2023 San Diego Bay Eelgrass Inventory

Prepared for:

U.S. Navy Region Southwest
Naval Facilities Engineering Systems Command

Port of San Diego

Prepared by:

Merkel & Associates, Inc.

April 2024

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICES

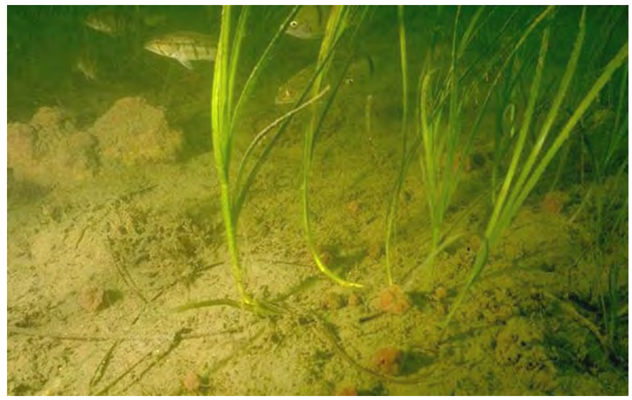
2023 SAN DIEGO BAY
EELGRASS INVENTORY UPDATE

Merkel & Associates, Inc.

May 2024

BACKGROUND

Eelgrass Distribution and Functions



Eelgrass is a native marine plant indigenous to the soft-bottom bays and estuaries of the northern hemisphere. The species is found from middle Baja California and the Sea of Cortez to northern Alaska along the west coast of North America and is common in healthy shallow bays and estuaries. In southern California, eelgrass is generally limited along the shoreward margin by desiccation stress at low tides and is limited along its deeper fringe by low light levels.

Eelgrass plays many roles within coastal bays and estuary ecosystems. It clarifies water through sediment trapping and stabilization and provides benefits through nutrient transformation and water oxygenation. Eelgrass serves as a primary producer in detrital based food webs and is directly fed upon by invertebrates, fish, and birds. It provides physical community structure and supports epiphytic plants and animals, which in turn are grazed upon by larval and juvenile fish, invertebrates, and birds. Eelgrass is a nursery area for commercially and recreationally important finfish and shellfish species, including fishes restricted to bays and estuaries as well as oceanic species, which enter the coastal areas to breed or spawn.

In addition to the high intrinsic values of eelgrass as a habitat, it also provides significant value as a tool for examining long-term trends in water quality improvement or deterioration. It has ideal characteristics for use in monitoring system change. Eelgrass is found at the end of the watershed within coastal bays and estuaries; and as such, monitoring the status of eelgrass resources helps to assess overall watershed management effectiveness. Eelgrass responds to persistent water quality stresses rather than short duration fluctuations. It is adapted to a wide range of tolerances and is capable of "averaging" exposure conditions including temperature, turbidity, seasonal light levels, sedimentation rates, etc., to result in either positive growth or a gradual decline. As a result, short-term variability such as can be seen with water quality testing, is of relatively little consequence to eelgrass. A more biologically meaningful measure of long-term trends in environmental stressors, such as elevated temperature or turbidity, can be seen in the response of eelgrass to chronic exposure to the ambient environment.

Eelgrass is considered to be a habitat forming species that creates unique biological environments. Because of the importance of eelgrass, it is afforded heightened regulatory protection status. As submerged aquatic beds, eelgrass is given special status under the Clean Water Act, 1972 (as amended), Section 404(b)(1), "Guidelines for Specification of Disposal Sites for Dredged or Fill Material," Subpart E, "Potential Impacts on Special Aquatic Sites." This special status has led to mitigation efforts implemented under the California Eelgrass Mitigation Policy (CEMP, NOAA 2014).

San Diego Bay

The eelgrass resources of San Diego Bay (the Bay) are significant not only on a local scale, but also regionally. San Diego Bay is the largest open water in southern California and one of only a handful of bays in California that supports sizeable eelgrass meadows. San Diego Bay ranks third behind Humboldt Bay and slightly behind San Francisco Bay in total eelgrass habitat, supporting approximately 16 percent of all eelgrass habitat within the State of California. San Diego Bay supports approximately 50 percent of the total amount of eelgrass resources in southern California.

Table 1. San Diego Bay eelgrass contribution to the estimated California statewide eelgrass area.

System	Acreage	% Total	Source
Humboldt Bay (2009)	~4,700	29%	M&A 2017
San Francisco Bay (2014)	2,790	17%	M&A 2014
San Diego Bay (2023)	2,595	16%	this report
Tomales Bay (2017)	1,820	11%	M&A 2022
Mission Bay (2013)	1,110	7%	M&A 2024
All Other Systems	~3,000	19%	M&A 2017
Total	**~16,015**	**100%**	

San Diego Bay is a 10,994-acre bay located between the City of San Diego to the north and east, the cities of National City, Chula Vista, and Imperial Beach to the east and south, and the City of Coronado to the south and west. The Bay represents the largest estuary in southern California. It is approximately 15.5 miles in length and contains 54 miles of shoreline. Portions of the Bay north of the Coronado Bay Bridge are narrow and deep, while most of the southern portions of the Bay are wide and shallow. Much of the northern and central Bay shoreline has been developed.

Eelgrass is predominantly a subtidal resource and as a result it is difficult to monitor and track changes in its distribution. Moreover, comparisons between various eelgrass surveys are burdened by advancements in technology and orders of magnitude advancements in precision and accuracy of mapping capabilities. Prior to the 1990's, eelgrass surveys in San Diego Bay were performed by a variety of techniques including trawl and grab sampling, diver transects, and true color and infrared aerial imagery (Lockheed 1979a, Lockheed 1979b, SDUPD 1979, SDUPD and California State Coastal Conservancy 1990). Mapping was aided by estimation of locations based on various landmarks and, on rare occasion, some controlled survey points from which relative locations were visually approximated. Small-scale eelgrass mapping was conducted primarily through the use of grabs and divers, whereas the large-scale efforts tended to rely on aerial imagery. However, aerial imagery was not consistently capable of detecting eelgrass at depth. As a result, shallow eelgrass beds were generally well mapped, but deeper eelgrass beds were often under-reported or missed entirely.

