Morro Bay National Estuary Program

Morro Bay Eelgrass Report 2013

Morro Bay National Estuary Program
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Contents

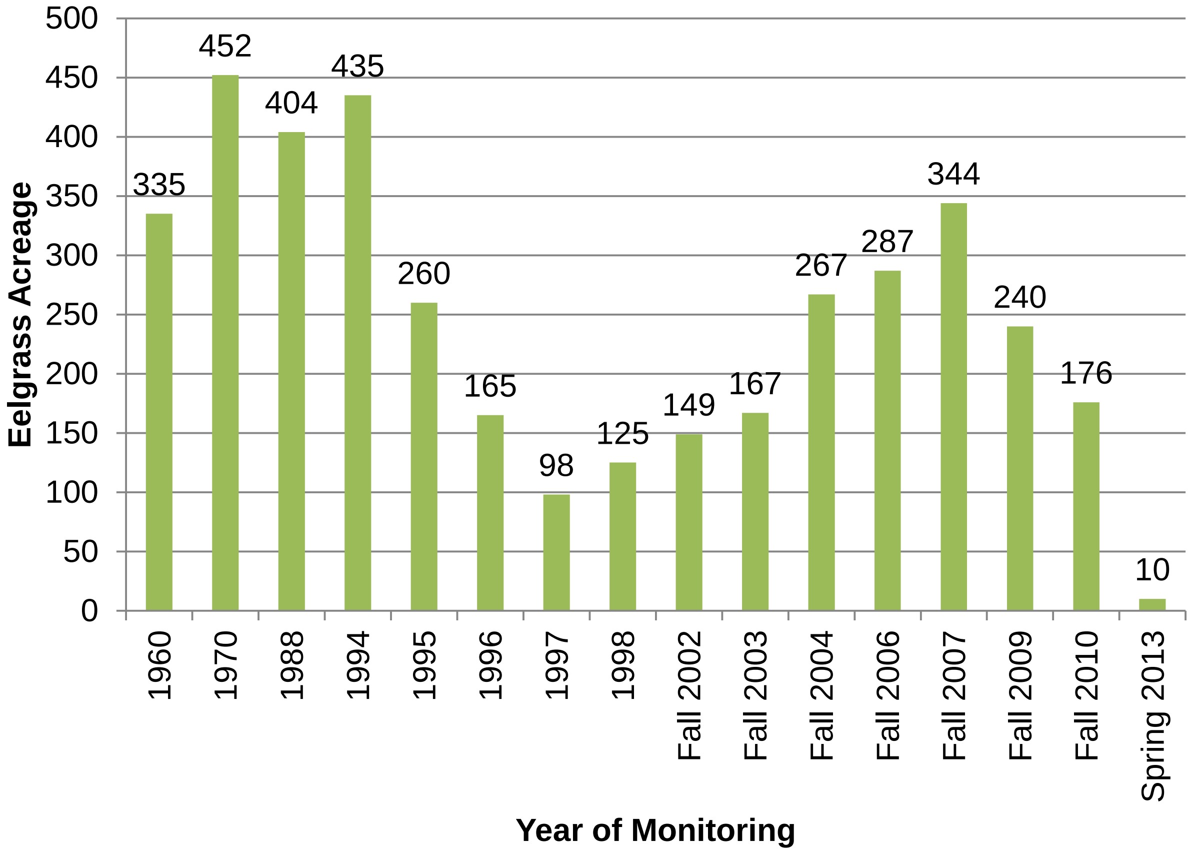
2013 Conditions Summary

The Morro Bay National Estuary Program (Estuary Program) monitors *Zostera marina* (eelgrass) and other intertidal vegetation on an annual or biennial frequency through the use of multispectral aerial imagery and digital classification. The mapping effort conducted in the fall of 2007 revealed a recent peak in eelgrass acreage (344 acres). Extent mapping in fall 2009 revealed a 30% decrease in eelgrass acreage compared to the 2007 peak value. The following winter (2009-2010) yielded above average rainfall and suspended substantial amounts of sediment in the watershed that drains into Morro Bay. Due to the decrease in eelgrass acreage from 2007 to 2009, and the observed sediment load into Morro Bay during the winter of 2009-2010, the Estuary Program proceeded with extent mapping again during November of 2010. The 2010 dataset revealed a further decline of eelgrass acreage: a decrease of -27% from 2009, and a net decrease of -49% from peak values in 2007.

Although an aerial flight and classification effort was planned for the fall of 2012, the flight did not take place due to weather conditions and logistical problems with the contractor. Thus, a flight took place in the spring of 2013. The aerial image and classification revealed a total of 10.25 acres of intertidal eelgrass, a -97% decline from peak values in 2007. When combining the estimates of intertidal acreage from the multispectral aerial imagery with sonar data collected by boat of the subtidal acreage, the estimated total acreage is 12 to 15 acres bay-wide.

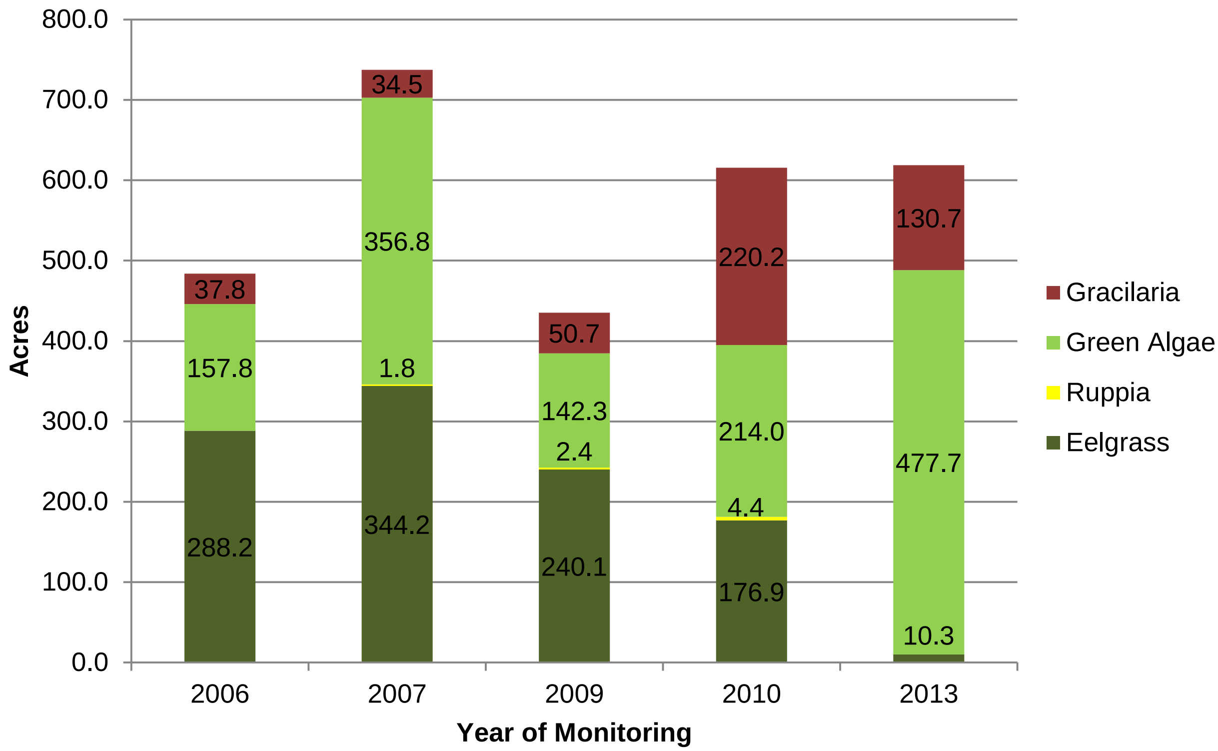
Eelgrass extent in Morro Bay has proven to be a dynamic resource throughout the most recent survey efforts. Earlier data collection efforts also indicate that eelgrass has not maintained a ‘stable’ state or distribution in Morro Bay. A summary of eelgrass acreage totals (collected by a variety of mapping methods) are shown below in Figure 1. The Estuary Program began mapping submerged intertidal vegetation using a consistent methodology of aerial imagery classification in 2003. Discrepancies in detection capability and resolution have not been quantified or reconciled for datasets generated prior to 2003.

Figure 1: Morro Bay Eelgrass Intertidal Acreage Values by Year



The classification scheme adopted by the Estuary Program in 2007 distinguishes between 17 different classes of substrate and vegetation. While the mapping effort was undertaken with the specific target of mapping eelgrass extent, the imagery can also be used to track changes in other types of submerged vegetation. The 2013 classification scheme indicates a substantial decline of eelgrass acreage and an increase in algae. From 2010 to 2013, the red algae *Gracilaria* underwent a decrease, while green algae increased in acreage. Note that while previous flights were conducted in the fall, the 2013 data was collected in the spring, which may account for differences in algae dynamics. Acres of the major classes of submerged vegetation are shown in Figure 2, below.

Figure 2: Recent Trends in Morro Bay Intertidal Submerged Vegetation Acreage



The dynamic conditions in Morro Bay make it difficult to discern which environmental variables may be driving the dominance shift in submerged vegetation. It is not believed that a single, distinct impact has resulted in the declines in eelgrass acreage over the last seven years. More likely, a combination of factors is driving the decline in eelgrass in Morro Bay. Eelgrass distribution may have been impacted due to diminished water clarity from winter storm runoff, algae blooms, or prolonged dredging operations in the northern extent of the harbor. Natural re-suspension of substrate due to storm events or wind may have also impacted water clarity.

The decline may have been accelerated by prolonged severe storm events that reduced water clarity in Morro Bay for long periods of the 2010-2011 winter season. Intertidal channel erosion and shear stress from the Tohoku tsunami tidal surges in March 2011 likely further impacted fragile eelgrass beds. Due to limitations in bathymetric data, the erosive impact of the tsunami surges cannot be quantified.

Maintaining vibrant intertidal eelgrass meadows in Morro Bay remains a priority of the Estuary Program. Restoration and transplanting of eelgrass from donor sites to areas that suffered eelgrass loss took place in August 2012 and August 2013. The Estuary Program is committed to sustaining this vital habitat and is actively pursuing funding and support for such additional restoration and monitoring work.

Introduction

Seagrass beds are an important component of coastal habitat and provide diverse benefits to coastal marine and migratory species as well as substantial benefit in the form of ecosystem services. Studies of fish diversity in eelgrass (*Zostera marina*) beds have indicated that species richness and biomass is significantly higher in eelgrass habitats compared with areas where eelgrass has been lost (Pihl, et al. 2006). Additionally, substantial exports of detritus to adjacent un-vegetated areas plays an important ecological role as a widespread nutrition source for detritivores (Bach, et al. 1986). Declines in seagrass distribution have been observed worldwide and are a growing cause for concern.

Declining seagrass distribution is attributed to many natural and anthropogenic factors in coastal ecosystems. Distribution may be limited naturally by light limitation, herbivory and natural changes in bathymetry. Light attenuation in the water column can also be impacted by natural resuspension of sediment due to storm events and seasonal phytoplankton blooms.

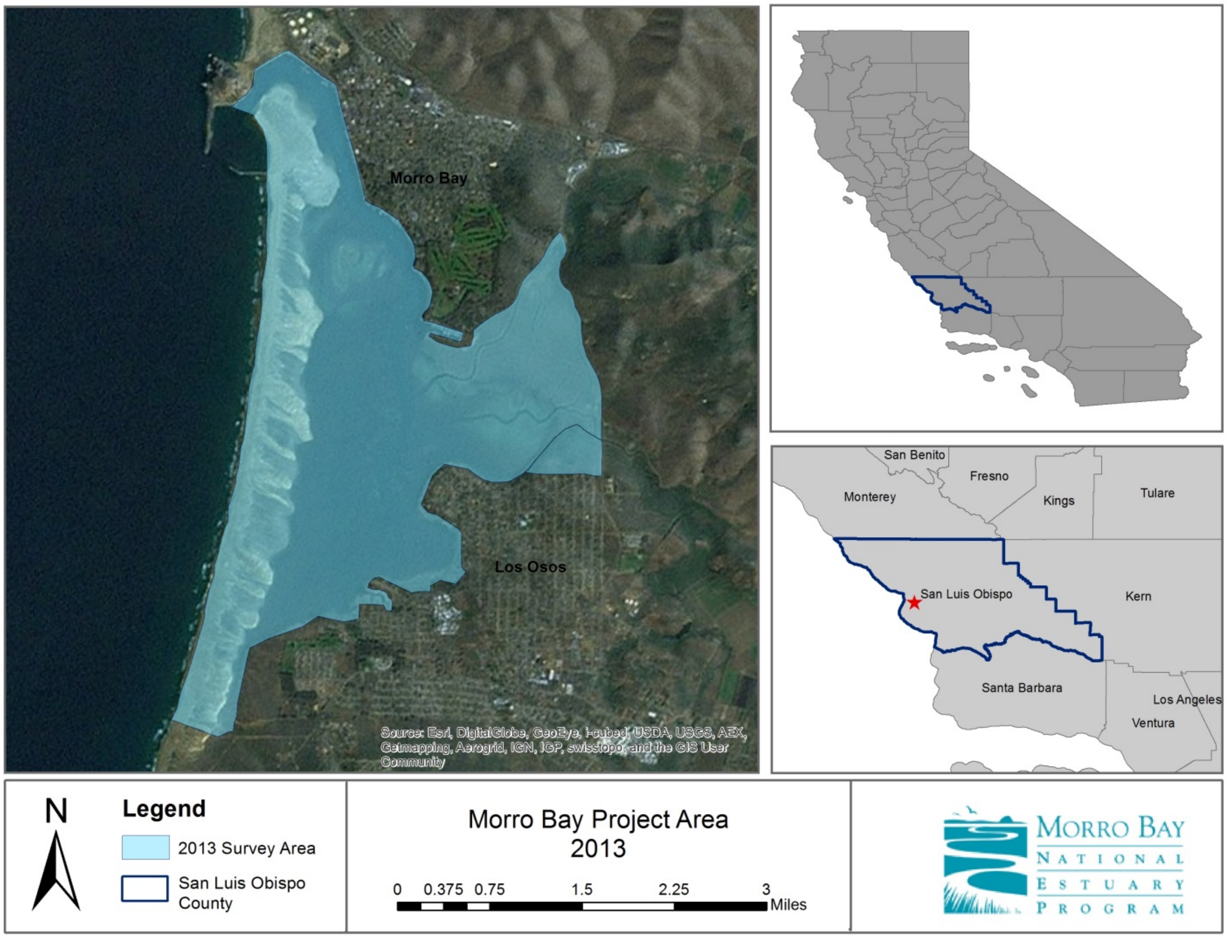
Anthropogenic impacts may be either direct or indirect. Direct impacts include seagrass removal by dredging, propeller scarring, or shading caused by boat moorings or pier construction. Indirect impacts include the introduction of invasive species and non-point source loading of nutrients, herbicides and sediment which negatively impact water clarity (Hauxwell et. al, 2003.) The indirect effects associated with sea level rise and climate change are not well understood but are widely expected to negatively impact seagrass distribution globally (Ralph, et al, 2007).

