) across many of the sites has notably increased starting in 2020. Fortunately, the appearance of *Ulva* does not seem to be suppressing eelgrass growth, as both organisms are currently experiencing increases in coverage. Of note, the changes in percent cover of eelgrass at sites where density decreased were more subtle than the respective decreases in density, highlighting that acreage increases can still be observed even if the density is starting to thin out at certain locations.

Permanent Transect Photos and Observations

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

Coleman Transect

Average eelgrass density has been fairly steady at this transect since 2016, and remains more than twice as high as the density observed in 2015. Current shoot density is comparable to pre-decline levels seen in 2007.

Figure 8. Permanent transect monitoring at Coleman Transect, 2016 to 2023.

Reference Transect

Eelgrass has made a significant 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 transformed the landscape to consist of eelgrass “islands” separated by small channels. In the past four years of monitoring, these “islands” have expanded into a large, continuous bed. Shoot density is similar to the pre-decline density observed in 2007.

Figure 9. Permanent transect monitoring at Reference Transect (previously “Tidelands”), 2017 to 2023.

Embarcadero Transect

This transect was established in 2017 and is the newest of the six permanent transect monitoring sites. Eelgrass density in 2023 was the lowest recorded at this site since its establishment and marks the third year of decline in a row. Erosion, as noted in the field by patches of eelgrass plants with exposed rhizomes, seems to be the most likely cause for the continued decline. The Embarcadero transect served as a harvest site for restoration efforts for multiple years.

Figure 10. Permanent transect monitoring at Embarcadero Transect, 2017 to 2023.

Marina Transect
After this transect was established in 2012, no eelgrass was present from 2013 to 2017. Patchy eelgrass began appearing in 2018 and 2019 and has since formed into a continuous bed. While the shoot density observed in 2023 represents a slight decrease since last year, it is still the second highest density recorded after more than a decade of monitoring.

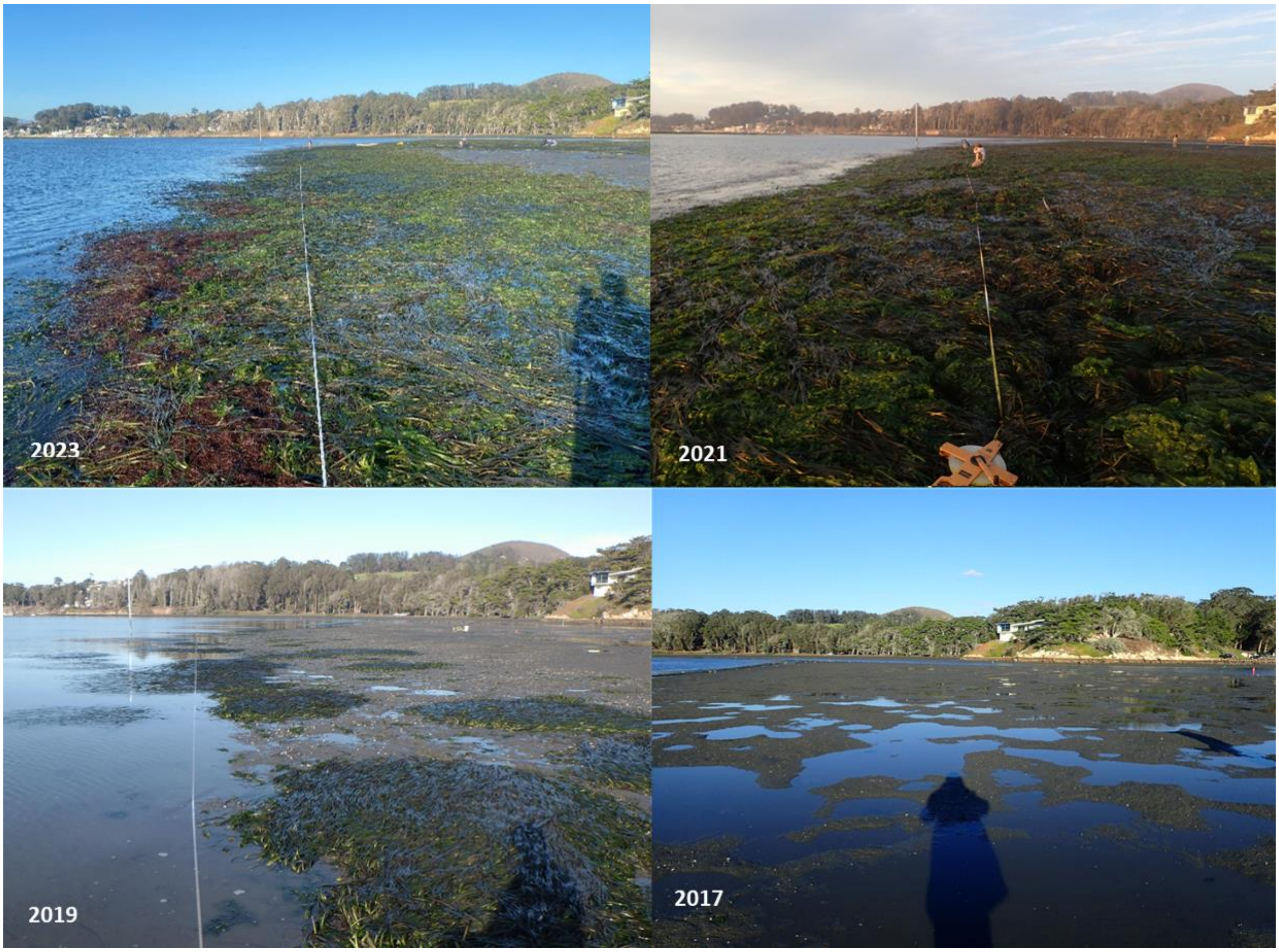

Figure 11. Permanent transect monitoring at Marina Transect, 2017 to 2023.

Chorro Transect

Shoot density at the Chorro transect returned to pre-decline levels in 2021 and continues to exceed these levels despite a notable decrease in density this year. Eelgrass had not been recorded here since 2010 but reappeared in 2019. Surveys were not conducted at this transect in 2011, 2012, 2015, and 2016 due to staffing limitations and time constraints.

Figure 12. Permanent transect monitoring at Chorro Transect, 2017 to 2023.

Pasadena Transect

The Pasadena transect had the highest observed shoot density in 2021 and 2022, although a closer inspection of the historic site photos revealed that an alternate transect had been surveyed during those years. This transect shares a start coordinate with the primary transect and has been determined to be adequately representative of eelgrass density throughout the bed. To confirm that the transects were similar, both transects were monitored this year and their respective densities were compared. Density at the alternate transect was higher but fell within the 95% confidence interval of the primary transect and was lower than the densities recorded in 2021 and 2022, consistent with the trend observed at the primary transect. The primary transect will be monitored for all future surveys, but the results from the alternate transect have been retained in Figure 6 as representative of conditions on the primary transect.