In 1988, sidescan sonar was first used to map eelgrass within the 2000-acre Mission Bay. The boat trackline was plotted using microwave navigation, and eelgrass density was determined from sonagraphic charts while diver transects were used to ground-truth the work effort (Merkel 1988). This approach was subsequently updated to make use of real-time differential GPS data to plot the centerline boat position as well as a CAD-based mapping effort (Merkel 1992). In 1993, the U.S. Navy applied this technology to San Diego Bay and provided the first comprehensive survey of eelgrass resources within the Bay (U.S. Navy 1994). The Navy and the San Diego Unified Port (Port)

District followed this effort with another baywide survey in 1999 using single-beam sonar methods (U.S. Navy 2000). In 2004 and 2008, Merkel & Associates carried out both eelgrass surveys and bathymetric mapping updates that included the entire San Diego Bay (Merkel & Associates 2005, 2009). In 2011, advancements in mapping technology were made with the application of interferometric sidescan sonar (ISS) to conduct the updated eelgrass mapping (Merkel & Associates 2011a). The use of ISS technology substantially improved the spatial accuracy of acoustic backscatter mapping. The 2017 and 2020 baywide eelgrass surveys made use of ISS with improvements in vessel positioning and heading correction through the use of real time kinematic (RTK) GPS (Merkel & Associates 2018b, 2021). Unmanned aerial vehicles (UAVs) were used to augment the ISS survey coverage extending eelgrass mapping through shallow marsh channels and within recently restored salt evaporation ponds of south San Diego Bay. The present 2023 baywide eelgrass inventory made use of the same technology as applied in 2017 and 2020 and continues to provide insight into long-term trends in eelgrass habitat and environmental change within the Bay.

Baywide eelgrass surveys have been conducted for tracking ecological and water quality conditions, detecting trends derived from anthropogenic influences or climatic changes, and for natural resource and development planning. The San Diego Bay Integrated Natural Resource Management Plan establishes recurrent baywide eelgrass surveys as a monitoring priority (US Navy and Port 2013). Eelgrass survey results are presented on a baywide scale. Depths are presented in feet using mean lower low water (MLLW) as derived from composite bathymetric charts prepared as a product of 2008 surveys (Merkel & Associates 2009) (Figure 1).

SURVEY AND ANALYSIS METHODS

Interferometric Sidescan Sonar

Survey equipment used for data collection included a digital interferometric sidescan sonar system with motion sensor integration, and RTK GPS for navigation. Data were collected by Merkel & Associates over the course of 19 survey days from July 3 to September 28 to result in full baywide coverage. Survey density was higher within shallow environments than was employed in more open deepwater environments where eelgrass would not be expected, and existing high-resolution bathymetry existed. Surveys in these areas were performed to confirm existing data sets.

Sonar

A hull mounted 468 kHz digital interferometric sidescan sonar system was used, which included SEA SWATHplus-H sonar, integrated with a Valeport miniSVP sound velocity sensor, and an SMC IMU-108 motion sensor to correct for speed of sound in water and roll, pitch, and heave of the survey vessel. The sidescan sonar data were collected with across-track swath widths of 31 m on both the port and starboard transducers. Tracklines were overlapped to provide for 100 percent seafloor coverage within the survey area. The acoustic wave phase difference at different sensors allows for triangulation of the position of the acoustically reflective surface.

Navigation

The navigation system used during the surveys employed an on-board dual antenna RTK GPS. The positional accuracy horizontal positioning of the survey vessel was maintained with a Hemisphere VS111 providing positional accuracy within 2 centimeters, 95 percent of the time. The secondary antenna provided heading and yaw correction. During the survey, the vessel was operated on parallel tracks with slightly overlapping sonagraphic records.

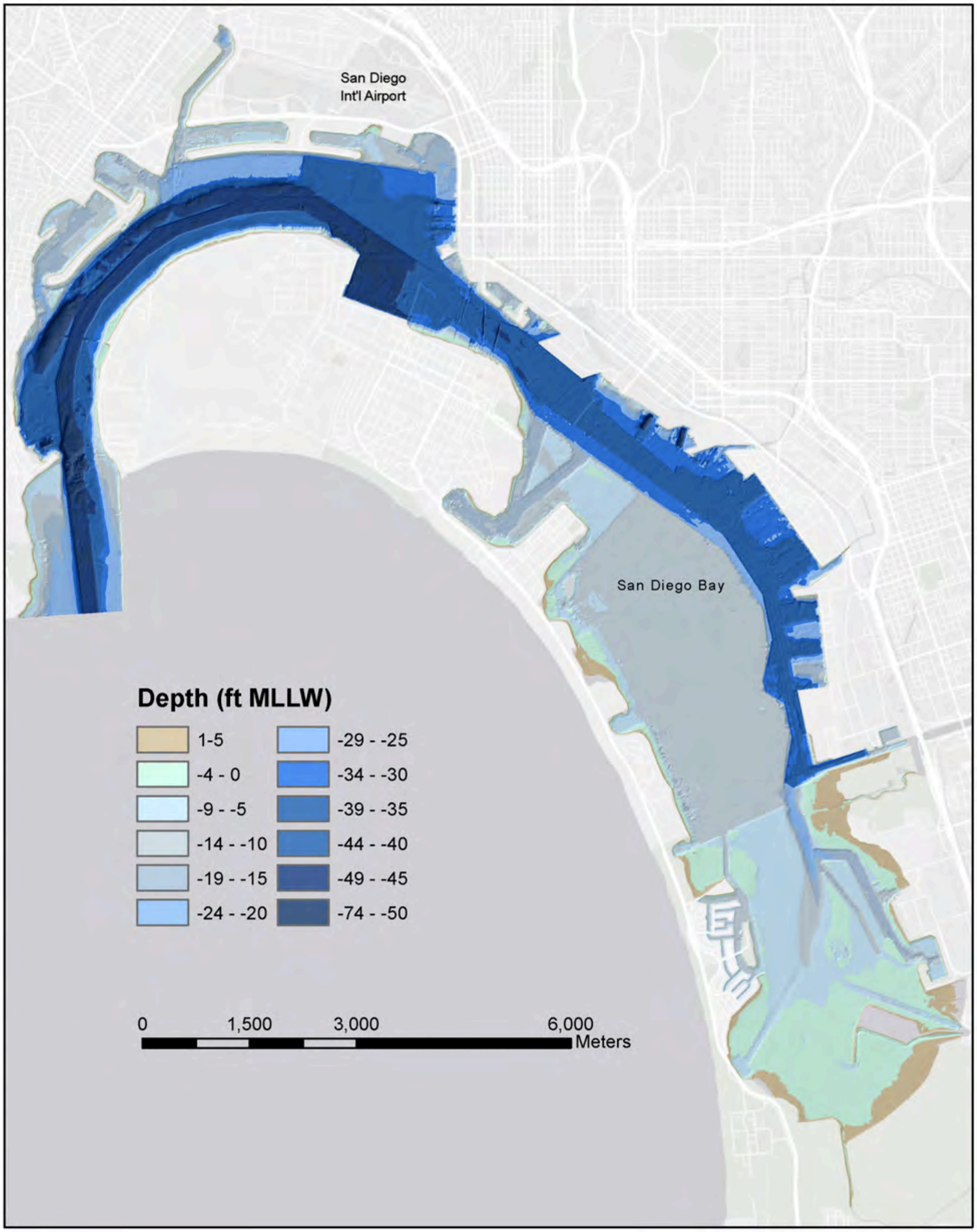


Figure 1. Composite bathymetry of San Diego Bay (Updated in 2008).