Morro Bay supports the third largest eelgrass dominated ecosystem in the southern California region (Bernstein et. al, 2011). Historic monitoring of eelgrass extent indicates that intertidal eelgrass beds may have spanned up to 500 acres in Morro Bay during the 1970s. Although development pressures in the Morro Bay watershed and harbor have not resulted in substantial direct impacts to eelgrass distribution, cumulative indirect impacts have likely driven recent acreage declines.

Morro Bay Project Area

Morro Bay is a shallow coastal lagoon located on California's central coast in San Luis Obispo County, shown in Figure 3. The town of Morro Bay (population 10,370) was founded in 1870 and is located in the northern extent of the estuary. The unincorporated community of Los Osos (population 14,276) is located on the southern shores of Morro Bay. 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.

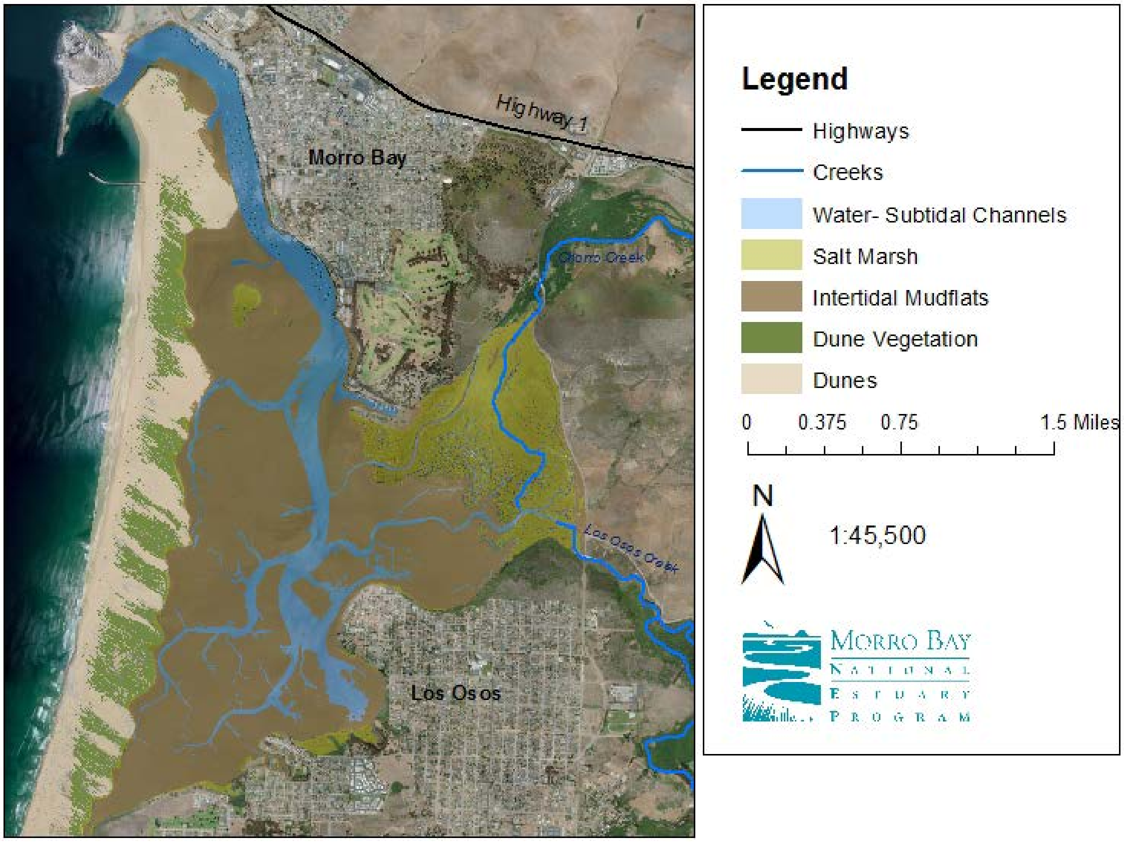
Figure 3: Morro Bay Project Area



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. Habitat types and distribution are shown in Figure 4. Although most seagrass acreage is known to occur in intertidal areas, subtidal eelgrass has been documented in the northern extent of the study area. To date, Japanese eelgrass (*Zostera japonica*) has not been identified in Morro Bay.

Figure 4: Morro Bay Estuary Habitat Types and Distribution



Morro Bay is a popular destination for outdoor recreation and is also an important port for commercial fishing and aquaculture operations. Recreational uses in the bay include kayaking, sailing, fishing, wildlife observing and waterfowl hunting. Commercial fisheries operate offshore and landings have grown steadily since bottoming out in 2000 (San Luis Obispo Tribune). Two commercial aquaculture operations grow Pacific oysters (*Crassostrea gigas*) and operate in conditionally-approved areas of the intertidal mudflats. A total of 287 acres are classified as potential aquaculture lease areas in Morro Bay (Baltan, Pers. Comm.).

The Morro Bay harbor is an important port, as it is the only commercial and recreational port between Santa Barbara and Monterey. Maintenance of the harbor as a port for fishing and recreational vessels requires frequent dredging operations. The harbor mouth is dredged annually by the Army Corps of Engineers to maintain a channel depth of approximately 40 ft. During 2008 and 2009, the Corps Yaquina hopper dredge removed 140,798 cubic yards (CY) and 151,067 CY of material (respectively) from the entrance channel and main channel. The Corps Yaquina did not dredge the mid channel or back channels of Morro Bay Harbor, and there were no documented impacts to eelgrass. Dredge spoils from this annual maintenance are deposited at the designated nearshore placement site.

In 2009, additional dredging of the mid channel was made possible by an American Recovery and Reinvestment Act award. Dredging operations were completed by AIS Construction Company (AIS) and excavated a total 573,969 CY of material in two discreet phases. From November 9, 2009 to February 26, 2010, a total of 438,802 CY were removed. During the second phase from August 8, 2010 to September 8, 2010, an additional 135,167 CY were removed. AIS utilized a hydraulic cutterhead dredge and an excavator dredge to remove all materials. Approximately 374,968 CY were deposited north of Morro Bay at Morro Strand State Beach and the remaining 199,001 CY were placed at the nearshore placement site utilized by the Yaquina dredge (Brus, Pers. Comm.).

The expanded dredging operations that took place in 2009 and 2010 resulted in the disturbance of approximately one acre of subtidal eelgrass in the northern area of the main channel. In accordance with the National Marine Fisheries Service Southern California Eelgrass Mitigation Policy, areas of eelgrass disturbed by the project required construction and successful establishment of a mitigation eelgrass bed at the ratio of 1.20:1. Accordingly, a mitigation plan was developed by Merkel & Associates, Inc. (M&A) for a mitigation bed to be constructed on the western side of the navigation channel. A mitigation planting area of approximately 2.4 acres was excavated and constructed during July of 2010 (Merkel, 2010a & 2010b).

Mitigation planting areas are required to be monitored annually for five years. Sidescan sonar surveys in 2011 from within the planting area revealed 1.28 acres of eelgrass, with healthy plants and few epiphytes. The turion density within the restoration area was 137.6 ± 49.9 shoots per square meter, with measurements taken from 20 locations. For comparison, the nearby reference beds have a total of 1.33 acres of eelgrass with a shoot density of 117.8 ± 58.9 shoots per square meter (Merkel, 2011). While more recent monitoring of mitigation beds has occurred, the results were not available for inclusion in this analysis.

Morro Bay Watershed

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 subwatersheds and through groundwater seepage in the Los Osos area. Non-urbanized lands in the Chorro Creek subwatershed are used primarily as rangeland and public parks. Non-urbanized lands in the Los Osos subwatershed are dominated by rangeland, row crop agriculture and commercial greenhouse nurseries. Multiple 303(d) listings and TMDL documents have identified a range of water quality impacts within the Morro Bay watershed and estuary.

Chorro Creek has approved TMDLs for biostimulatory nutrients and dissolved oxygen. An upgrade to the California Men's Colony Wastewater Treatment Plant in 2007 resulted in a substantial reduction in nitrate concentrations in discharged effluent. Analysis of water quality data collected downstream of the plant through June 2010 indicates a decrease in nitrate concentrations by as much as 52% following the upgrade. However, analysis of orthophosphate data indicates a significant increase in orthophosphate concentrations downstream of the plant following the upgrade. The impact of the increased orthophosphate concentrations on Chorro Creek and Morro Bay is not well known. Due to widespread BMP Implementation and improved quality of treated effluent, the 2008 303(d) review resulted in a recommended de-listing of Chorro Creek for dissolved oxygen impairment.

Los Osos Creek (including Warden Creek and Warden Lake) has an approved TMDL for nutrient impairment (2005). Progress in reducing nutrient concentrations in surface waters has been limited in the Los Osos subwatershed. In 2011, the Coastal San Luis Resource Conservation District (CSLRCD) began implementing a Coastal Nonpoint Source Pollution Control Program Section 319(h) grant to address nutrient loading and inputs in the Los Osos Watershed. The project specifically targets nutrient loading from agricultural operations into Warden Creek and lower Los Osos Creek. The CSLRCD is working with the University of California Cooperative Extension to determine nutrient budgets and allocations for farming operations throughout the project area. The Estuary Program conducts nutrient monitoring at four stream sites to determine ambient conditions, including nutrient loads.

Both the Chorro Creek and Los Osos Creek drainages were listed in a pathogen TMDL for Morro Bay in 2004. The pathogen impairments are believed to be driven largely by non-point sources which could potentially include livestock, failing septic systems and wildlife. High levels of pathogens are not believed to impact seagrass distribution in Morro Bay.

Chorro Creek, Los Osos Creek and the Morro Bay estuary were listed as impaired for sediment, with a sediment TMDL approved in 2004. Widespread adoption and installation of Best Management Practices (BMPs) has taken place since the TMDL was approved. The majority of the sediment load is delivered to the estuary during large winter storm events (Tetra Tech, 1998), with the majority of the load originating in the Chorro Creek watershed. New data collection efforts undertaken by the Estuary Program have worked on quantifying sediment loading during storm events in the Chorro Creek watershed (Gillespie, Kitajima, 2011).

Submerged Vegetation Extent Mapping Methods

The Estuary Program monitors eelgrass extent through bay-wide mapping on an annual or biennial frequency to track changes in eelgrass distribution. Extent mapping is completed through the collection and digital analysis of multi-spectral imagery. Due to environmental limitations (water clarity, tide height) imagery collection typically takes place during extreme low tides in November. Environmental conditions make it necessary to acquire proprietary imagery of Morro Bay to complete the project. Ground verification surveys are completed in advance of imagery collection, and as needed following preliminary vegetation classification.

In 2012, the Estuary Program awarded a contract to Ocean Imaging (OI) to collect and analyze multispectral aerial imagery of the Morro Bay study area. OI previously collected aerial imagery for vegetation mapping efforts in Morro Bay during 2004, 2006, 2007, 2009 and 2010. It was deemed beneficial to continue work with OI based on their acquired knowledge of conditions in Morro Bay through previous mapping efforts.

Imagery Collection and Analysis

The flight that was originally planned for the fall of 2012 did not take place. Potential flight dates in November failed due to contractor logistics and poor weather. The Estuary Program canceled the potential dates for December because of the minimal amount of eelgrass present as a result of Brant geese grazing. Because of the value of the data for future restoration efforts, flight dates were selected for the April through June 2013 timeframe. Optimal conditions for the flight were time periods when the sun angle was favorable for water penetration (between 18 and 35 degrees) in conjunction with a minus tide. Imagery collection was performed in peak weather conditions of which there are two: cloudless clear skies and solid cloud cover above 8,000 feet AGL (above ground level). OI monitored cloud coverage during the day with GOES and NOAA-AVHRR satellite imagery acquired in real-time. OI also obtained visual and aviation reports from Morro Bay contacts directly by phone. USGS ground control was used for this effort. Accuracy of the imagery is +/- 3 meters (90% of pixels).