The photos below show the dramatic transformation that took place at this site over the past five years. 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 13. Permanent transect monitoring at Pasadena Transect, 2018 to 2023. Note the differing orientation of the alternate transect sampled in 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 directly on the transect, it is not captured in the data collection. Most transects are not permanently marked which makes it challenging 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 in 2015 as a joint effort between Dr. Jennifer O'Leary of California Sea Grant and the Estuary Program. 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 a lack of optimal tides, the fall monitoring and subtidal monitoring efforts 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 of eelgrass health indicators using ImageJ software. Manual photo processing for 2023 has not been conducted yet, as the Estuary Program is currently exploring ways to automate this process to save staff time and reduce the subjectivity of photo analysis.

Figure 14. Bed condition monitoring sites at Coleman Beach, North Sandspit, Reference Bed, Reference West, Windy Cove, and Oyster Bed.

Results

The Estuary Program conducted spring 2023 monitoring at Coleman Beach, North Sandspit, Reference Bed, Reference West, Windy Cove, and Oyster Bed sites. North Sandspit and Reference Bed were both established at the beginning of the project but have had gaps between sampling years due to a lack of available tides. Spring monitoring had not been conducted at North Sandspit since 2017, and the Reference Bed site was modified to include an additional transect (Reference West) running perpendicular to the historic transect, which has experienced significant erosion and now contains only 18 meters of contiguous eelgrass. The Oyster Bed transect was established and monitored for the first time this year. This site was originally a Permanent Plot monitoring site, but after this project was discontinued in 2022, the site was modified into a 150-meter transect to fit the protocol of the Bed Condition project. The figure below displays the results of preliminary data analysis using only the spring intertidal data from 2016 to 2023.

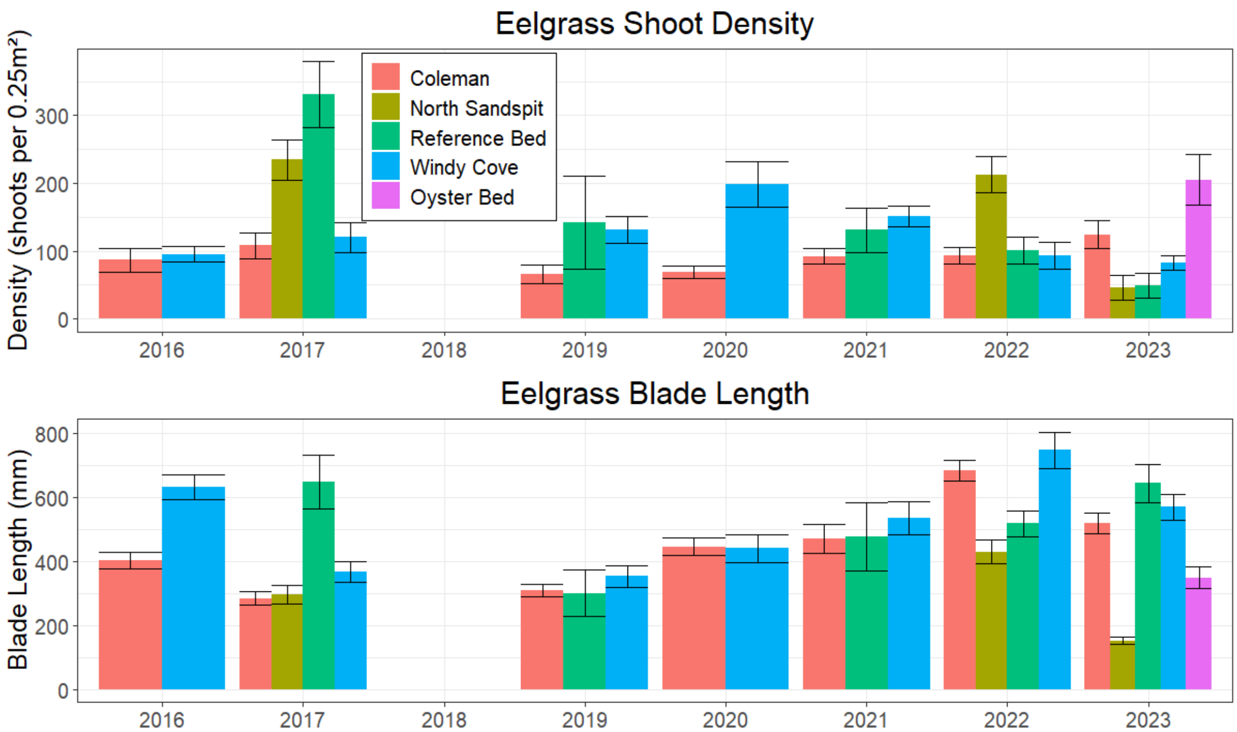

Figure 15. Eelgrass shoot density and blade length results from spring intertidal sampling events. No sampling was conducted in 2018. Reference Bed is represented as the combination of results from the historic transect and the new Reference West transect. A missing bar indicates years when a site was not sampled. Error bars represent the standard error.

Trends in eelgrass shoot density are site-specific. Density at Coleman has been remarkably stable, similar to the density results during the winter Permanent Transect monitoring at this site, while Reference Bed has experienced a steady decline from over 300 shoots per quadrat in 2017 to less than 50 shoots per quadrat in 2023. The location of the Reference Bed transect is different from the Reference transect monitored during Permanent Transect sampling, which has seen the opposite trend in density since 2017. Density decreases were also observed at North Sandspit and Windy Cove. Oyster Bed, the new site added this past year, had the highest eelgrass shoot density out of all sites monitored in 2023. It is important to note that quadrat locations for this project are chosen based on the presence of available eelgrass to survey, and bare patches are actively avoided. This means that the densities collected during this project are more representative of conditions within the eelgrass beds as opposed to the full extent of the monitoring site and are more prone to overestimate density than the permanent transects.

Average blade length has increased since 2019 at Coleman, Reference Bed, and Windy Cove. Blade lengths at North Sandspit and Oyster Bed were notably shorter than the longer running monitoring sites during the 2023 surveys.