The first trackline within each area was located 15 to 20 meters from the shoreline allowing full coverage of the Bay floor up to the middle intertidal zone or above. Once the initial trackline had been completed, the vessel moved offshore in approximately 25-meter increments and paralleled the primary trackline. Maintaining a line parallel to the primary trackline was accomplished by the use of a real-time position and digital trackline map. Once sufficient shoreline buffer had been developed, straight-line swaths were employed to minimize data loss occurring in turns. High wave environments and areas with significant vessel traffic were surveyed at night to maximize the quality of acoustic records collected. Following the completion of the sonagraphic survey, the stored sidescan data were post-processed into a series of geo-rectified mosaic images covering all surveyed areas of San Diego Bay.

Low Altitude Photogrammetry

During extreme low tides, a UAV was flown within the south Bay along pre-programmed flight patterns at 300 feet of elevation. Surveyed areas included marshland channels, restored salt ponds, and the Sweetwater River channel over marshland channels and shore margins. Photographs were collected at intervals providing 75% forward lap and 65% side lap between photographs that were collected with a 20-megapixel camera to obtain imagery with a native pixel size of 30mm. Images were processed into spatially rectified true color orthophoto mosaic images using Agisoft Metashape Professional. The registered images were then used to support heads-up digitization of eelgrass. Spectral shifts, dynamic range adjustments, and other spectral analyses tools were applied to enhance the separation of eelgrass signatures from other features such as algae in order to aid in mapping.

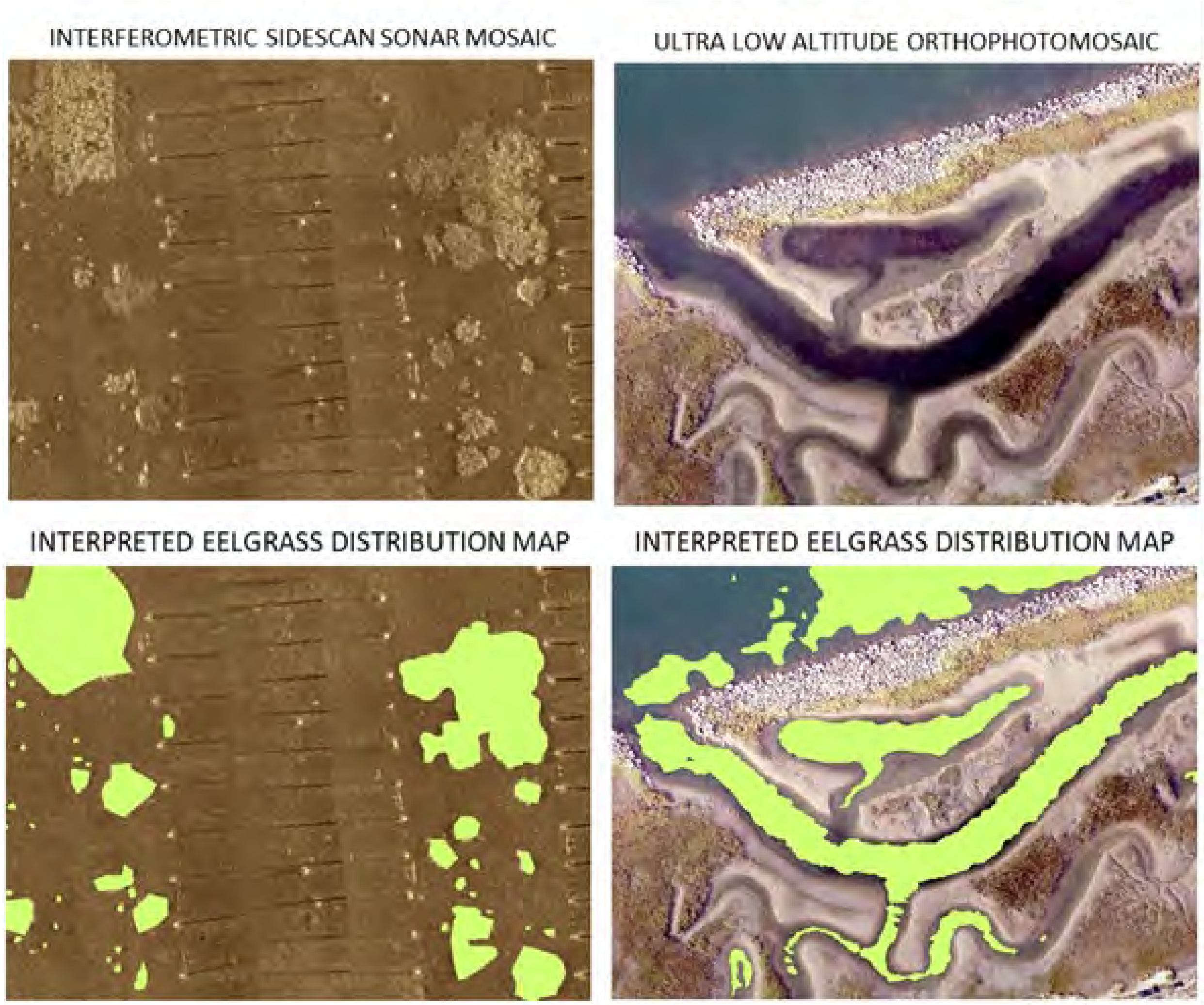
Ground-Truthing

Remotely operated vehicle (ROV) and drop video camera spot checks, as well as low-tide surface inspections, were used to ground-truth maps prepared using sonagraphic data. The distribution of ground-truthing sites was non-random and primarily focused on sites identified as having substantial discrepancies existing between the prior surveys and the present survey. Additionally, ground-truthing focused on southern portions of the Bay where warm water conditions favor the abundance of the subtropical upright bryozoan, *Zoobotryon verticillatum*. This large bryozoan returns a similar but substantially less acoustically reflective signal as eelgrass; and thus, sonagraphic interpretation was expected to be most questionable in these areas. The south Bay region also supported limited occurrences of widgeon grass (*Ruppia maritima*), a short, densely growing, seagrass found in areas around the Chula Vista Wildlife Reserve and within the Otay River estuary. This required some initial signature verification based on the growth state of both eelgrass and widgeon grass at the time of mapping. Surfgrass (*Phyllospadix* spp.) occurs on the rocks of Zuniga Jetty, but not on soft bottom and thus is not confused with eelgrass in the mapping effort.