All imagery represented in this mosaic was acquired on May 28, 2013 between the hours of 8:45 a.m. and 9:45 a.m. PST at an altitude of 3,500 ft. Imagery was acquired from a Cessna plane by OI's contractor using a filter combination of 451-550-640-790 nm. The tidal levels during the flight were between -0.58 and -0.30 feet. Imagery was acquired at a spatial resolution of 0.48 meters using a Microsoft UltraCam-X digital camera acquiring in the red, green, blue and near-infared bands. The image mosaic was created by merging several individual UltraCam-X scenes geocorrected to a spatial accuracy of +/- 2 meters using tools from the ERDAS Imaging as well as ESRI ArcGIS software packages.

Upon completion of this flight, image data were downloaded from the DMSC onto a computer hard drive and back-up copies were burned on CDs. Pre-processing included a two-step procedure to eliminate slight band-to-band misalignment. This was done using customized software to first compute an overall x-y direction shift of bands 1, 3 and 4 relative to band 2. Each of the 4-band shifted image frames was then run through a Fast Fourier Transform (FFT)-based pattern recognition routine, which tiles the image into 80 pixel sections and computes a secondary, regional pixel shift on each band.

The pre-processed image data were then imported into TNTmips image processing software for further manipulation. Each DMSC image frame contains in its metadata the DGPS-logged location of the frame center. This allows rapid auto mosaicking of a multi-image set. However, the accuracy deemed necessary for this project necessitated further, manual geopositioning correction of each acquired frame. The obtained image frames were manually georeferenced to a 2003 aerial photo obtained from the Estuary Program. Once each frame was georeferenced, it was then rectified with a 50cm cell size. The rectified images were then exported out of TNTmips to an ArcInfo/BIL format. The exported frames were imported into the Erdas Imagine mosaic tool, where cutlines were generated for overlapping frames and a final mosaic was produced.

OI staff utilized prior classification schemes from 2007, 2009 and 2010 as well as pre-flight ground verification work to generate the preliminary 2013 submerged aquatic vegetation (SAV) classification scheme. The 2013 classification was created using an algorithm specifically developed to optimize the imagery collected during the flight.

The 2013 classification scheme included 12 classes of vegetation and substrate throughout the survey area. Table 1 includes all of the class names and descriptions within the 2013 dataset. Class descriptions do not include all species present within each class but describe the dominant array of species.

Table 1. Classification Categories and Descriptions

Class Name	Class Description
Water	Subtidal channel. Water depth prevented classification of substrate or vegetation.
Mud/Sand	Bare substrate, no vegetation detected.
Zostera	*Zostera marina*.
Green algae	Green algae, including Chaetomorpha spp., Ulva spp., Enteromorpha spp. and others.
Gracilaria Sp	Red algae, predominantly Gracilaria spp.
Zostera Wrack	*Zostera marina*, non-growing vegetation detached from substrate.
Shadows	Shadows cast by maritime infrastructure, vegetation, etc.
Beach Wrack	Non-growing vegetation detached from substrate, of all types except Zostera.
Dune/Terrestrial vegetation	Lupinus spp., *Artemisia californica, Baccharis pilularis, Ericameria ericoides, Erigonium parvifolium, Eriophyllum staechadifolium, Isocoma menziesii, Lessingia filaginifolia, Lotus scoparius, Salvia mellifera.* Additional herbaceous native and non-native species also present.
Maritime Infrastructure	Maritime infrastructure includes piers, moorings, aquaculture equipment, boats, etc.
Salt Marsh	*Sarcicornia virginica, Jaumea carnosa, Distichlis spicata,* Atriplex spp., *Carex obnupta, Frankenia salina,* Juncus spp., *Limonium californicum, Potentilla anserina*, Scirpus spp., *Triglochin concinna*. Additional native and non-native species likely present.
Freshwater Marsh	Carex spp., Juncus spp., Scirpus spp., Eleocharis spp., *Typha latifolia.* Additional native and non-native species likely present.

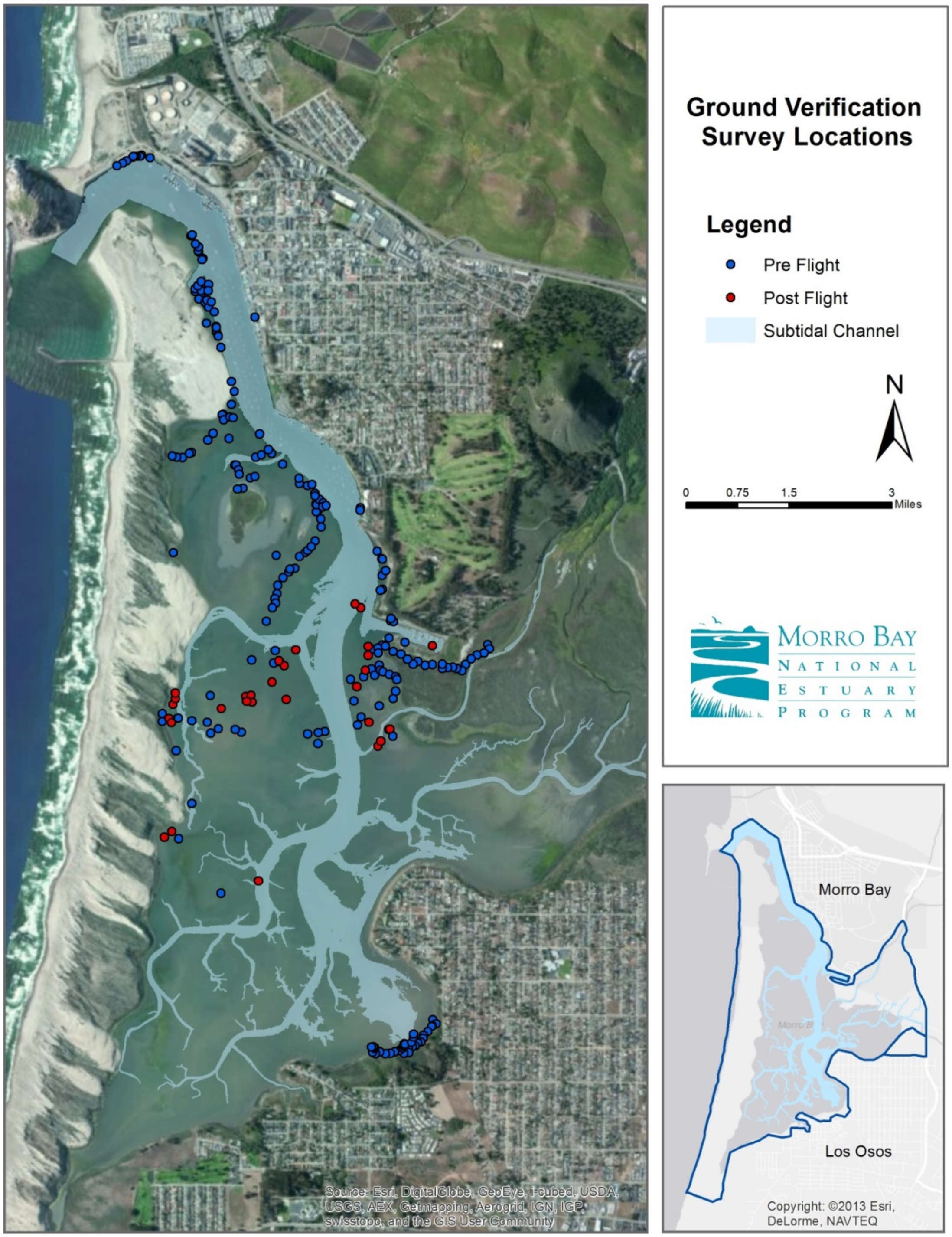
In previous maps, three classification categories were assigned to eelgrass. The criteria were based on a sliding scale with two factors: reflectance in the near-infrared and continuous coverage. Categories of dense, medium and patchy eelgrass were incorporated into the classification. For the 2013 map, only one classification was used for eelgrass, and it encompasses the three categories used in previous maps. Due to lack of intertidal eelgrass acreage, dividing the eelgrass into multiple categories based on density was deemed to not be worth the effort required.

Classification Scheme and Ground Verification

The classification of the multi-spectral imagery was done in multiple iterations. A combination of an unsupervised and supervised approach was used to derive each of the target classes. An initial classification was done to identify a “water and bare” class using a customized algorithm developed by OI in previous wetland mapping projects. The next iteration targeted eelgrass, macroalgae, and other aquatic vegetation within the Morro Bay Estuary. Using the “water and bare” class to mask out areas of the estuary, OI focused the classification algorithm only on pixels with the remaining target classes.

Pre-flight ground verification data was incorporated into the algorithm for the preliminary classification. The extent of pre and post-flight ground verification efforts is shown below in Figure 5. Detailed explanations of pre and post-flight field methodologies are located in Appendix A.

Figure 5: Pre and Post Flight Ground Verification Extent



Changes in Intertidal Vegetated Acreage

The 2013 dataset included substantial changes in total eelgrass acreage.

Relative to 2007, 2009 and 2010, there was an overall net decline of eelgrass in 2013 eelgrass acreage. Table 2 details the changes in acreage over the last four surveys from 2007 to 2013.

Table 2: Intertidal Vegetated Acreage Fluctuations, 2007-2013

Class Name	***2007***	***2009***	***2010***	***2013***
Water	523.4	429.8	487.4	419.0
Maritime_Infras.		10.9	9.4	11.4
Mud_Sand	709.7	1098.3	881.3	1561.9
Net Acreage Unclassified or Unvegetated:	***1233.1***	***1538.9***	***1378.1***	***1992.3***
Zostera_Dense	129.3	75.9	103.5	-
Zostera_Medium	98.8	59.4	49.7	-
Zostera_Patchy	116.1	104.8	23.8	-
Net Zostera Acreage:	***344.2***	***240.1***	***176.9***	***10.3***[1]
Chaetomorpha_sp	*	106.8	131.0	-
Ulva_Spp	*	18.2	9.8	-
Enteromorpha_sp	356.8	17.2	73.2	-
Net Green Algae Acreage:	***356.8***	***142.3***	***214.0***	***477.7***[2]
Gracilaria	34.5	50.7	220.2	130.7
Net Gracilaria Acreage:	***34.5***	***50.7***	***220.2***	***130.7***
Zostera_Wrack		2.6	0.7	1.6
Ruppia	1.8	2.4	4.4	-
Salt_Marsh	386.7	365.4	361.8	393.2

[1]In the 2013 mapping effort, only one classification was used for eelgrass and it encompasses the three categories used in previous maps.
[2]Although speciated green algae data has been reported in past maps, breaking out algae by genus was not determined in 2013 due to the extensive post-flight fieldwork that would be required.

Acreage classified as 'Mud_Sand' indicate that no vegetation was detected at the time of survey. Acreage denoted as 'Water-Subtidal Channel' was not assessed for vegetation due to water depth and/or poor water clarity. Some of the acreage within this class contains subtidal eelgrass, although the extent of subtidal eelgrass was not verified for this map. However, surveying work conducted by M&A utilized sidescan sonar surveys to verify subtidal eelgrass extent.

The 2013 extent of intertidal eelgrass for the entire project area is shown in Figure 6. A comparison of 2007 through 2013 intertidal eelgrass extend is shown in Figure 7. As previously stated, the 2013 imagery data was collected during the spring season, while data for previous maps was collected in the fall.

Figure 6: 2013 Morro Bay Intertidal Eelgrass Map (Full Extent)