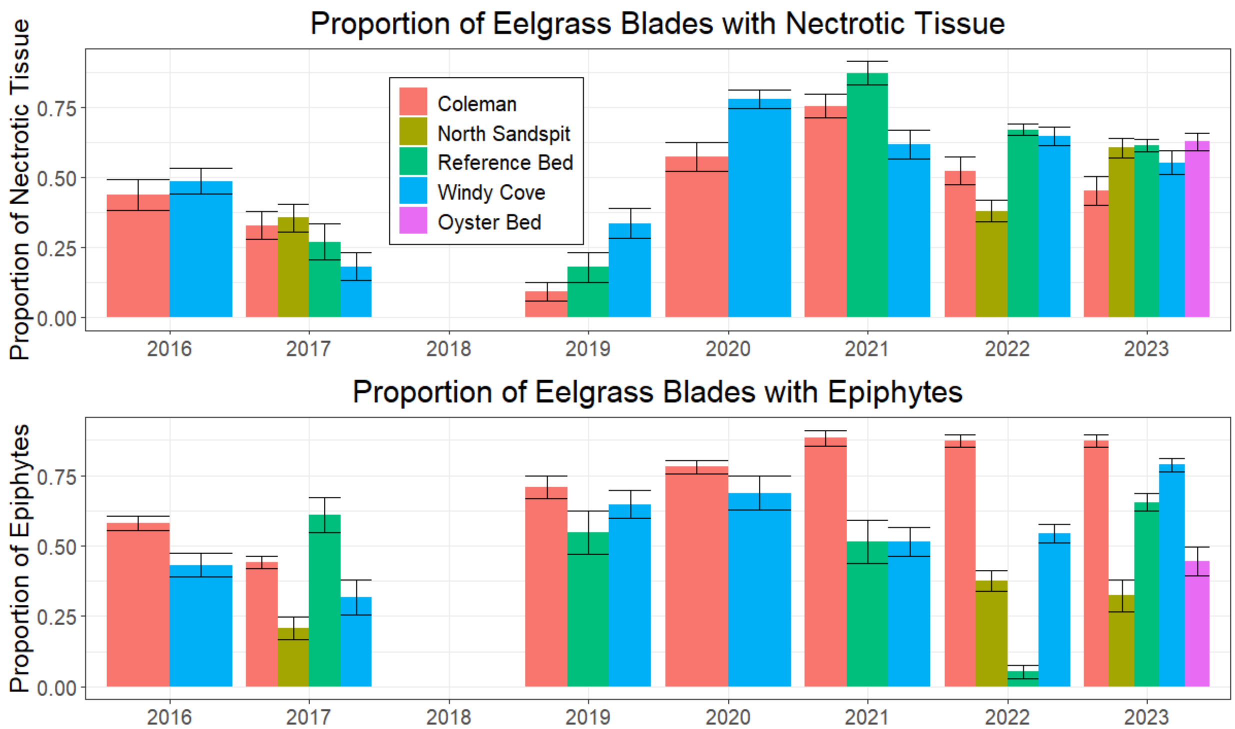

Figure 16. Blade condition results from spring intertidal sampling events. No sampling was conducted in 2018. Reference Bed is represented as the combination of results from the historic transect and the new Reference West transect. Sites were not sampled in years where their respective color bar is absent. Error bars represent the standard error.

Estimating eelgrass blade condition involves a detailed assessment of health metrics on five stipes at each quadrat. For each stipe, the presence or absence of necrotic tissue and epiphytes on each blade are recorded. The proportion of eelgrass blades containing epiphytes and/or necrotic tissue is derived by dividing the number of blades that had these indicators present by the total number of blades assessed at that site. Results from Coleman, Reference Bed, and Windy Cove (the sites monitored most consistently) show that the average proportion of blades containing necrotic tissue increased significantly from 20% in 2019 to 75% in 2021 but has since fallen back to an average of 54% of blades in 2023. This average proportion is very similar to the proportions recorded at North Sandspit and Oyster Bed in 2023 as well. In general, it appears that the abundance of necrotic tissue fluctuates more from year-to-year than it does between sites.

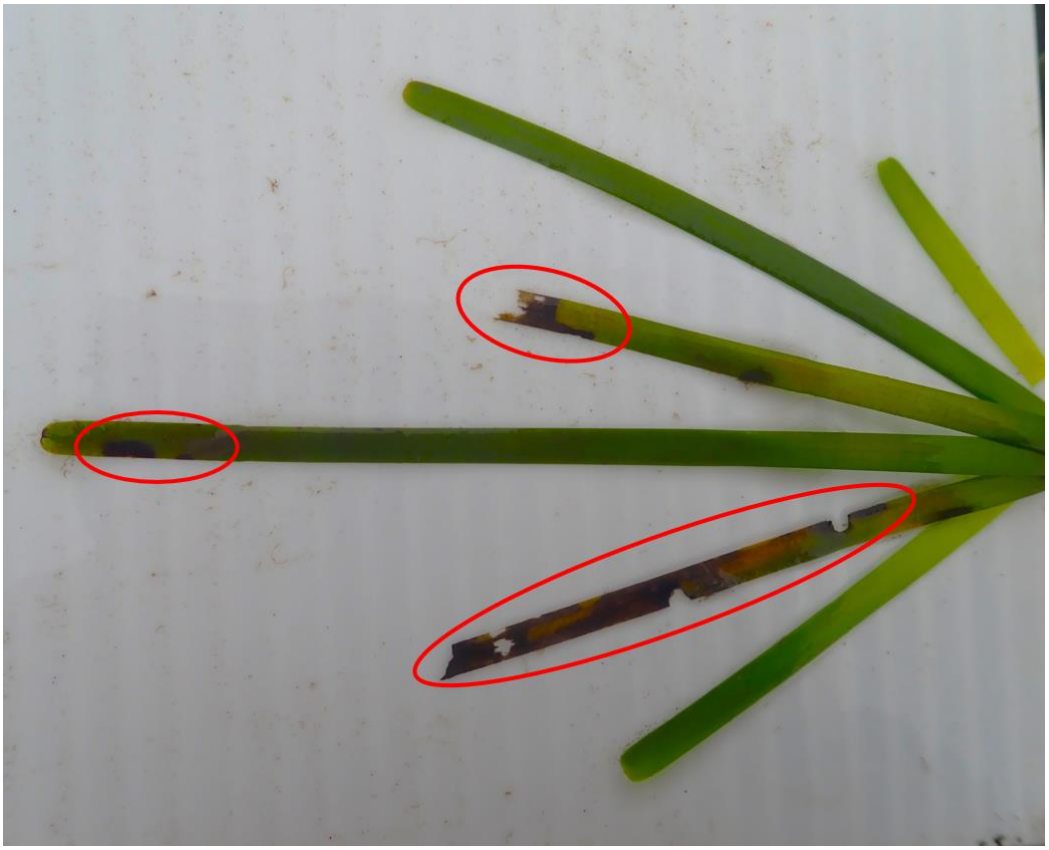

Figure 17. Eelgrass stipe from Oyster Bed during the spring 2023 Bed Condition survey. Examples of necrotic tissue on the blades are circled in red.

On the other hand, the proportion of blades with epiphyte coverage typically varies more across sites than it does between years. The site closest to the mouth of the bay, Coleman, consistently has the highest 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.

Macroalgae Monitoring

History

The Macroalgae Monitoring project began in May 2023, driven by the notable increase in algae abundance observed during field surveys since 2020. This project was developed to track changes in macroalgae cover and biomass both spatially and temporally. Sites were established to examine variations in macroalgae cover throughout the estuary as well as across differing elevations. In addition, co-location with eelgrass monitoring sites will aid in developing a better understanding of how the density of macroalgae affects eelgrass beds.