Other ground-truthing efforts were focused in areas of mixed rubble and soft bottom where *Sargassum muticum* can generate similar, but distinguishable acoustic signatures to those of eelgrass. Finally, ground-truthing efforts occurred around marinas, docks, and other areas where sonagraphic surveys were encumbered by limited open water access and where eelgrass distribution patterns are complex and frequently sharply demarcated by density changes. Although ground-truthing efforts were focused in some regions of the Bay, all portions of the Bay were ground-truthed to the level of detail required to confirm the accuracy of the sonagraphic data analysis.

Eelgrass Mapping

The sonar mosaic and orthophoto mosaic images were imported into geographic information systems (GIS) software to delineate eelgrass beds through on-screen digitization of the acoustic signatures of eelgrass observed in the sonographic and photographic records. Eelgrass was manually digitized from the image sources as discrete vegetative plant patches. In the case of sonar mosaics, the individual survey swaths were mapped and then survey layers flipped to observe the bottom from differing survey angles to verify that eelgrass patches were observed. This allowed for detection of plants within the sonar nadir gap. For orthophoto mosaics, spectral shifts and dynamic range adjustments were used to separate eelgrass signatures from conflicting algae. In many cases, overlap in coverage by ISS and UAV data provided cross platform mapping verification capabilities. For purposes of mapping, the 2023 eelgrass inventory used a tight-line mapping wherein eelgrass features were individually mapped as opposed to mapping eelgrass by cover classes. The mapped eelgrass patches were then merged into a single shape-file reflecting the 2023 eelgrass distribution.



Examples of interpreted mosaic files from interferometric sidescan sonar surveys and UAV ultra-low altitude orthophotography covering shallow marsh channels and other vessel inaccessible portions of the survey area.

RESULTS

Information presented in this report has been prepared for use in digital format and large-scale presentation format for the Navy and Port District. Reduced versions of graphics are incorporated in this document for completeness of interpretation.

Eelgrass

The 2023 eelgrass distribution within San Diego Bay extended over a total bottom area of 2,595.38 acres (Figure 2). The distribution of eelgrass follows the general patterns of distribution noted in prior surveys. The greatest extent of eelgrass is found within the shallow southern ecoregion of the Bay with more extensive eelgrass also being found on the shallower fringes of the western Bay shorelines where gradual soft shorelines are more prominent (Figure 1). Other smaller beds occur scattered throughout the more developed regions of the Bay where shallows allow for adequate light levels to support eelgrass habitat. Eelgrass beds also exist at the mouth of San Diego Bay within the shallows outside of Ballast Point and along Zuniga Jetty on North Island.

DISCUSSION

The 2023 survey year eelgrass distribution was very similar to that of the 2020 survey with the overall coverage being 99.9 percent of that present in 2020. Notably, the 2023 survey saw substantial expansion of eelgrass into deeper waters along the margins of existing beds. The observed lower limit expansion extends beyond the prior maximum extent of eelgrass recorded during the eight prior surveys extending over three decades (Figure 3). The extent of eelgrass present in both 2020 and 2023 exceeded the next highest year, 2004, by 25 percent. Notable expansions in eelgrass observed in 2020 and again in 2023 were below the deeper margins of previous bed distributions extending into deeper troughs of the south Bay ecoregion, within the outer channels of the Coronado Cays, and onto the flat bay floor within the south-central Bay ecoregion. This eelgrass has extended down a 3-foot vertical step that defines the boundary between the south and south-central Bay ecoregions and onto the flatter dredged bay floor at -10 to -12 feet MLLW around the Naval Amphibious Base where eelgrass has also expanded into deeper waters, and on the deeper floors of Fiddler’s Cove and Crown Cove. In the north-central ecoregion, expansion beyond the prior recorded maximum extent is principally found in the deeper waters of the Tuna Basin and Marriott Marina basins. In the north Bay ecoregion the pattern of eelgrass expansion into deeper waters was also observed with greater eelgrass at depth being observed at the Harbor Island West and East Basins, and within America’s Cup Harbor. All of these same deeper basins showed expansion beyond prior depth distribution during the 2020 survey with expansion continuing in 2023.

Throughout the Bay, eelgrass is observed to be restricted to the shallower portions of the baywide depth range (Figure 4). Eelgrass grows most extensively in waters ranging from approximately +1 to -8 feet MLLW. However, the -2 feet foot MLLW depth range had the greatest percentage of available substrate occupied by eelgrass with 90.7 percent of the bottom in this range supporting eelgrass. Over 70 percent of the Bay falling between -2 and -4 feet MLLW supported eelgrass in 2023. Some notable deviations from this typical range are seen in areas on higher mudflats and at the toe of riprap slopes, where wave scour, boat propeller scars, and activities of rays have created small perched pools that can support eelgrass habitat above the +1 foot MLLW elevation that typically defines the upper elevation of eelgrass in San Diego Bay.

Figure 2. Eelgrass vegetated cover for San Diego Bay 2023 baywide survey

Figure 3. 2023 Eelgrass relative to prior maximum extent ee distribution (1993 - 2020)