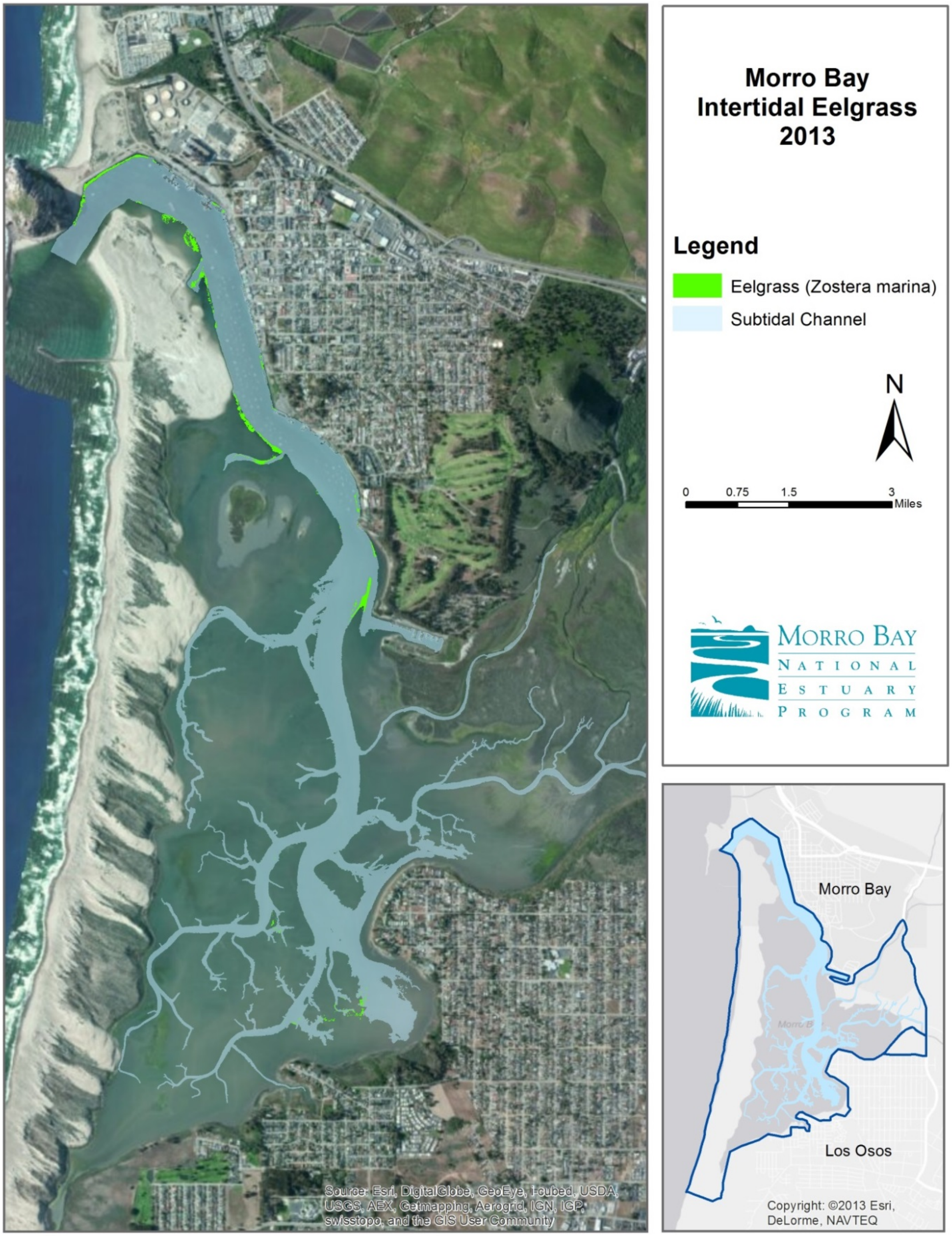
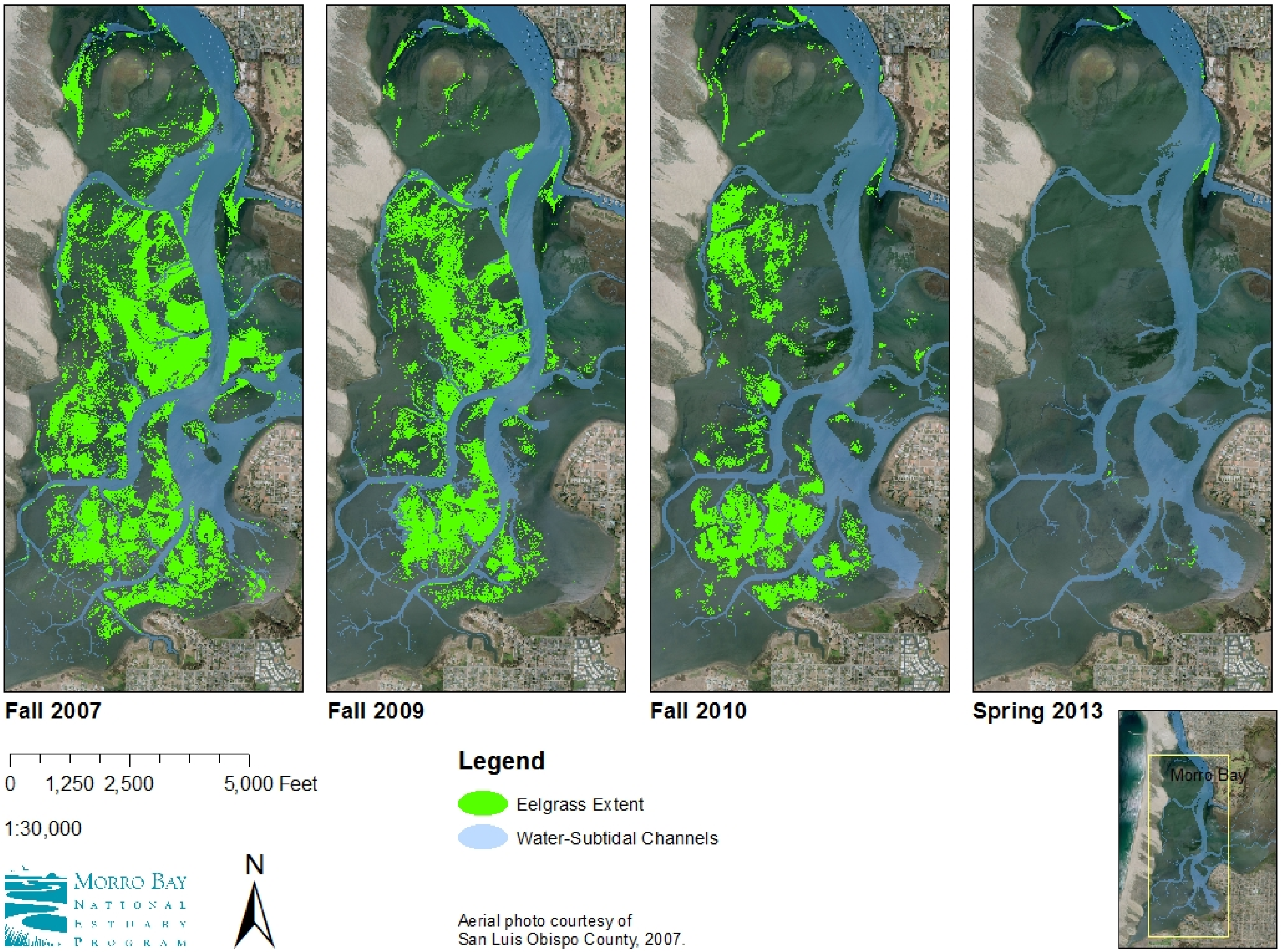


Figure 7: 2007 to 2013 Morro Bay Intertidal Eelgrass Map (Full Extent)



Eelgrass Distribution 2007 through 2013

The relatively frequent eelgrass mapping in Morro Bay has allowed for spatial comparisons of intertidal eelgrass distribution. Figures 8 through 10 indicate intertidal eelgrass extent mapped in fall 2007, fall 2009, fall 2010 and spring 2013. These figures demonstrate the raw dataset, at a scale of 1:20,000, for each year that data was collected. Data for all years uses as a base map an aerial photo from 2007, courtesy of San Luis Obispo County.

Previous eelgrass mapping and monitoring efforts are detailed in reports written for each specific effort. These reports are available for download and review on the Estuary Program's website: www.mbnep.org