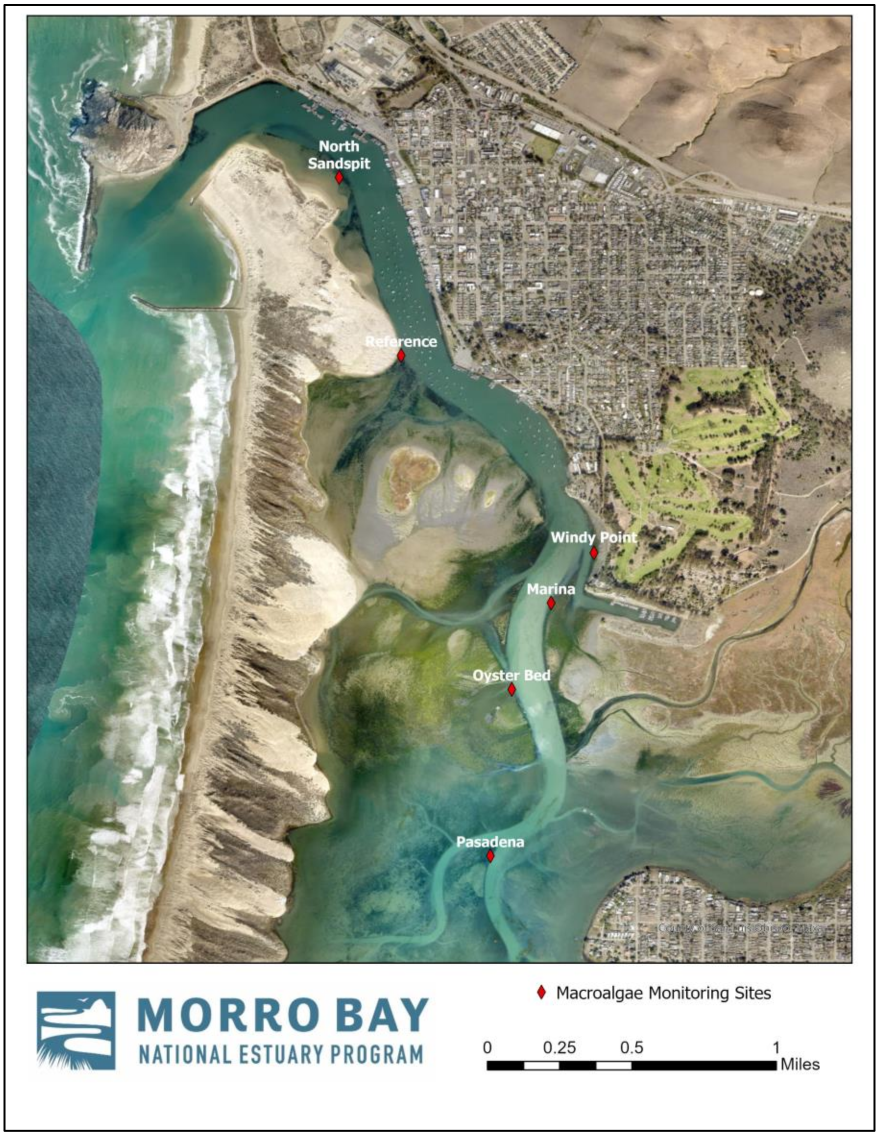

Figure 18. Macroalgae monitoring site locations.

Methods

In 2023 and 2024, surveying was conducted three times per year in the Spring (May), Summer (July/August), and Winter (February) during low tides that fall below -0.5ft MLLW. To account for the changes in abundance of drifting algae over short time scales, the monitoring takes place within a single low tide series over several consecutive days. Estuary Program and Tenera Environmental staff work together on the fieldwork component of the project, which involves quadrat monitoring along three transects at each site. Each transect has been established at a specified elevation in relation to the MLLW tide datum using LiDAR results from a 2022 survey. Transect elevations are set at -0.5ft MLLW (Low), 0ft MLLW (Center), and 0.5ft MLLW (High). These elevations were chosen because they encompass the range of elevations where eelgrass and algae exhibited the highest degree of interaction during preliminary site scouting. Elevation change between transects was verified *in situ* using an auto level in July 2023.

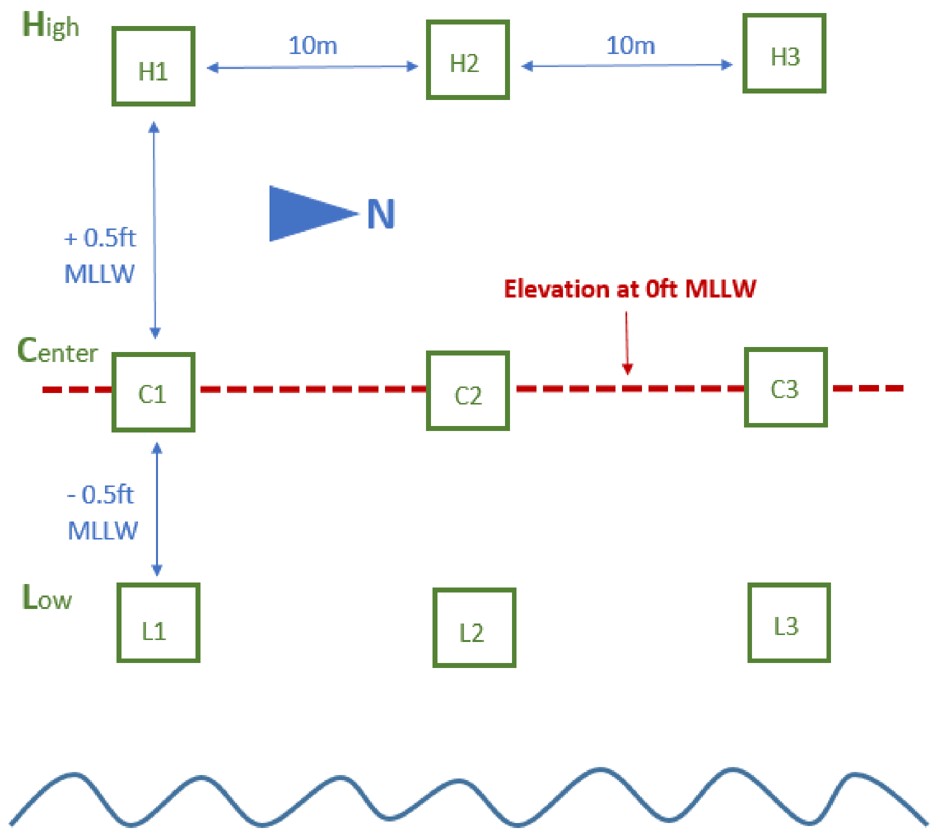

Figure 19. Schematic displaying quadrat placement for the macroalgae monitoring sites. The center transect is established at 0ft MLLW, with a high and low transect spaced at elevations 0.5ft above and below MLLW respectively. Three quadrats are monitored on each transect, spaced ten meters apart, resulting in a three quadrat by three quadrat grid for the study area.