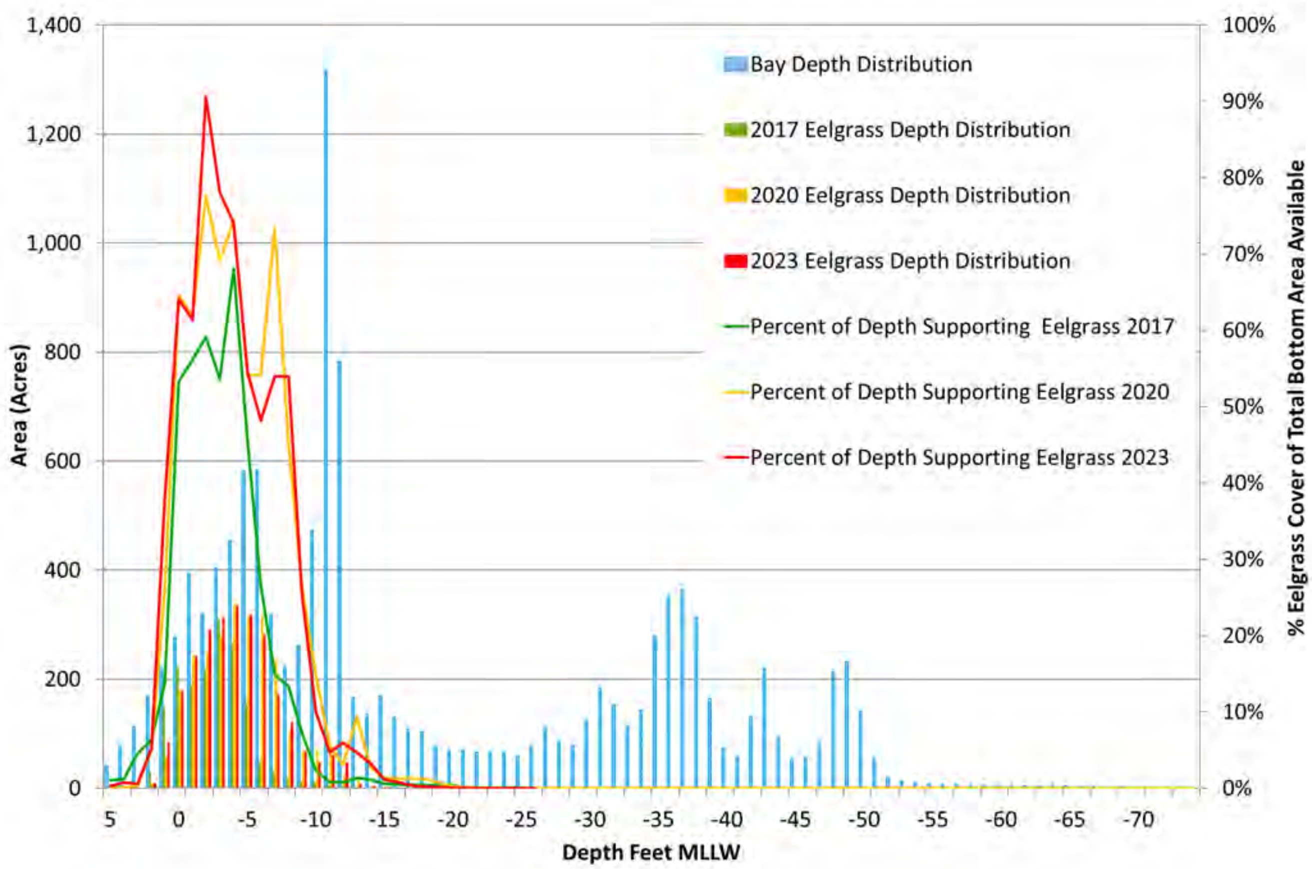


Figure 4. San Diego Bay depth distribution by percentage of total area.

In addition, deepwater eelgrass beds are found at the mouth of the Bay outside of Ballast Point where clear water and sandy sediments support the broad-leaved Pacific eelgrass (*Zostera pacifica*). At the mouth of San Diego Bay, these beds rarely extend to depths in excess of -21 feet MLLW but are generally restricted to depths in excess of -12 feet MLLW. A very small amount of eelgrass also regularly has occurred in deeper waters within the eastern portion of the central Bay where clear water often occurs around the commercial piers that are exposed to flows from the deep navigation channel. The deeper distribution of eelgrass observed in 2020 and in 2023 is particularly interesting in that expansion has entered into depth ranges of the bay that have historically not supported significant eelgrass. To explore this further, eelgrass depth distribution has been plotted on the most recent composite bathymetric data compiled from a number of primary and secondary sources in 2008 (Merkel & Associates 2009). It is recognized that the 2008 composite bathymetry is now substantially out of date and needs to be refreshed; however, it provides a reasonably good tool for exploring changes in eelgrass distribution across the Bay's bathymetric range. Plotting the 2017, 2020, and 2023 data on the depth distribution for the entire Bay reveals that the general expansion of eelgrass in 2020 and again in 2023 is skewed towards deeper waters (Figure 5). Further, when the area of eelgrass is divided by the area of available bottom within each depth bin, the percent occupancy of the Bay bottom by depth can be determined. From this, it can be seen that the expansion of eelgrass at deeper depths is entering into a bathymetric range between -10 to -12 feet MLLW. This depth range constitutes 21 percent of the total Bay area and nearly 2,600 acres, dwarfing the areal extent of any other three-foot depth band represented in the Bay (Figure

4). This is of tremendous importance in that there is considerable potential for eelgrass expansion in this depth range whereas there is limited potential for expansion within the shallower core of the eelgrass distribution range.

If the 2020 and 2023 deeper water eelgrass was to persist and expand within the same depth ranges over the long-term, the Bay would have the capacity for near doubling of the present eelgrass habitat. However, this condition is not expected to persist. Normal variability in water clarity renders eelgrass at these depths inherently unstable from year to year, and sea level rise will continue to reduce potential for eelgrass persistence at deeper depths. To evaluate how much of an anomaly the 2020 and 2023 eelgrass distribution represents, the depth distribution of prior baywide eelgrass inventories has been plotted along with the mean and standard deviation of all nine baywide surveys conducted since the first survey conducted in 1993 (Figure 5). This plot shows relatively consistent upper and lower eelgrass extents and a more variable eelgrass area within the core of the depth range. It also shows the 2020 and 2023 deep water depth extension as significant anomalies well outside of the norm compared to other inventory years and the overall historic mean. However, it is notable in the graph, coded by year, that there has been a relatively consistent trend of increasing eelgrass expansion within the core of the depth distribution range (0 to -5 feet MLLW).