Figure 8: Intertidal Eelgrass Extent, 2007-2013

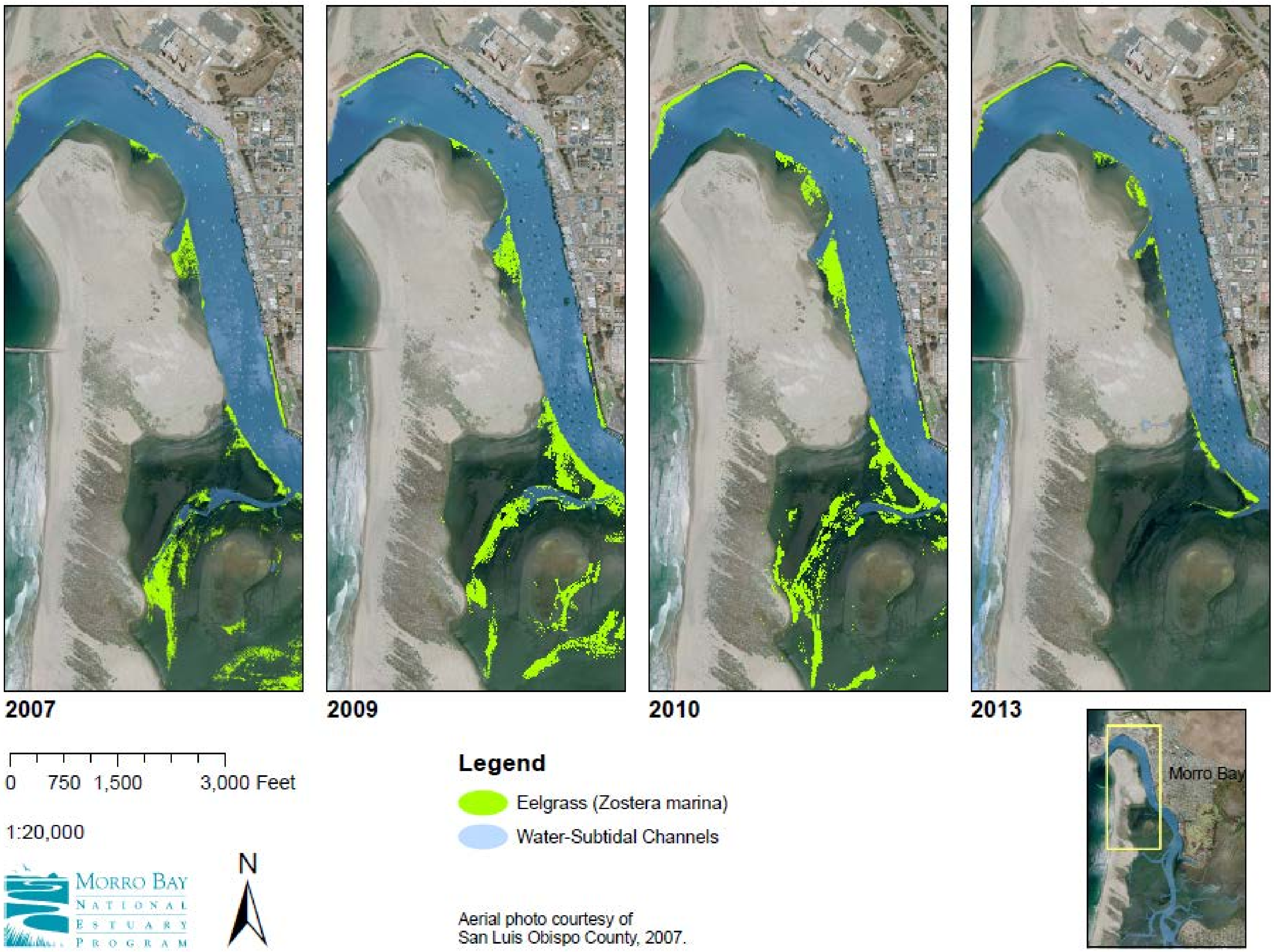


Figure 9: Intertidal Eelgrass Extent (Central Area) 2007-2010

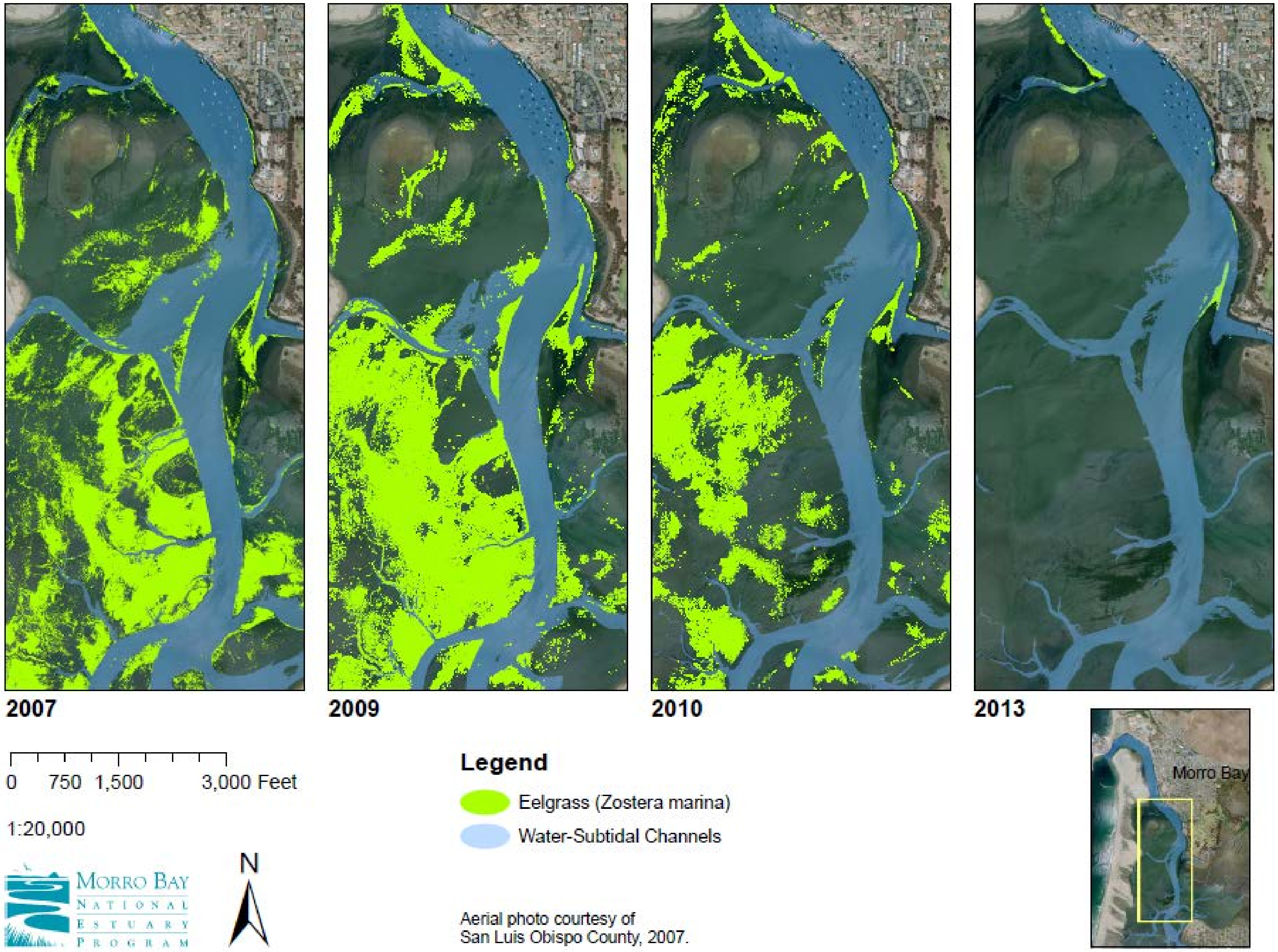
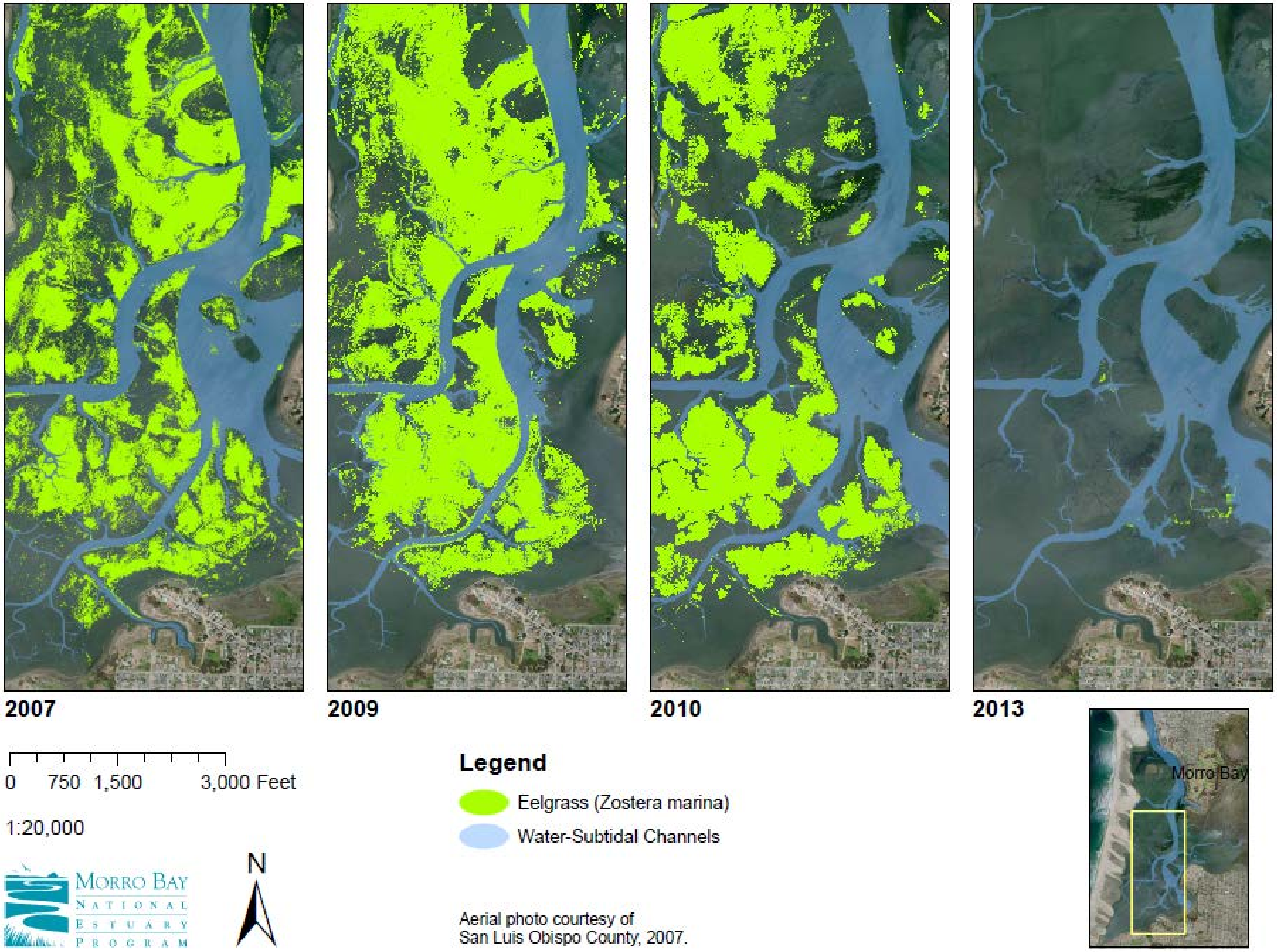


Figure 10: Intertidal Eelgrass Extent (Southern Area) 2007-2013

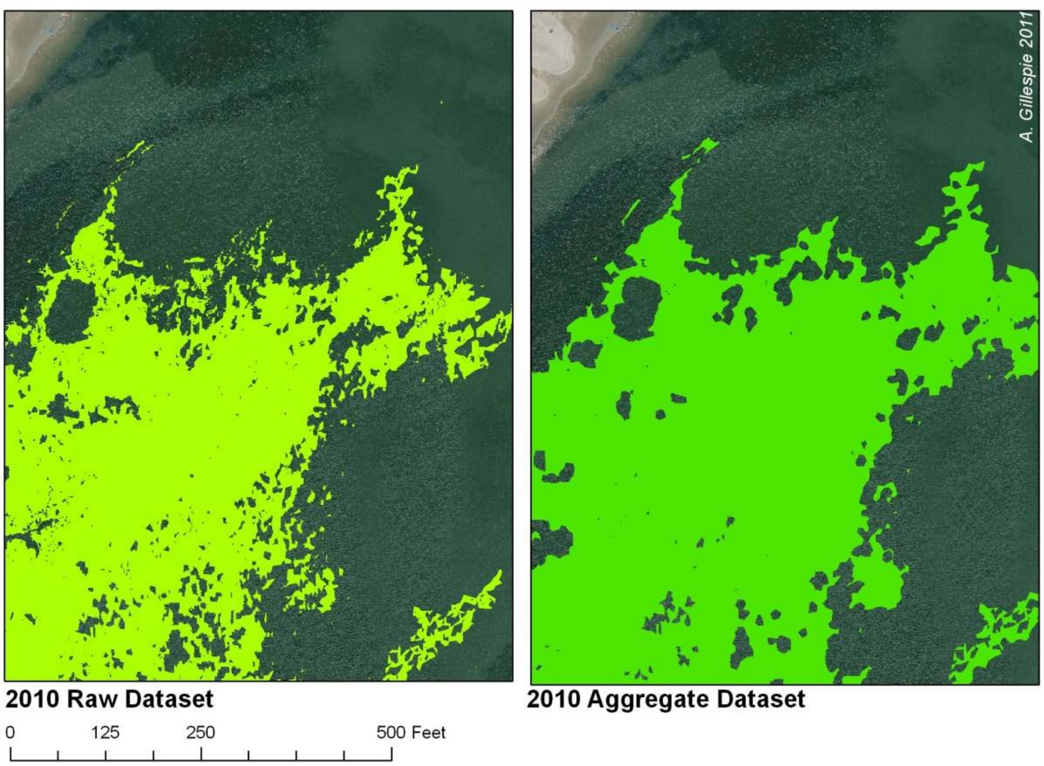


Potential Habitat vs. Realized Extent

In order to better visualize changes in eelgrass extent, geospatial modeling was used to aggregate and merge datasets from the four most recent surveys, effectively compositing all areas where eelgrass had been detected between 2007 and 2013. Creating this aggregated shapefile or “composite layer” helps estimate the total potential eelgrass habitat in Morro Bay. Comparison of individual datasets to the composite dataset allows for calculation of the percentage of potential habitat utilized by eelgrass during each survey year.

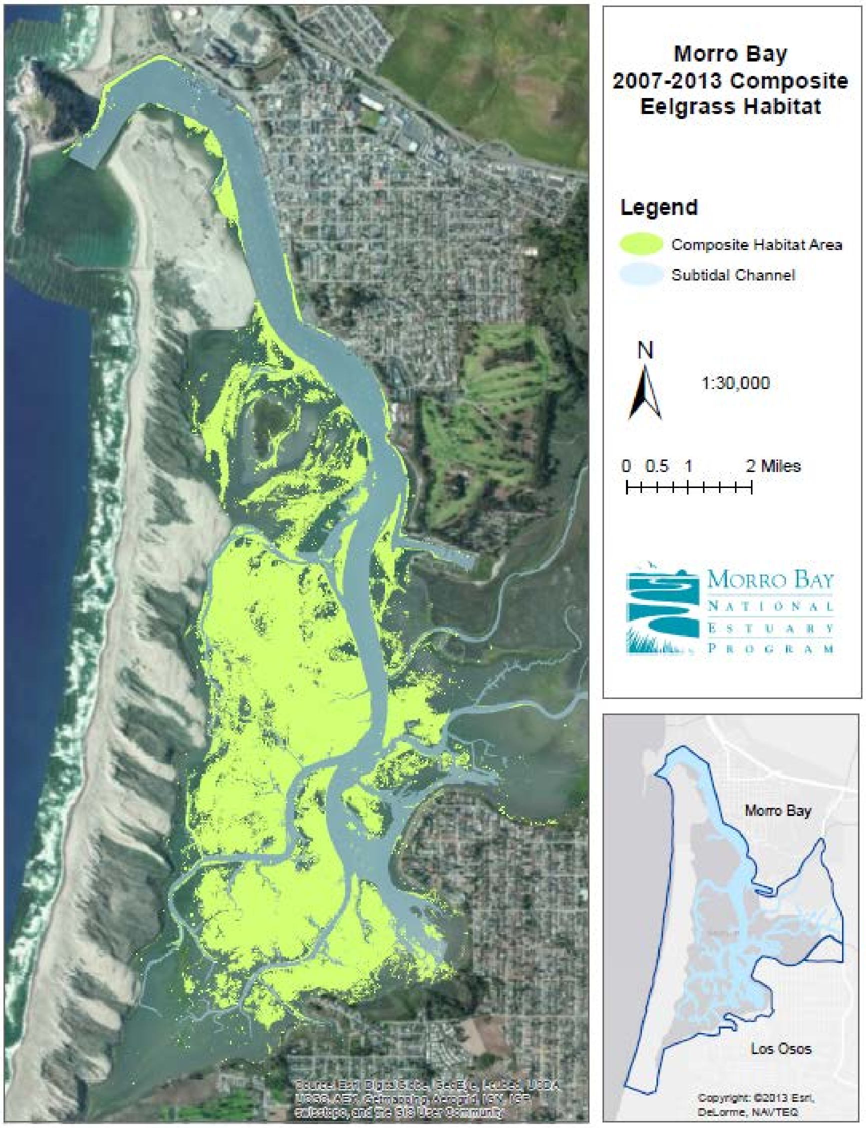
ESRI’s polygon aggregation tool was utilized to condense the datasets from each survey into fewer large polygons, and encompass small areas in between individual polygon fragments where eelgrass was likely to have occurred. Modeling was conducted within ArcMap 10.1 using the Aggregate Polygons Toolset. Two iterations of aggregation processes were run in order to compare model outcomes of the datasets. Details of the aggregation processes are included in Appendix B. The final aggregation distance selected was 9 square feet, the minimum polygon area was selected as 9 square feet, and the minimum hole size was specified as 81 square feet. This increased the minimum polygon size from ~1.72 square feet in the raw dataset, to ~9.05 square feet. An example of a raw dataset and aggregated dataset is shown in Figure 11.

Figure 11: Demonstration of Data Aggregation Process



Once aggregation was complete, the 2007, 2009, 2010 and 2013 eelgrass datasets were merged to create one dataset. This merged dataset generated a composite of all eelgrass habitat detected between the years of 2007 and 2013. The composite dataset delineated approximately 902 acres as potential eelgrass habitat in the Morro Bay study area, shown in Figure 12.

Figure 12: 2007-2013 Composite Intertidal Eelgrass Habitat



The composite eelgrass habitat layer is shown beneath each year of eelgrass data in Figure 13 in order to demonstrate shifts in eelgrass from 2007 to 2013. Figure 14 demonstrates the utilization of the composite habitat area by both eelgrass and *Gracilaria sp.* from 2007 to 2013.