Quadrat sampling consists of two methods for estimating the percent cover of different vegetation types. The first method involves visually estimating coverage of eelgrass, multiple algae species, and bare ground at a resolution of five percent. The second method utilizes point-intercepts at 25 intersection points spaced in a five-point-by-five-point grid. An algae sample is then collected from the inner 0.25m^2, which is transported back to the lab where it is refrigerated until further processing. Eelgrass health metrics such as the patchiness of the bed, presence of epiphytes, and incidence of decaying tissue throughout the survey area are collected as well.

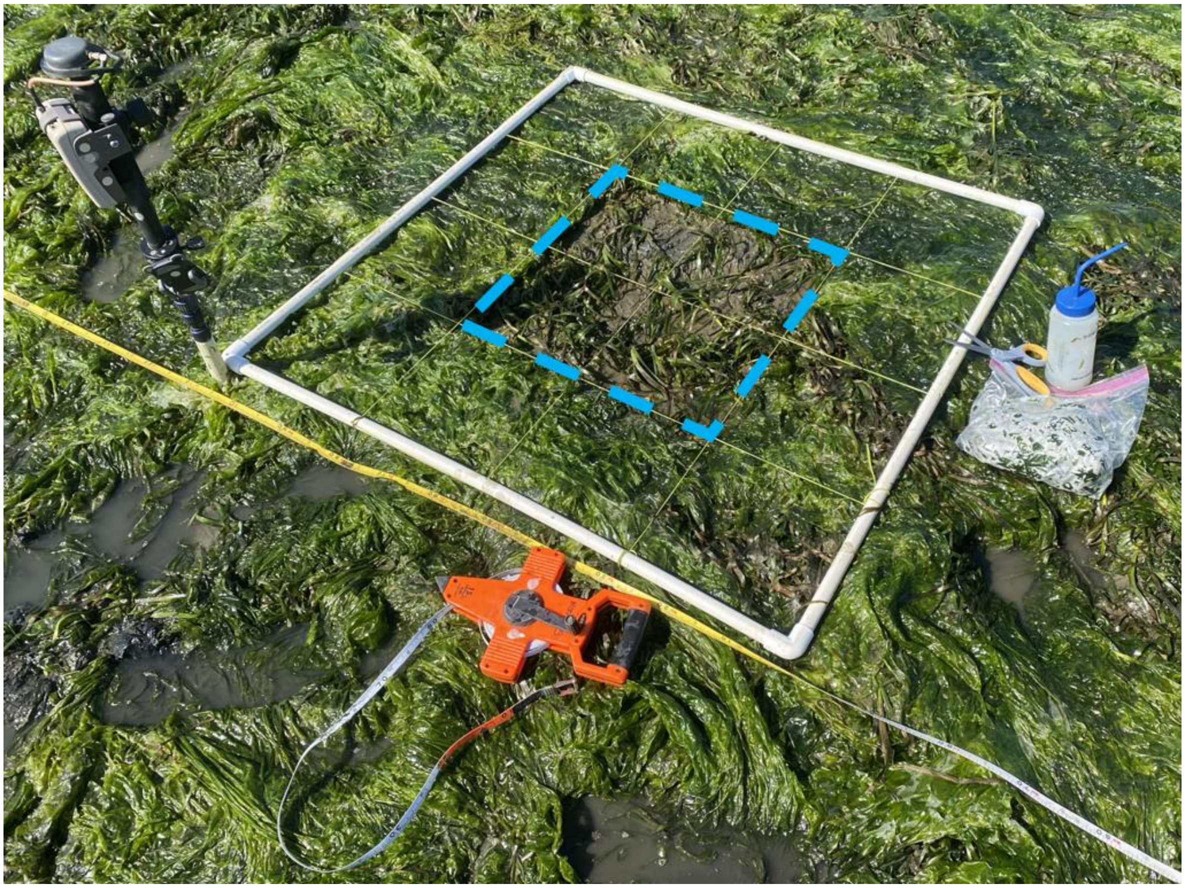

Figure 20. Algae biomass samples are collected from the four center squares of a one-meter by one-meter quadrat, as indicated by the blue dashed line in the photo above. The *Ulva* mat has been cut away and collected for dry weight processing, revealing shoots of eelgrass hidden underneath the algal mat.

After the completion of fieldwork, Estuary Program staff dry and weigh algae samples in the lab. Before drying, algae samples are thoroughly rinsed to remove mud and invertebrates. They are then placed in an oven at 80°C and are reweighed every two days until drying is complete. The resulting dry weights are then standardized to grams of alga biomass per square meter.

Results

Macroalgae monitoring was conducted in May 2023, August 2023, and February 2024. Due to inclement weather making site access difficult, the Pasadena site was not monitored in February 2024.

The percent cover and biomass methods were designed to represent differing impacts of algae abundance. Percent cover represents the two-dimensional extent of algal coverage that serves as a canopy, potentially covering eelgrass and preventing its ability to effectively photosynthesize. The biomass metric is derived from dry weights of algal material and represents the bulk three-dimensional extent of the algal mat. This is of interest as higher algal abundance may contribute to soil conditions that are anoxic and high in sulfides, conditions which are detrimental to eelgrass growth (Gustafsson & Bostrom 2014). Algae belonging to the genus *Ulva,* commonly referred to as "sea lettuces," were the most abundant throughout all seasons, making up 84% of the total algae biomass collected during our surveys. In general, algae biomass and percent cover followed similar trends, and a linear regression between percent cover and biomass of *Ulva* was statistically significant ($p<0.001$, $R^2=0.34$).