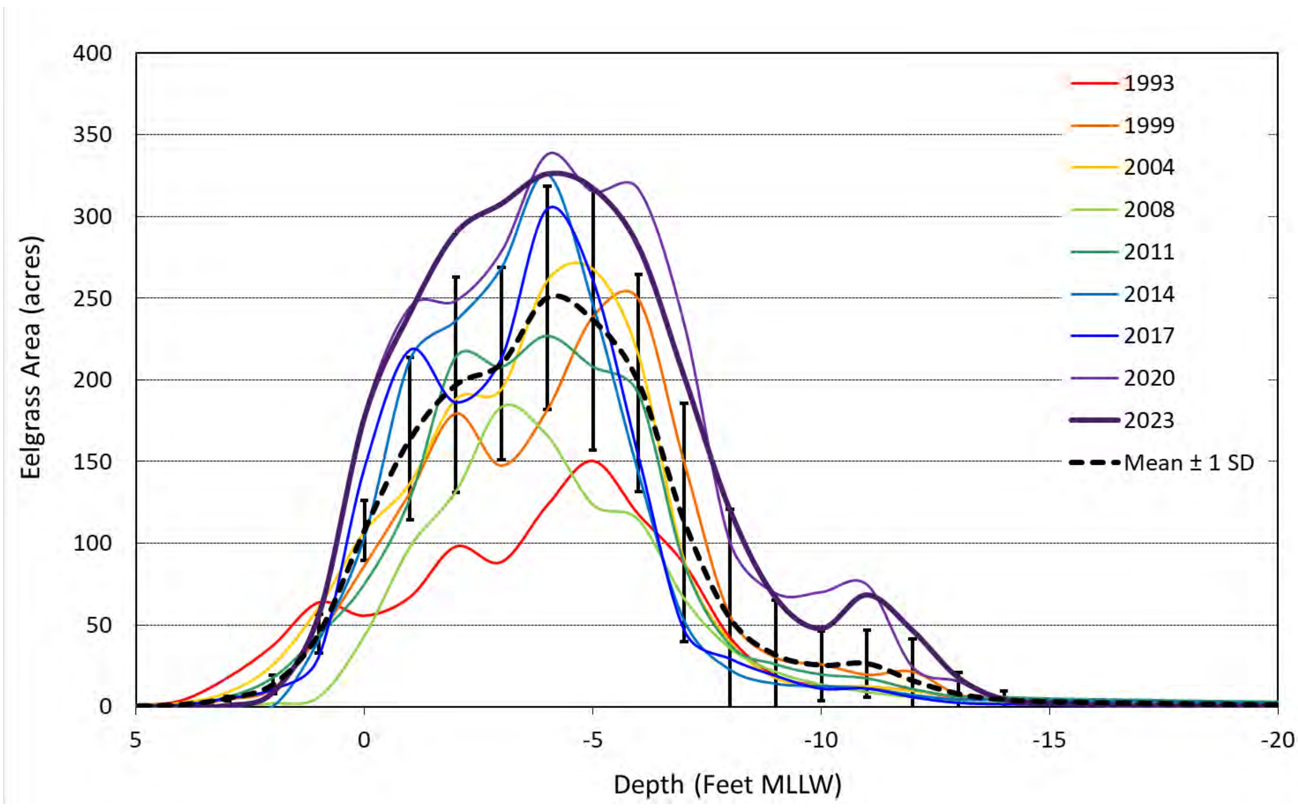


Figure 5. Eelgrass area distribution by depth and baywide survey year.

In addition to the trend of increasing coverage of eelgrass within the core of the depth distribution, there has also been an overall long-term trend of increasing eelgrass extent within the Bay over the past three decades with the most recent 2020 and 2023 surveys revealing nearly identical total eelgrass extents (Figure 6, Table 2). This pattern has been strongly driven by a trend of increasing eelgrass area within the south Bay ecoregion with the other ecoregions playing lesser and mixed roles with respect to the eelgrass extent in the Bay. In the case of 2023, eelgrass continued to increase in the south Bay ecoregion from that observed in 2020, however all other ecoregions showed substantive to minor declines in eelgrass that offset these gains (Table 2).

Eelgrass is not evenly distributed across the ecoregions and neither is the capacity for expansion and contraction with the beds. For the most part, eelgrass in the north Bay and north central Bay ecoregions is restricted to fringing eelgrass beds along the margins of deep harbor areas with limited expansion potential, while the south Bay, south central Bay, and outside Ballast Point ecoregions have greater capacity for eelgrass expansion with slight sustained increases in water clarity.

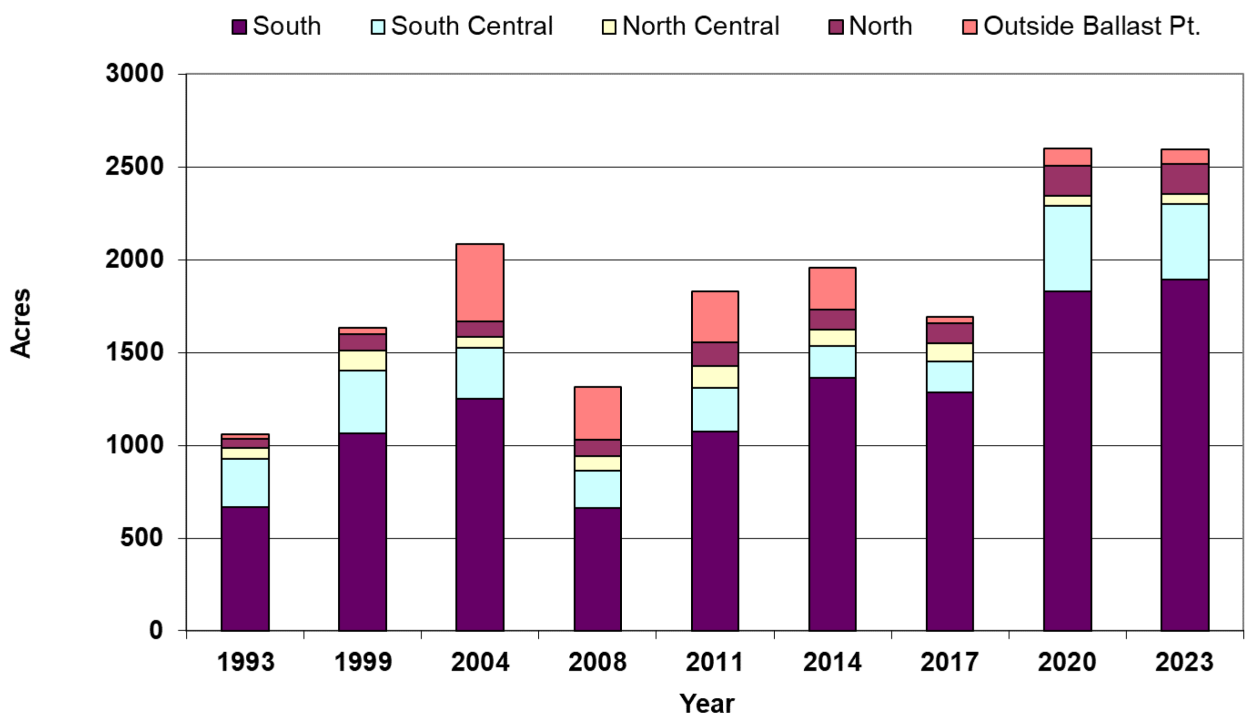


Figure 6. Eelgrass area distribution by ecoregion and baywide survey year.

Table 2. San Diego Bay eelgrass area distribution by ecoregion and survey year.

Eco-Region	**1993**	**1999**	**2004**	**2008**	**2011**	**2014**	**2017**	**2020**	**2023**
Outside Ballast Pt.	26.1	35.6	413.8	286.0	276.4	226.2	33.6	89.6	80.1
North	50.0	87.8	83.4	85.4	126.7	106.5	110.9	162.9	161.5
North Central	56.2	109.6	61.7	78.2	117.1	90.2	95.1	54.1	51.0
South Central	261.8	335.5	273.0	204.4	234.9	167.6	166.1	463.3	411.5
South	697.3	1065.1	1251.7	660.8	1075.2	1365.2	1287.1	1827.9	1891.3
TOTAL	**1091.4**	**1633.7**	**2083.7**	**1314.8**	**1830.4**	**1955.7**	**1692.8**	**2597.9**	**2595.4**

Despite recent periods of high variability of eelgrass, the long-term trend has been for increasing eelgrass coverage in San Diego Bay. The upward trend has a lot to do with the 2020 increase of over 900 acres of eelgrass from the 2017 eelgrass coverage and the continued persistence of these gains through 2023. The 2020 gains reflect a 53.5 percent survey-to-survey increase and is the single largest change in eelgrass coverage recorded over the monitoring program. Conversely, the 0.1 percent decline observed between the 2020 and 2023 surveys reflect the least amount of overall eelgrass change recorded during the monitoring program.