Figure 13: 2007 to 2013 Intertidal Eelgrass Distribution of Composite Habitat

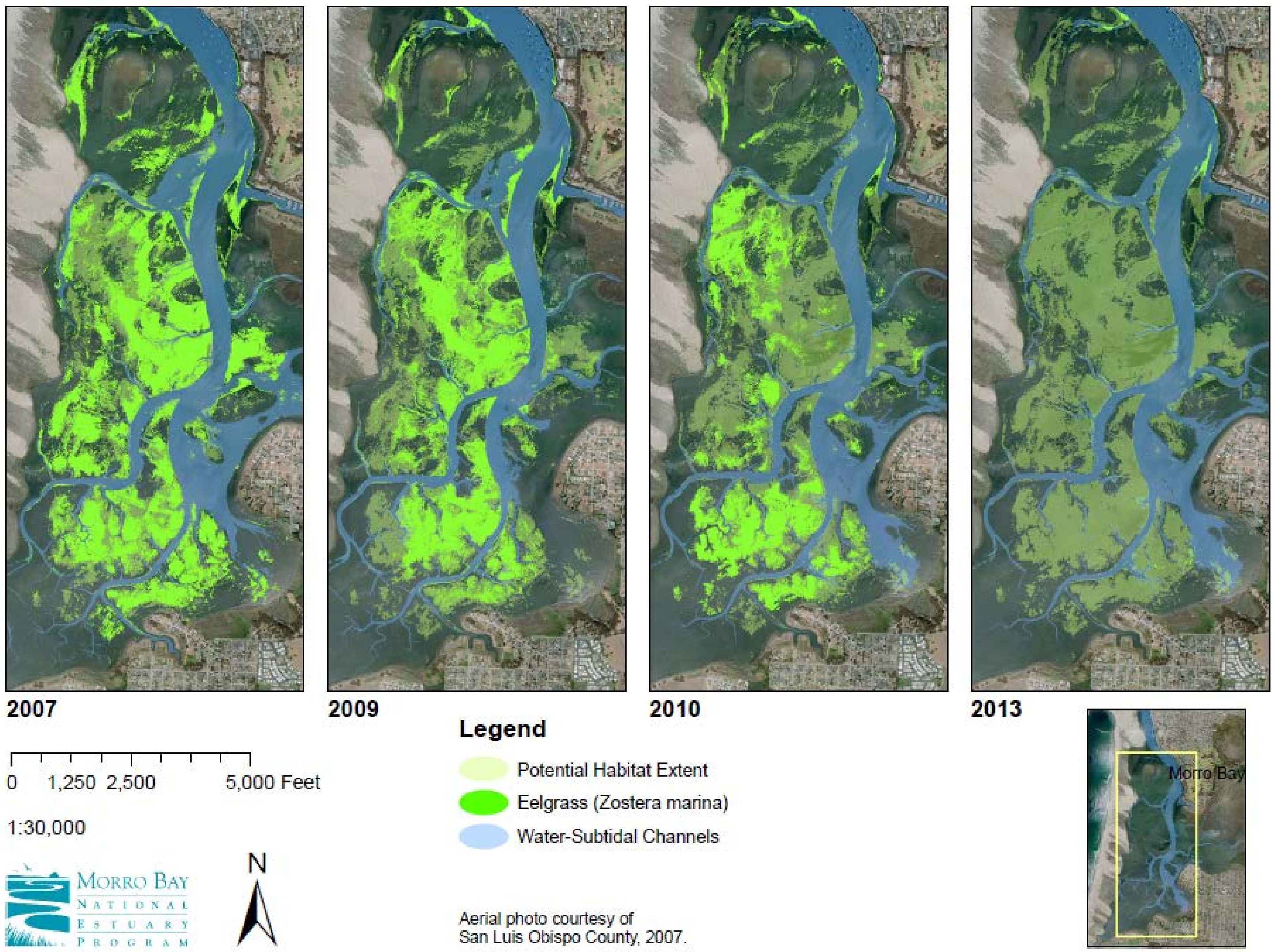
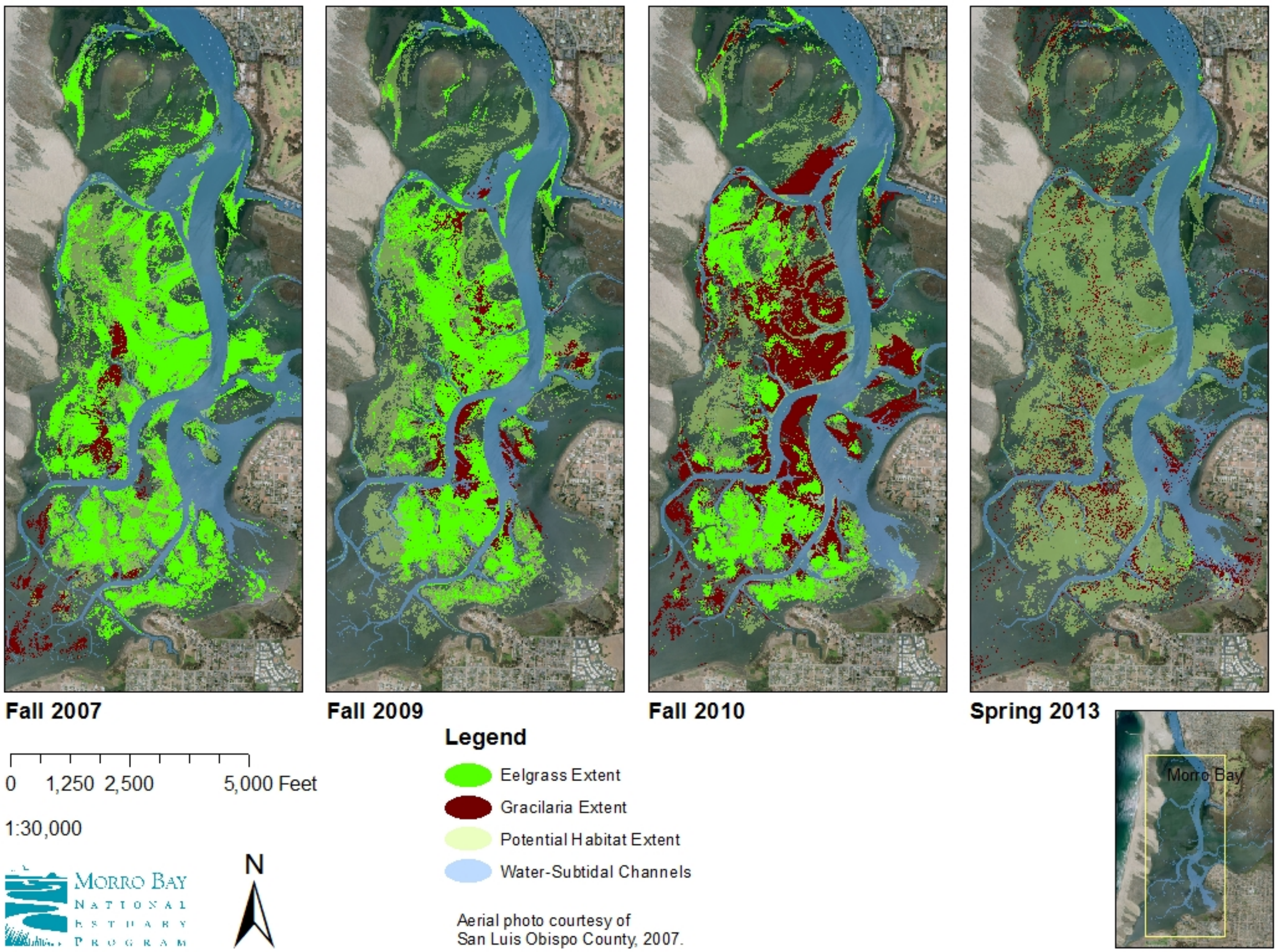


Figure 14: Intertidal Eelgrass and Gracilaria distribution within composite habitat area



In each year of monitoring, eelgrass was detected in less than 50% of the composite habitat area. The data further indicate that eelgrass in Morro Bay does not maintain a stable extent within the available potential habitat. In 2007, eelgrass covered approximately 44.22% of the composite habitat area. The 2009 aggregated data indicated that eelgrass had declined to cover only 32.13% of the composite habitat area. The 2010 data revealed that eelgrass covered only 23.66% of the composite habitat area. The 2013 aggregated data showed eelgrass covered only 1.14% of the composite habitat area.

While an expansion of *Gracilaria sp.* was evident in the 2010 map, the 2013 dataset shows a decrease in the red algae. However, green algae coverage increased from 214 acres in fall 2010 to 477 acres in spring 2013. This shift in algae population is likely a function of the time of year. In general, algae appear to utilize areas within composite eelgrass habitat as well as other areas in the intertidal mudflats. The extent to which competition for habitat may be driving the decline in eelgrass is unknown. Further study on the interaction between these two vegetation types is needed to understand the potential impacts on eelgrass.

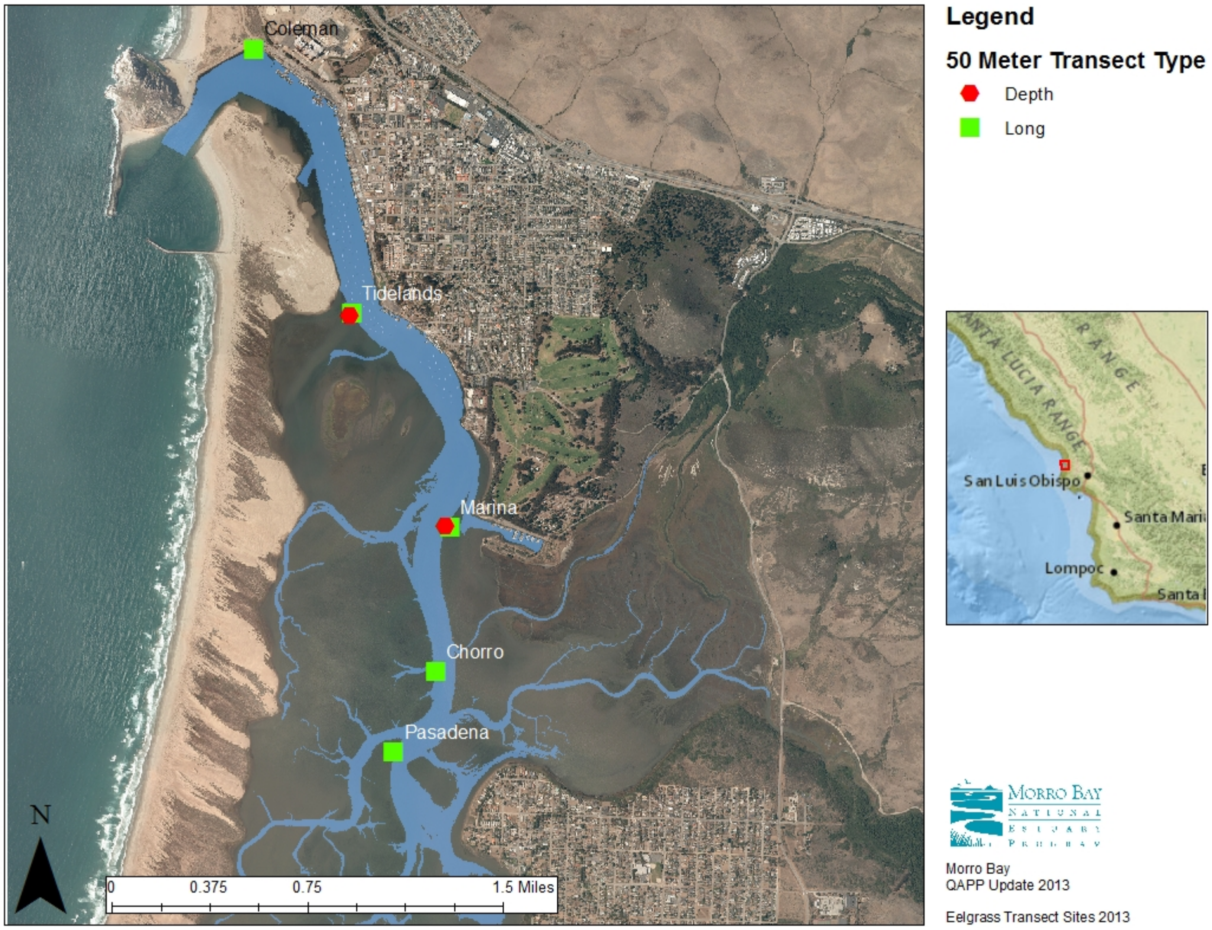
Shoot Density and Biomass Monitoring

In February 2005, Estuary Program and Battelle Marine Sciences staff established four permanent transects for annual monitoring in Morro Bay. Regions and potential sites for these transects were delineated by Battelle to represent different zones within the bay and capture differences between these zones. In fall 2012, an additional transect was added near State Park Marina to capture the dynamic nature of beds in that region.

Annual monitoring typically included measurements of shoot density and biomass along 50-meter transects at each of the four locations. At each transect, measurements of shoot density were collected inside a 0.50 m^2 quadrat, spaced 2.5 meters apart. Shoot density measurements provide a relative assessment of bed density, and spatial variability across the four transects. Within each measured quadrat, estimates of percent eelgrass coverage, macroalgae coverage and bare substrate were recorded. Above ground biomass samples were collected immediately adjacent to each transect, spanning the length of the 50 meter transect. Exposed rhizomes or flowering shoots were excluded from biomass measurements. Sample collection for biomass analysis requires a scientific collection permit from the California Department of Fish and Wildlife. Because Estuary Program staff did not hold a current permit, this biomass monitoring could not be conducted in the fall of 2013.

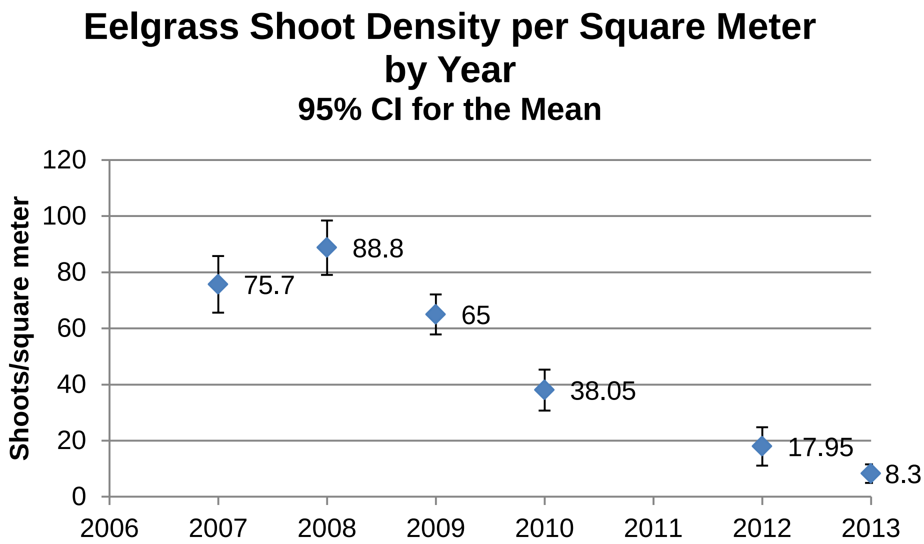
Transect fieldwork was conducted during extreme low tides during the late fall, as this period provides the best tidal windows for accessing sites. The timing of transect monitoring typically coincides with the imagery flight and can provide a useful qualitative assessment of conditions on the intertidal mudflats. Transect monitoring did not occur in 2011. Monitoring took place at five locations in 2012 and 2013. In 2013, the five transects were monitored over four days, November 1 and November 13 through 16. Staff accessed the sites by boat and conducted monitoring on foot. Figure 15 indicates the location of the five transects.