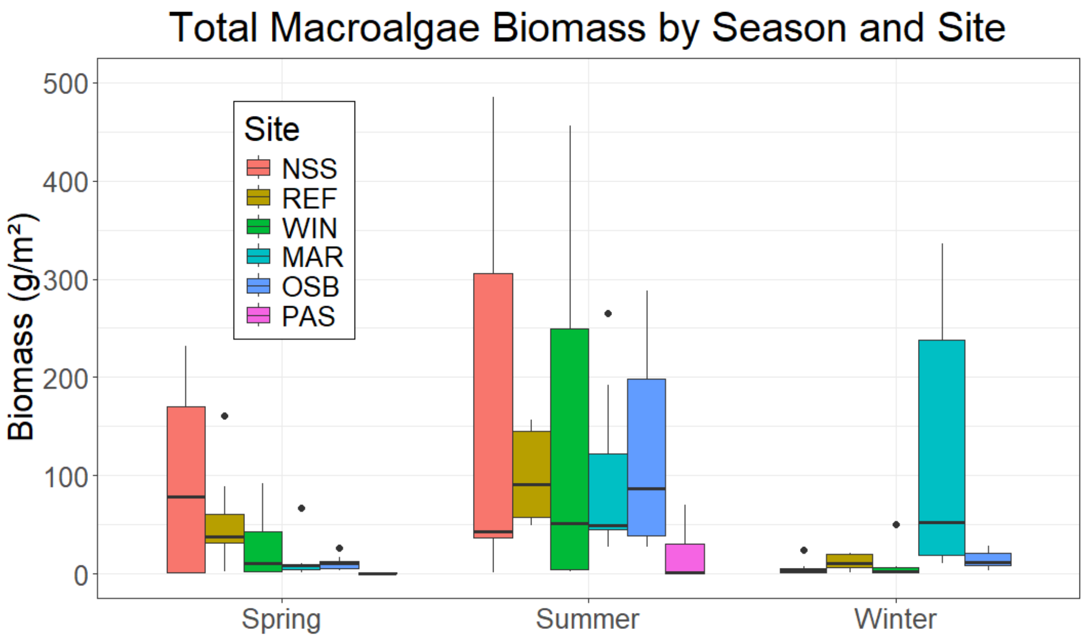

Figure 21. Total macroalgae biomass (g/m^2) by survey season. Survey sites are arranged by increasing distance from the mouth of the bay. The PAS transect was not sampled during the winter surveys in February 2024.

The seasonality of macroalgae abundance within Morro Bay largely tracked with trends in upwelling intensity and light availability. Upwelling is the process where surface water masses are driven offshore, which pulls deeper water masses to the surface along the coast. These upwelled water masses are rich in nitrates, which promotes blooms of drift algae like *Ulva* that are carried into the estuary by tidal exchange. Our spring surveys were conducted during peak upwelling intensity, and we observed a steep gradient in algae abundance from the front bay decreasing to the back bay, reflecting the steady transport of algae into the estuary. In the summer, weaker currents and lighter winds promote the retention of algae, while ample sunlight contributes to growth throughout the bay. The majority of sites experienced their highest algal biomass and percent cover results in the summer. In the winter, macroalgae abundance dropped to its lowest point at all sites except for MAR. The estuary-wide decrease in the winter is due primarily to light limitation, stormwater influx from the creeks, and the lack of upwelled nutrients during these months. Small-scale hydrodynamic variability resulting in areas of reduced current velocity during tidal exchange and proximity to nutrient influx from stormwater runoff may explain the retention of algae at MAR through the winter, although further analysis would be required to confirm.

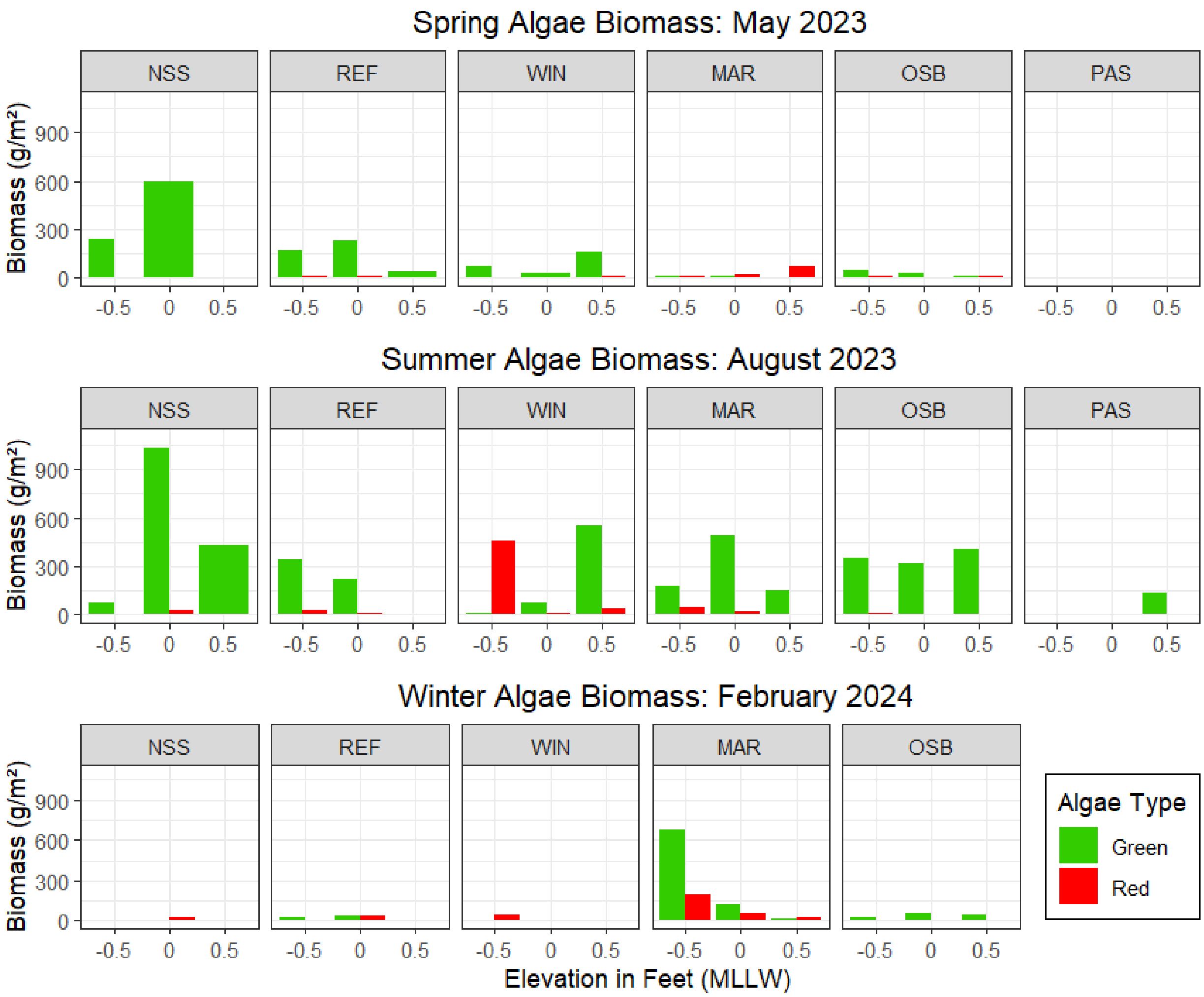

Figure 22. A more detailed look at macroalgae biomass during each survey. The rows of the figure have been grouped by season, while the columns have been grouped by site. Each subplot displays the total biomass (g/m^2) of green algae and red algae by transect elevation. The PAS transect was not sampled during the winter surveys in February 2024.