Over the past three decades of baywide inventories, there have been a number of large events that have shaped eelgrass distribution and coverage patterns. Several but not all of these have been captured in the baywide eelgrass inventory program. Most notable in Figure 6 is the substantial loss of eelgrass between 2004 and 2008. This loss appeared to be related to a combination of a 2005 El Nino Southern Oscillation (ENSO) event and a biologically mediated decline given the pattern of losses occurring in expansive high-density beds rather than in isolated less dense beds and the pattern of subsequent recovery. Similar anomalous declines in the region’s eelgrass beds were also observed in other systems such as Mission Bay (Merkel & Associates 2008a). Between 2014 and 2017, a significant decline in eelgrass was noted as a result of two potentially unrelated or possibly synergistic stressors that led to major declines. The first was a strong and persistent marine heat wave that led to record setting temperature during a strong 2015/2016 ENSO event and increased thermal stress on plants. The second is considerable wave impact damage to areas of eelgrass beds outside of Ballast Point. It is not known whether thermal stress and weakening of the integrity of the eelgrass beds made them more susceptible to storm damage, or whether the storm damage would have removed beds outside of the Bay, irrespective of the condition of these beds prior to the big wave south swell storms. What is not as evident in the data is the fact that eelgrass in 1999 was significantly depressed from conditions in 1996 due to the effects of the 1997-1998 ENSO event that resulted in loss of hundreds of acres of eelgrass in the central portion of the south Bay ecoregion (Merkel & Associates 2000).

The 2011 regional survey suggested that prior declines observed in the 2008 survey were reversing with expansion of eelgrass being observed during the survey. The 2014 survey provided evidence of continued recovery. However, the 2017 survey revealed a subsequent decline in eelgrass with the majority of the decline occurring in shallower portions of the Bay. The decline was a notable reduction in upper margins of eelgrass beds. The pattern of declines reported in 2017 has been completely reversed in the 2020 baywide survey with no discernible change in core areas of the beds occurring from 2020 through 2023. However, gains in eelgrass at lower bed elevations continued to be apparent between 2020 and 2023.

Changes in eelgrass extent within San Diego Bay are generally believed to be transitory responses to prevailing environmental conditions prior to the surveys and potentially extending through the survey period. However, over longer periods of repeated survey intervals, a robust picture of the system norm dilutes inter-survey variability. Depending upon the nature and scale of stressors that act on eelgrass, both the areas of the bed and the extent of bed gains and losses vary. To begin to illuminate the robust and less stable patterns of eelgrass distribution, a frequency distribution map has been prepared (Figure 7). This map presents the spatially explicit eelgrass persistence patterns within the Bay as percentage of the times during baseline surveys that an area supported eelgrass. The frequency of eelgrass presence is derived by dividing the number of times eelgrass was present at a particular raster location by the total number of baywide surveys conducted.

Figure 7. Eelgrass occurrence frequency for the baywide eelgrass (1993-2023).

As the number of surveys increases, the stability and variance in the map can be quantified. In the future, running averages will allow for distinguishing trends from interannual variability.

While the recent baywide surveys would suggest an overall long-term gradual increasing trend in habitat area within San Diego Bay (Figure 6), the real picture is more complicated. A closer review reveals that increases in eelgrass are driven by the net of gains and losses within different ecoregions of the Bay. Eelgrass habitat is marked by seasonal and inter-annual variability such that on a fine scale, gains and losses of eelgrass habitat occur throughout the Bay, and it is appropriate to consider the distribution of eelgrass in a more probabilistic sense (Merkel & Associates 2000). Thus, various portions of the Bay have a higher or lower probability of supporting eelgrass habitat at any given time. When evaluating the eelgrass frequency results (Figure 7), it is evident that some areas within the Bay had highly consistent presence of eelgrass, while other areas supported eelgrass only during one or two of the survey years. In some cases, the eelgrass frequency map indicates the presence of eelgrass within areas that are no longer suited to support eelgrass due to development that has occurred since the first surveys were conducted three decades ago.

From a resource management standpoint, it is appropriate to consider that areas that lack eelgrass during a particular survey period may support eelgrass at other times. Further, it is also reasonable to acknowledge that not all eelgrass beds provide the same consistency in habitat values and thereby ecological function through time. As such, planning efforts should consider both spatial and temporal characteristics of the resource when evaluating benefits or detriments that may occur as a result of land-use and habitat management decisions. Substantially more complicated is the need to consider effects of actions located outside of eelgrass beds on parameters that influence eelgrass habitat development or sustainability. These may include alterations to circulation patterns, or nutrient and sediment loading of the Bay.

The ability of eelgrass to weather short-term stressful environmental conditions has been demonstrated on a number of occasions through natural and experimental restriction of resource availability. However, prolonged stresses such as consistent light limitation will result in a decline in eelgrass habitat. Within most sub-tropical and temperate environments, desiccation stresses limit the upper edge of eelgrass growth, and light requirements needed to balance respiration and fuel metabolism (photo-compensation depth) set the lower limits of eelgrass growth in soft-bottom bays. This trend holds true in San Diego Bay; and as a result, a distinct topographic, but seasonally variable boundary typically defines the upper limit for eelgrass between 0.0 and +1.0 feet MLLW. A less distinct lower limit is defined by differences in depth and light penetration. The addition of potential biologically limiting factors on bed distributions creates a new complication to the standard model for eelgrass distribution patterns in San Diego Bay.

The differing survey methods used prior to 1993 prevent in-depth comparisons of longer-term trends in San Diego Bay eelgrass abundance. However, on a decadal scale, eelgrass does appear to have historically expanded in its range in the Bay when compared to the best estimates that can be made from prior historic surveys and ancillary historic photographs and data. Eelgrass expansion within the Bay is likely the result of improved water quality and restoration efforts. Raw-sewage and industrial-waste discharges into the Bay have been significantly reduced since the 1970s (SDUPD and California State Coastal Conservancy 1990, USFWS 1998). The improved water quality has resulted in lower total particulate matter that would otherwise decrease light availability for eelgrass. Additionally, stresses related to nutrient enrichment leading to plankton and macroalgal blooms have declined with reductions in waste discharges.