Figure 15: Transect Monitoring Locations



Eelgrass shoot densities have been variable from year to year and across sites. Figure 16 summarizes the mean shoot density across all sites from 2007 until 2013. The data collected in 2013 indicated that shoot densities had fallen to the lowest density since data collection began.

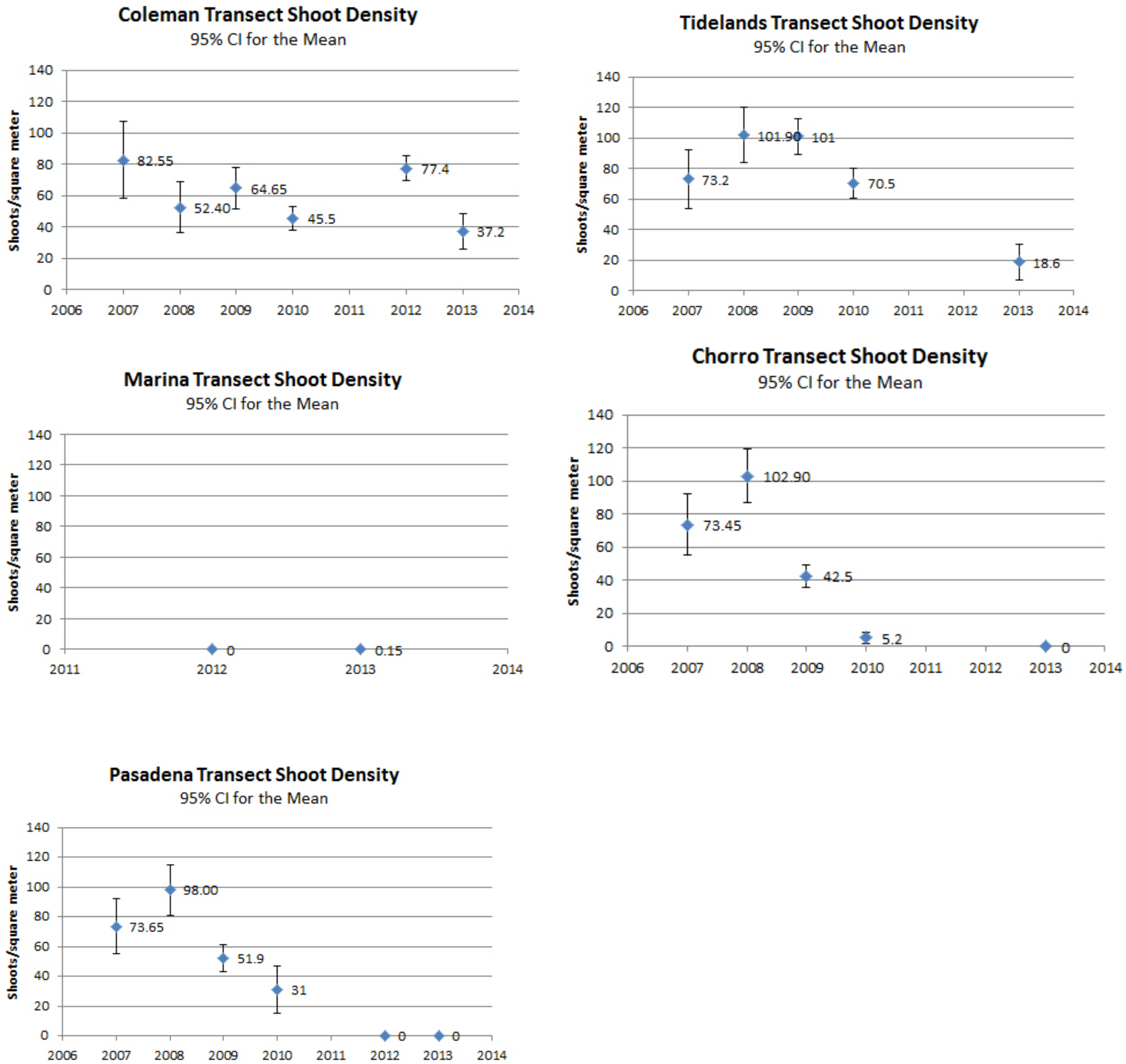
Figure 16: 2005 to 2013 Intertidal Eelgrass Shoot Densities



Although shoot densities declined at all sites in 2013, some sites saw more substantial declines than others. Data is summarized by location in the following figures. Transects located in the northern extent of the bay (Coleman and Tidelands) have generally maintained higher shoot densities than sites in the southern extent of the bay. The Chorro and Pasadena transects in the southern extent of the bay have shown generally similar trends in shoot density over the seven-year monitoring period. These sites also yielded the lowest shoot densities in 2013 and are located near areas where the most dramatic losses of eelgrass have occurred. The Marina transect, which was added in 2012, had low shoot densities in both years monitored.

Digital photos are taken at each transect monitoring site to document site conditions. Site photos along with general observations of the sites are provided.

Figure 17: Intertidal Eelgrass Transect Shoot Densities by Site



Pasadena Transect:
No intertidal eelgrass was observed along the transect in 2012 or 2013. Some eelgrass was present in 2010 and earlier. In deeper water near the transect, mature healthy subtidal eelgrass was present.

Chorro Transect:

No intertidal eelgrass was present. The site has had no to low eelgrass coverage since 2010. In the 2006 to 2009 time period, intertidal eelgrass coverage was dense. No eelgrass, either intertidal or subtidal, was observed in the area immediately outside of the transect area.

November 5, 2010

November 5, 2010

November 13, 2013

Coleman Transect:
Slightly lower intertidal eelgass cover was observed than in the previous two years (2010 and 2012). A great deal of trash was present in the area. The eelgrass appeared to be wilted and not as robust as in past surveys. There was no large change in shoot densities from previous years.

Tidelands Transect:
Intertidal eelgrass is present and healthy. Due to the shape of the bed, the transect went through a bare area, which decreased the percent coverage values. Eelgrass density was high throughout the bed.

Marina Transect:

This transect had low coverage numbers in 2012 and 2013. Near the transect area, subtidal eelgrass was present in the deeper channel.

Subtidal Eelgrass in Morro Bay

To augment the aerial classification data obtained during the flight, M&A conducted surveys of subtidal regions using hull-mounted interferometric side scan sonar. Sidescan sonar uses differential acoustic reflectivity to map the sea floor by providing a backscatter image of the sea floor (Merkel, 2013). This method integrates ship motion and the speed of sound sensors, as well as a dual antenna differential global positioning system (dGPS) that allows for high spatial accuracy (Merkel, 2013). Combining the sidescan sonar survey with the aerial imaging information provides a more comprehensive survey of eelgrass within Morro Bay.

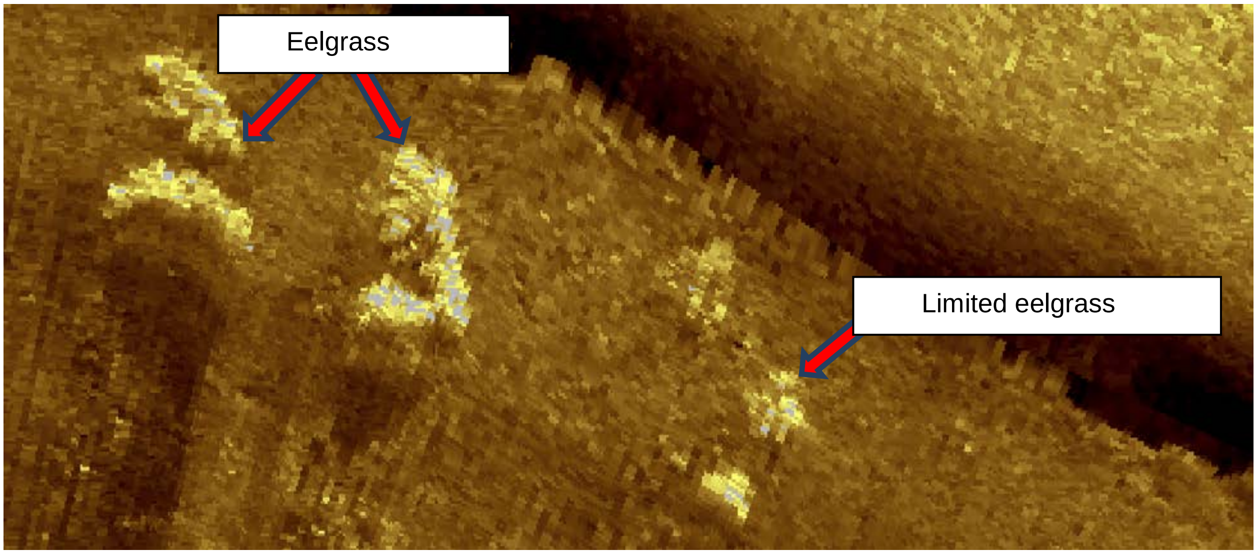
In July 2013, M&A collected sidescan sonar data of eelgrass in regions of the bay including open areas, shallow channels, developed areas supporting piers and docks, and all areas that were planted with eelgrass in 2012. Side scan sonar data were collected at a frequency of 468 kilohertz (kHz) over a 70 meter wide swath that was centered on the boat.

Sidescan sonar survey swaths were parallel to each other and overlapped each side of the 2012 eelgrass planting plots. This allowed the eelgrass planting plots to be viewed from two angles. All data were collected in latitude and longitude using the North American Datum of 1983 (NAD 83) and then converted to the Universal Transverse Mercator system in meters (UTM).

Following completion of the surveys, sidescan sonar traces were joined together and geographically registered. A drop camera was used to verify eelgrass located in the sidescan sonar surveys. Once verified, eelgrass on the planted transects was digitized by creating bounding polygons using ESRI ArcGIS software on the spatially rectified aerial photograph that was generated from the aerial flight.

Figure 18 shows a sidescan sonar mosaic of eelgrass within one of the 2012 eelgrass pilot plots as observed in July 2013. Bright reflections apparent in the image are from eelgrass plants aligned on the original planting array. Expansion of planting units can be observed in the planting units on the left, while limited expansion has occurred within units to the right.

Figure 18: Sidescan Sonar Mosaic of Eelgrass



Using digitized boundaries of eelgrass generated as a result of the sidescan sonar surveys, a total of 5.62 acres of eelgrass was calculated. Including the eelgrass acreage resulting from the aerial classification creates a comprehensive method of eelgrass distribution mapping. In GIS, the ArcMap Intersect Tool was used to calculate the amount of overlap between the sidescan sonar and classification shapefiles. This Intersect Tool discovers geometric relationships (intersections) between the two shapefiles and writes these intersections as a separate shapefile. The total area of eelgrass was determined by combining the area classified as eelgrass from the flight with the sidescan sonar area, and then subtracting the intersect area (calculated in GIS). The results are shown in the Table 3. Incorporating sidescan sonar data with aerial classification data allows for monitoring eelgrass trends at the project site with a substantial degree of accuracy and repeatability over time.

Table 3. Eelgrass Acreage Calculation Combining Aerial Classification Data and Sidescan Sonar

Shapefile Dataset	**Acreage**
Eelgrass – Classification	10.29
Eelgrass - Sidescan Sonar	5.62
Total Eelgrass– Classification and Sidescan Sonar (including overlap)	**15.91**
Intersect	0.92
Total Eelgrass – Classification and Sidescan Sonar (without overlap)	**14.99**

The total bay acreage assessed for subtidal eelgrass via sidescan sonar was not available at the time this report was compiled.

Restoration Efforts

Recent decreases in intertidal eelgrass acreage are of concern to the Estuary Program and its partners, and in 2012, actions were taken to restore this valuable habitat. The Estuary Program, M&A, the Black Brant Group, and Morro Coast Audubon Society partnered to create and implement a five-step recovery strategy. The effort involves harvesting non-infected eelgrass plants from the northern portion of the bay and replanting them in the southern and central parts of the bay. The steps of the recovery strategy are as follows:

Step 1: Pilot Planting

This effort was completed in September 2012 and involved creating eelgrass test plots to determine which areas of the bay best supported eelgrass. A total of 4,200 eelgrass shoots were harvested from a donor bed at Coleman Beach, prepared for planting by volunteers on shore, and then transplanted to test sites in the central and south bay. Twenty-one pilot plots were planted for a total of 1.04 acres of planting area.

Step 2: Bay-wide Submerged Vegetation Mapping

The Estuary Program effort created a bay-wide multi-spectral map in May 2013 to identify locations of intertidal eelgrass and other vegetation types. During this same timeframe, M&A gathered sidescan sonar data of subtidal areas. These two data sets were merged, and Estuary Program staff and volunteers as well as M&A staff conducted ground truthing to create a bay-wide inventory of intertidal eelgrass for the spring of 2013. This effort was completed in July 2013.