Results displayed in Figure 22 (above) show a more detailed breakdown of this year's results. The survey season had the most significant effect on algae biomass, while impacts from elevation and site location were minimal. Red algae, largely comprised of *Gracilaria*, exhibited different trends in spatial distribution throughout the bay than green algae. *Gracilaria* was primarily found at the mid bay and back bay sites, appearing to favor the comparatively warmer water temperature in these regions of the estuary.

So far, macroalgae abundance does not seem to be negatively impacting eelgrass in a measurable way. On the contrary, the recent expansion of eelgrass acreage may actually promote more algal retention as drift algae is caught by the blades, as observed in similar studies (Bell & Hall 1997). Our results show that quadrats with proportionally more eelgrass present than bare ground held four times the amount of algae biomass than quadrats that had higher proportions of bare, unvegetated ground. Further monitoring is needed to uncover the long-term impacts of the increase in macroalgae biomass and cover on eelgrass beds in the Morro Bay estuary.

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 Army Corps of Engineers (ACOE) to maintain a channel depth of approximately 40 feet.

ACOE began their annual dredging in Morro Bay on May 14, 2023, and the project was completed on June 7, 2023. During active dredging, ACOE contracted M&A to conduct weekly water sampling at locations greater than 1,000 feet away from dredging (Reference Station), down current of the dredge footprint (Compliance Station), and at the dredge material 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% or greater difference between the Reference Station and Compliance Station. In addition, dissolved oxygen levels must remain above 5 mg/L and pH between 7.0 and 8.5. According to the post-project report, no water quality exceedances were encountered during dredging activities. Adequate dissolved oxygen was maintained throughout the project, ranging between 7.1 mg/L to 8.8 mg/L (M&A, 2023).

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 consulting firms like Tenera Environmental and Padre Associates using scuba divers and/or sonar before, during, and after construction projects. In 2023, two surveys were conducted to support construction projects on or near the Embarcadero. The conclusions of the surveys were as follows:

- A pre-construction survey for the extension of the coastal harborwalk, a public access walkway, at 715 Embarcadero. Known as the Van Beurden Harborwalk Project, construction will involve the conversion of existing deck spaces into walkways and their connection to the existing harborwalk path. A SCUBA survey conducted by Tenera found approximately 17m^2 of eelgrass within the survey area, however none of this eelgrass is expected to be negatively impacted during the construction. On the contrary, the removal of portions of the existing wharf and catwalk will actually open up 21m^2 of sandy habitat for potential eelgrass growth, since it will no longer be continuously shaded. All new construction will be over rocky rip-rap habitat and will not shade any eelgrass habitat.
- A post-construction survey after two piles were repaired at the Glads Landing dock, just south of the Embarcadero at 225 Main Street. The original wooden piles had been damaged by the shipworm mollusk and were covered with steel sleeves for reinforcement in November 2022. To assess project-related impacts to eelgrass, SCUBA divers from Padre Associates conducted the post-construction survey in September 2023. The two eelgrass patches that had been documented during the pre-construction survey had experienced density increases and no negative impacts to eelgrass were identified.

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.

Automated Eelgrass Classification using Drone Imagery

As mentioned earlier in the "UAV Drone Mapping" section, a machine learning model for the classification of eelgrass has been under development. This project is a collaborative effort between researchers at Stanford and Cal Poly and its successful quantification of eelgrass acreage in 2019 was the subject of a recent publication (Tallam et al 2023). The researchers use a state-of-the-art image segmentation machine learning technique to delineate eelgrass beds by assigning each pixel in the orthomosaic of drone imagery a classification of "eelgrass" or "non-eelgrass."

The model performed very well on the 2019 imagery, receiving an F1 accuracy score of 80.9% and was able to accurately identify and annotate eelgrass when compared to the hand-digitized map. In some cases, the model exhibited higher precision than the map annotated by hand. In a small number of cases, false positives were detected due to the similarities in appearance of green algae mats and eelgrass beds. The researchers believe this issue can be resolved by employing a multi-class image classification model, where each type of vegetation would be assigned a respective class, as opposed to solely "eelgrass" versus "non-eelgrass." As the model is further optimized, it has the potential to dramatically reduce the effort spent on digitizing eelgrass acreage maps, reducing both the time and cost of eelgrass mapping and allowing for more frequent surveys.

The model was recently applied to drone imagery collected in 2022 but is awaiting verification. In previous years, the model accuracy was verified by comparing its output to the hand-digitized maps but with the end of manual digitization, a new method was required. The current verification process utilizes 1,000 points randomly distributed throughout the imagery, which a team of validators will review to note the type of vegetation (or lack thereof) found at each point. Validators pay special attention to the presence of algae and whether eelgrass beds are submerged, as these represent situations where the model has struggled in the past. These additional annotations will provide valuable information regarding the proportion of model error attributed to these special cases and how it can be further optimized. The 2022 eelgrass acreage will be available upon the completion of this validation process.

Water Quality Monitoring

Dr. Ryan Walter from Cal Poly's Physics Department continues to maintain water quality instrument packages at the front bay and the back bay, as well as 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.

Figure 23. Cal Poly students check on the instruments at the back bay sensor station. The top of the station houses meteorological instruments for measuring weather parameters and a solar panel to power all the sensors (left). Water quality instruments are kept submerged but can be serviced by raising them above the water line with a pulley system (right). Photos courtesy of Ian Robbins.

Dr. Emily Bockmon of Cal Poly's Chemistry Department oversaw numerous ocean acidification monitoring and carbonate chemistry sampling efforts. Data from two autonomous pH sensors are automatically uploaded from the sensor to the web and can be viewed here: https://data.cencoos.org/#metadata/100050/station. Data calibration, processing, and sensor maintenance are ongoing.

Dr. Bockmon and her students also conduct monthly carbonate chemistry sampling at seven shore locations. Nutrient sampling was added at three of the shore sampling locations in 2021, and an additional three locations were added in 2022. In addition to these ongoing projects, two bay-wide boat transects were conducted in May and August to further characterize the physical and chemical environment in the estuary at low tide. Results from transect surveys conducted in 2018 were recently published, providing a baseline of carbonate chemistry within the estuary following eelgrass decline (Bartoloni et al 2023). Results from the latest transects are expected to be summarized in an upcoming publication once analysis is complete.

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, led by Drs. Laurie McConnico and Silvio Favoreto, 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 faculty and students. 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. The past five 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.

Genetic sequencing has proven to be an invaluable tool for wasting disease research in recent years. In 2022, 40 eelgrass tissue samples were processed using 16S rRNA sequencing to investigate the bacterial microbiome in association with wasting disease. This analysis was inspired by similar studies that have uncovered how the presence of particular bacterial families, such as the Cellvibrionaceae, facilitate wasting disease by degrading eelgrass cell walls (Beatty et al 2022). Results from Cuesta's exploratory analysis have shown that blades with necrotic spots harbor twice the number of microbial species as healthy blades and that the microbial community changes depending on the location of eelgrass in the bay. In order to further investigate the relationship between bacteria and wasting disease, this analysis will be replicated using 180 preserved samples collected between 2019 and 2023, with results expected by early 2025. An additional genetic study is concurrently underway to identify the different strains of *Labyrinthula spp.* found at the collection sites to better understand the diversity of this pathogen throughout the estuary.

Figure 24. Cuesta students led by Dr. Laurie McConnico and Dr. Silvio Favoreto collect eelgrass blades to be analyzed for the presence of *Labyrinthula spp*. Photo courtesy of Dr. Silvio Favoreto.

Along with genetic sequencing, the use of artificial intelligence (AI) has also promoted the expansion of research by reducing the amount of time and expertise needed to identify wasting disease lesions from photos. Researchers at Cornell University developed an artificial intelligence approach called [EeLISA (Eelgrass Lesion Image Segmentation Application)]() that can quickly analyze images of eelgrass blades to differentiate between healthy and diseased tissue. Cuesta researchers worked with the team at Cornell to customize the tool for use on Morro Bay's eelgrass and have achieved 97% accuracy detecting wasting disease lesions. Given the success of this method and its remarkable efficiency compared to manual photo analysis, the Estuary Program is currently looking into incorporating this tool into our existing monitoring surveys.

Further sampling and analyses are expected to take place during 2024 and will be used along with the data from previous years to assess temporal changes in the slime mold. These long-term data sets will be critical to better understand 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 over 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 13,000 brant, as was recorded in 1951. The more recent counts, displayed in Figure 32, 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.

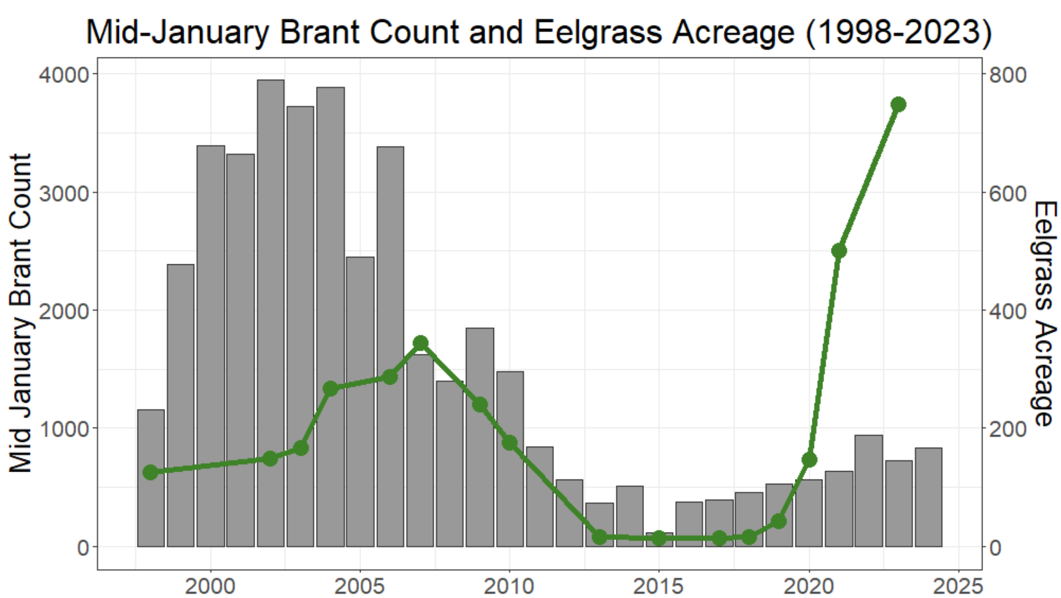

Figure 25. Results of the Mid-January Brant count from 1998 to 2023 compared with eelgrass acreage. Brant counts are available through January 2024 and the latest eelgrass acreage data comes from drone flights in spring 2023.

The hope is 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 fewer 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.

Fish Biodiversity Research

A series of surveys to investigate changes in fish populations due to fluctuations in eelgrass acreage were reinstated in fall 2023. The survey methods are based on research conducted by Dr. John Stephens of Occidental College in 2006 and 2007, representing fish populations during pre-decline eelgrass conditions, and again in 2016 and 2017 by Dr .Jennifer O'Leary, representing post-decline conditions. The results from these original surveys were published in 2021 and documented changes in fish species composition throughout the estuary due to eelgrass loss (O'Leary et al. 2021).

Figure 26. Fisheries monitoring locations, colored by the type of monitoring conducted. Survey sites include four shoreline beach seine locations, four intertidal beam trawl locations, three otter trawl locations within the dredged channel, and five fyke net locations within tidal channels.

The 2023 trawl and seine surveys were conducted to capture the composition of fish during post-recovery eelgrass conditions and compare them to the previous results. In addition to the traditional method of identifying and counting fish by hand, an environmental DNA (eDNA) sample was collected at each of the sites. The eDNA samples were sent to Jonah Ventures for sequencing and will encompass a broader range of species than those physically collected during sampling. A second round of surveys will take place in spring 2024, after which results will be analyzed and included in next year's eelgrass report.

Upcoming Projects

- **Eelgrass Acreage Mapping:** The Estuary Program will partner with Cal Poly for a bay-wide UAV drone survey during winter 2024. The imagery will be processed using their machine learning model to provide an acreage map of eelgrass extent. This effort will be accompanied by an extensive ground-truthing effort that utilizes both field surveys and manual review of the imagery to ensure model accuracy.
- **Continuation of Monitoring Projects:** In 2024, the Estuary Program plans to conduct monitoring of permanent transects, bed condition locations, and macroalgae sites. Despite reaching the highest recorded acreage this year, the continuation of eelgrass monitoring is essential for ensuring timely restoration efforts in the event of a large decline.
- **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 2024. Dr. Bockmon of Cal Poly will also continue to oversee the operation of the autonomous pH sensors at the mouth and back bay locations, along with monthly shoreline carbonate chemistry and nutrient sampling. Dr. Laurie McConnico and Dr. Silvio Favoreto of Cuesta College will continue their annual data collection to further our understanding of Eelgrass Wasting Disease 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 we have not yet determined the exact explanation for the recovery, it is likely the result of a combination of shifts in elevation, water quality, natural recruitment, and restoration efforts. 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 climbed to record highs in 2023, more than double the acreage present pre-decline, yet broader changes in climate will continue to modify 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 during the spring and summer. Consistent monitoring will be key in adapting to and addressing future changes.

In 2024 and beyond, we will build upon our existing knowledge of eelgrass and its complex relationships with macroalgae proliferation, sedimentation, wasting disease, and more. We will continue to stay up-to-date on restoration strategies so we can respond quickly and efficiently in case of a subsequent decline or die-off. 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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