Step 3: Monitoring of Pilot Plots

M&A conducted monitoring of pilot plots in July 2013. Of the 21 planting areas established in 2012, ten of the plots (48%) contained eelgrass. All of the surviving eelgrass was at lower elevations, mostly in the subtidal region rather than the intertidal. 77% of the plantings at -2 feet MLLW survived, and 68% of the plantings at -3 feet survived.

Figure 19 contains a map of the pilot planting areas. Locations where eelgrass was detected in the July 2013 monitoring effort are shown in green.

Figure 19: Locations of 2012 Eelgrass Pilot Planting Locations

Step 4: Planting

Based on information from the 2012 pilot effort, a second more extensive planting effort was staged in an eight-day period in August 2013. Over 100 volunteers and partners, including non-profits and agencies, provided the funding and people power to prepare 9,775 eelgrass planting units which were installed in 49 plots, totaling approximately 2.4 acres. During harvesting, some eelgrass was flowering. This material was set aside and placed into mesh bags which were attached to buoys for seed dispersal. The locations of planting plots and buoy-deployed seed bags are illustrated in Figure 20.

Figure 20: 2013 Eelgrass Planting Locations

Step 5: Future Planting and Monitoring Efforts

More widespread eelgrass recovery will require additional monitoring and planting efforts. M&A is expected to return in July 2014 to monitor the 2013 planting areas. In the interim, the Estuary Program and its partners are working toward the goal of securing adequate funding and volunteer support for a planting effort in August 2014.

Discussion

The decline of seagrass meadows, specifically eelgrass, is well documented in scientific literature, both over time and throughout their global geographic extent. While increases in seagrass area have been observed in some areas, the increases are not substantial enough to offset globally observed declines. Recently published research notes a median -3.7% rate of change for seagrass meadows with a declining trajectory (Waycott et al, 2009). In Morro Bay, eelgrass acreage and distribution has fluctuated significantly over time. The current rate of eelgrass decline in Morro Bay was calculated using raw, un-manipulated data from the 2007, 2009, 2010 and 2013 surveys. From 2007 to 2009, eelgrass acreage declined by -30%. The declining trajectory continued from the 2009 to 2010 surveys with a decline of –26% during the one year period. From 2010 to 2013, the eelgrass acreage declined by -94%. The overall net decline of intertidal eelgrass in Morro Bay from 2007 to 2013 is approximately –97%. This rate of decline of Morro Bay intertidal eelgrass is substantially higher than range of values reported in recent literature (Waycott et al, 2009. Costello et al, 2011).

Subtidal eelgrass acreage, incorporated into the mapping effort for the first time, indicated a substantial amount of eelgrass acreage (5.6 acres) relative to amount remaining in the intertidal region (10.3 acres). Results from the pilot planting in 2012 indicated that eelgrass survival was higher in the deeper waters, possibly indicating a shift in conditions that favor eelgrass.

The decline of eelgrass meadows in Morro Bay appears to be unevenly distributed throughout the intertidal mudflats. Eelgrass beds in the northern extent of the study area have maintained a relatively stable presence and shown modest declines in shoot density. Areas in the central and southern portions of Morro Bay have shown more severe declines. Further site-specific study is needed to determine what factors may be driving the differing rates of decline throughout Morro Bay.

The overall decline of eelgrass in Morro Bay cannot be directly attributed to any specific impact. Rather, a suite of direct and indirect impacts to eelgrass habitat is likely responsible. A potential factor in eelgrass decline may be a biological pathogen that has been discovered in the bay. Only a few beds in the north of the bay remain unaffected (Merkel, 2013). In addition to this pathogen, Graciliaria spp., Ulva spp. and Enteromorpha spp. macroalgae are smothering eelgrass beds throughout the bay. The reason for the increase in macroalgae and decline of eelgrass may be due to numerous factors including nutrient loading, changing water quality conditions, changing elevations, changing climate and other factors.

The Estuary Program as well as the general public has been concerned by the recent losses of eelgrass in Morro Bay. A coalition of organizations has partnered with the Estuary Program to develop and implement a recovery strategy to restore this habitat. Results from a pilot replanting effort in 2012 led to an expanded effort in 2013. Initial information on the success of the second planting effort will be collected in the summer of 2014 during the peak growing season.

The Estuary Program is currently seeking funding and volunteer resources to support recovery efforts for 2014 to 2017. While the causes of the decline here in Morro Bay are still not well understood, the Estuary Program and its partners are working to protect remaining eelgrass beds, understand the reasons for decline, and restore this keystone species in Morro Bay.

References

Bach, S.D., Thayer, G.W., LaCroix, M.W., 1986. Export of detritus from eelgrass (*Zostera marina*) beds near Beaufort, North Carolina, USA. Marine Ecology Progress Series 28, 265-278.

Baltan, Jill. California Department of Public Health, Pers. Comm.

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

Brus, Kirk. Army Corps of Engineers, Pers. Comm.

Costello, C.T. Kenworthy, W.J. 2011. Twelve-Year mapping and change analysis of eelgrass (*Zostera marina*) areal abundance in Massachusetts (USA) identifies statewide declines. Estuaries and Coasts, 34, 232-242.

Gillespie, A. & Kitajima, A. 2011. Morro Bay National Estuary Program's Implementation Effectiveness Program Suspended Sediment Monitoring Report 2011. Morro Bay National Estuary Program.

Greve, T.M., Krause-Jensen, D., Rasmussen, M.B., Christensen, P.B. 2005. Means of rapid eelgrass *(Zostera marina L.)* recolonisation in former dieback areas. Aquatic Botany, 82, 143-156.

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

Merkel, Keith. Merkel and Associates Incorporated, Pers. Comm.

Merkel & Associates. 2010a. Final Eelgrass Survey Map and Memorandum for Estero Bay Maintenance Dredging, Morro Bay, CA and Final Eelgrass Mitigation Dredging Template. Prepared for U.S. Army Corps of Engineers Los Angeles District, March 2010.

Merkel & Associates. 2010b. Final Eelgrass Mitigation and Monitoring Plan in support of the Morro Bay Maintenance Dredging Project, Morro Bay, California. Prepared for U.S. Army Corps of Engineers Los Angeles District, June 2010.

Merkel & Associates. 2011. Final 12-Month Post-Transplant Eelgrass Survey for the Morro Bay 2010 Maintenance Dredging Project, Morro Bay, CA. Prepared for U.S. Army, August 2011.

Merkel & Associates. 2013. 2013 Monitoring and Transplant Report, Morro Bay Eelgrass Recovery Program, Morro Bay, CA. Prepared for the MBNEP, November 2013.

National Marine Fisheries Service. 1991. Southern California Eelgrass Mitigation Policy. (1991, Revision 11). R.S. Hoffman, ed.

Pihl, L., Baden, S., Kautsky, N.,Ronnback, P., Soderqvist, T., Troell, M., Wennhage, H. 2006. Shift in fish assemblage structure due to loss of seagrass *Zostera marina* habitats in Sweden. Estuarine, Coastal and Shelf Science 67,123-132.

Sneed, D. 2010. Morro Bay fishing is back from the depths. San Luis Obispo Tribune, July 4, 2010.

Ralph, P.J., Durako, M.J., Enriquez, S., Collier, C.J., Doblin, M.A. 2007. Impact of light limitation on seagrasses. Journal of Experimental Marine Biology and Ecology 350, 176-193.

Tetra Tech, 1998. Morro Bay National Estuary Program Sediment Loading Study. Prepared for Morro Bay National Estuary Program, August 1998.

Waycott, M., Duarte, C.M. Carruthers, R.G. Orth, R.J. Dennison, W.C. Olyarnik, S. Calladine, A. Fourqurean, J.W. Heck, K.L. Hughes, A.R. Kendrick, G.A. Kenworthy, W.J. Short, F.T. Williams, S.L. 2009. Accelerating loss of seagrassess across the globe threatens coastal ecosystems. Processdins of the National Academy of Sciences 106, 12377-12381.

Williams, S.L. 2007. Introduced species in seagrass ecosystems: Status and concerns. Journal of Experimental Marine Biology and Ecology 350, 89-110.

Appendix A: SAV Classification Ground Truthing Effort

Pre-flight ground truth data collection was conducted by Estuary Program staff and Geoventure Consulting on the following dates:

November 1, 2012
November 5, 2012
November 6, 2012
November 7, 2012
April 18, 2013
April 23, 2013
April 30, 2013
May 1, 2013

The purpose of the pre-flight ground truth effort was to conduct focused field investigations within areas that were difficult to classify during previous survey efforts. The Estuary Program and Geoventure Consulting conferred with OI to identify specific polygons to focus on for the preliminary survey effort. Polygons were provided to the Estuary Program and Geoventure Consulting in the form of GIS shapefiles and overlaid on the most recent aerial of the survey area. Shapefiles were uploaded into a Trimble Juno 2 hand-held GPS unit for use within the field.

Through post-processing the point data with respective buffers, the total area surveyed by the Estuary Program and Geoventure Consulting during pre-flight ground truth surveys was approximately 23.8 acres. The 23.8 acres surveyed is considered to represent the minimum area of coverage necessary for this type of effort. However, the intention of the pre-flight surveys was not to demonstrate a high area of coverage but to provide a baseline of data for which to compare post-flight data within areas that have been challenging to define in the past.

Out of 219 points collected during the survey effort, the majority of the points recorded were observations of mud/sand or Gracilaria spp. (refer to Table 3). Data collected during the pre-flight survey effort were downloaded, packaged and forwarded to OI.

Table 4. Pre-flight Ground Truth Data Summary

Survey Area	23.8 acres
Total Number of Point Data Collected	219 points
Breakdown of Point Data by Dominant Vegetation	
Bare Mud/ Sand	99 points
Eelgrass	26 points
Fresh Marsh	1 point
Green Algae	42 points
Maritime Infrastructure	1 point
Mixed Algae	3 points
Red Algae	17 points
Ruppia	1 point
Salt Marsh	29 points
Wrack	1 point

Post-flight ground truth data collection was conducted following preliminary classification of the aerial photo. The purpose of the post-flight ground truth effort entailed focused field investigations within areas where substrate or vegetation could not be clearly discerned from the aerial imagery. Specific survey areas were determined by OI and were provided to Geoventure Consulting in shapefile format. This data was overlaid on an aerial photo and uploaded to GPS units for navigational purposes while in the field.

Geoventure Consulting conducted post-flight ground truth surveys on August 13th and 15th of 2013. Biologists kayaked to the survey locations specified by OI using a GPS Trimble Juno 2 to navigate. Each survey area was assessed by visually observing aquatic vegetation and recording polygons and point sample data with the use of the GPS unit. All data was submitted to OI for incorporation into the final classification scheme.

Table 5. Post-flight Ground Truth Data Summary

Survey Area	2.6 acres
Total Number of Point Data Collected	30 points
Breakdown of Point Data by Dominant Vegetation	
Bare Mud/ Sand	9 points
Eelgrass	2 points
Green Algae	4 points
Maritime Infrastructure	2 points
Red Algae	12 points
Wrack	1 point

Appendix B: Eelgrass Aggregation Procedure

Polygon aggregation of the raw data was completed utilizing analysis tools within ArcMap 10.1. It was determined that aggregating individual polygons into larger areas was necessary to reduce the number of individual polygon records and processing time required for additional spatial modeling. Two iterations of polygon aggregation were completed in order to test the accuracy of aggregation outcomes.

Aggregation parameters were consistent with the 2010 Eelgrass Monitoring Report and utilized an aggregation distance of 9 ft, with minimum polygon area selected as 9 ft^2, and the minimum hole size specified as 81 ft^2. This increased the minimum polygon size from ~1.75 ft^2 in the raw dataset, to ~9.05 ft^2. The resulting spatial statistics for this aggregation process are indicated in the column titled 3'x3' Aggregate Data.

Table 6: Spatial Statistics for Aggregated Polygon Shapefiles

Year	Category	Raw Data	3' x 3' Aggregate Data
2007	Minimum Polygon Area (ft^2)	1.742	9.05
	Mean Polygon Area (ft^2)	67.87	2420.77
	Number of Records (n)	218,307	7213
	Total Acreage for 2007	**340.22**	**400.8**
2009	Minimum Polygon Area (ft^2)	1.72	9.08
	Mean Polygon Area (ft^2)	66.56	2853.27
	Number of Records (n)	144,997	4450
	Total Acreage for 2009	**240.1**	**291.5**
2010	Minimum Polygon Area (ft^2)	1.722	9.05
	Mean Polygon Area (ft^2)	54.45	2675.90
	Number of Records (n)	141,540	3491
	Total Acreage for 2010	**176.925**	**214.45**
2013	Minimum Polygon Area (ft^2)	2.48	9.92
	Mean Polygon Area (ft^2)	189.05	2272.89
	Number of Records (n)	2,372	227
	Total Acreage for 2013	**10.29**	**11.84**

Once each year of raw data had been aggregated, the datasets were merged to create a single file. The four unique datasets were merged via the Data Merge toolset in the ArcMap 10.1 suite. The resulting file contained a composite of all areas where eelgrass was observed during 2007, 2009, 2010 and 2013. This area was used to represent the composite or potential habitat area where eelgrass has been documented, and may occur in future surveys. The composite area of intertidal eelgrass habitat was determined to be 918.39 acres, as indicated in Table 7.

Table 7: Spatial Statistics of Composite Eelgrass Habitat

2007 to 2013 Composite Intertidal Habitat Area	**3' x 3' Aggregate Data**
Minimum Polygon Area (ft^2)	9.05
Mean Polygon Area (ft^2)	2602.13
Number of Records (n)	15381
Total Acreage	**918.81**