Recent expansions of eelgrass into deeper portions of the Bay have been coupled with emerging changes in bed biomass and canopy morphology. Eelgrass within the Bay is becoming shorter in stature and leaf widths are substantially narrowing within San Diego Bay as well as in other low influx embayments in Southern California, such as Mission Bay. In the 1990s through at least the early 2010s the eelgrass canopy throughout most of the subtidal depths of the south and south-central Bay was typically about 500 – 700 mm in height (K. Merkel, pers. obs.). However, recent bed sampling associated with blue carbon investigations have found the eelgrass canopy to be approximately half this height throughout the Bay. Further, during the 2021-2023 investigations leaf widths were also found to be reduced to a scale where marking leaves for growth rate calculation was hindered (ESA et al. 2023).

The shrinking canopy height and narrowing leaf width has been coincident with expanding spatial distribution of eelgrass. Unfortunately, since canopy height and leaf width have not been systematically tracked, the often lauded gains associated with trajectory of expansion of beds has not been tempered with a realization that the biomass of eelgrass and the complexity of canopy structure may actually be concurrently diminishing in the Bay. It is hypothesized that the declining stature of eelgrass concurrent with expanding cover is likely related to reducing nutrient supply being delivered to the Bay. This may be related to both the long-term drought that has prevailed for over 11 years, and increased run-off controls within the surrounding watersheds that discharge to the bays. There are multiple lines of evidence that would suggest that this hypothesis may be correct. First, similar patterns of declining stature are being seen in cordgrass marsh within San Diego Bay, as well as within other southern California bays such as Mission Bay and Newport Bay. Turbidity levels within San Diego Bay have reached long-term low levels, regularly averaging below 1 NTU compared to levels typically above 5 NTU more than a decade ago. Presently, investigations are underway by the Navy and Port to test the hypothesis that nutrient loading is limiting eelgrass canopy mass. This includes both observational data collection at nutrient enriched (storm drains or bird roosting areas) and non-enriched areas, as well as through fertilizer application studies within test plots distributed through the Bay.

The long-term monitoring program for eelgrass in San Diego provides an important and insightful view of eelgrass not as snapshots in time, but rather as a persistent, however, dynamic resource. To make full use of this monitoring program as a tool in assessing environmental trends, it is critical that it be continued into the future. In addition to the baywide surveys that are conducted on an approximately 3-5 year cycle, the Navy and Port also complete more frequent semiannual surveys of indicator transects. In order to optimize the value of the transect surveys as a supplement to the less frequent baywide surveys, the transect monitoring and methodology has been adjusted in recent years and coupled with defined bay segments. This allows the transect monitoring conducted during intervening years between baywide surveys to be used to develop estimators of overall eelgrass presence and eelgrass extent by Bay segment (Merkel & Associates 2022a). This program has been modeled after a similar effort that has been developed and tested in San Francisco Bay and which has now been applied for management purposes in the past several years (Merkel & Associates 2008b, 2011b, 2013, 2018a). This supports the broader efforts to implement regional eelgrass monitoring for the Southern California Bight (Bernstein et al. 2011).

USE OF THESE EELGRASS MAPS

Poster versions of the eelgrass inventory maps are provided in Appendix 1. Because of the level of error inherent in regional mapping, these data should only be used as a general measure of the health of the system over time and as a planning tool. Eelgrass data reflect a particular period in time and are anticipated to be seasonally and stochastically dynamic. Information cannot be extrapolated for impact assessment purposes or site-specific uses. While maps are generally accurate with respect to location of eelgrass, it is clear that eelgrass within San Diego Bay is dynamic. For this reason, it is essential that these maps not be over applied to situations for which they are not suited.

Eelgrass maps and bathymetric data are for planning and resource management purposes only and are not to be used for project specific analyses or navigation purposes. The authors make no representation regarding the accuracy of these maps for navigation applications.

RECOMMENDATIONS

The current baywide monitoring serves well to provide an additional benchmark for assessment of bed distribution change within San Diego Bay. This is the ninth such comprehensive survey conducted in thirty years (1993-2023) and has provided tremendous value in assessment of change in eelgrass distribution patterns and dynamics on a bay scale. However, there remains room for improvement to and advancement of this monitoring effort that would further the insights into eelgrass dynamics and trends. These improvement opportunities and recommendations are provided below with associated benefits behind each recommendation.

1) Develop updated bathymetry for the Bay and develop a new composite bathymetric elevation spatial data layer for the Bay. The present baywide bathymetry was prepared in 2008 as a hybridization of the best available bathymetric data over large portions of the Bay. This was combined together, identifiable errors were removed, and missing data infill was completed by new bathymetric data collection. The principal objective of this effort was to provide a comprehensive and corrected bathymetry to support physical and ecological modeling for the bay. Unfortunately, by the nature of data fusion, some of the data sets represented in the 2008 composite bathymetry were originally collected in the 1990s and are thus aging. In addition, not all of the data were of comparable resolution and thus there is considerable variability in the resolution of the data used to develop the composite. Finally, there has been many cycles of maintenance dredging in various areas, and some sizable new dredging and filling efforts undertaken since the effort was completed. While these changes would likely have limited influence on baywide circulation, they will effect analysis of changes in the Bay that relate to shoreline slopes and Bay elevations. This includes evaluation of eelgrass depth distribution, capacity for eelgrass expansion, effects of sea level rise on eelgrass, and opportunities for implementation of sea level rise adaptation strategies for the natural and built environments. This refreshed bathymetric survey would also support future hydrodynamic and ecological modeling efforts such as those being completed in recently for San Francisco Bay.

2) Augment the baywide survey with *in situ* eelgrass bed condition metric data collection. The present monitoring program provides good information on the distribution of eelgrass beds within San Diego Bay but it does not capture the condition of beds relative to some of the functions eelgrass provides or the health of the beds. The goal of this recommended effort would be to augment the monitoring program with systematic sampling that is distributed across the beds in a manner that allows for estimating the overall character and condition

of the Bay's eelgrass resources. It is recommended that in situ sampling efforts be distributed across the Bay eelgrass beds by sampling eelgrass, where it occurs on the 37 baywide monitoring transects. Sampling should be conducted at every 5-foot contour elevation on which eelgrass is present (e.g., 0, 5, 10, 15 ft MLLW), with data kept separate by depth and location for subsequent analysis. The sampling should be conducted in summer-fall (August-October) and should include collection of the following information: shoot height, leaf width, shoot density, % flowering, % epiphytic loading, % sediment loading, leaf color and turgor, and % wasting disease. Using these data, the bay segmentation applied to baywide transect monitoring, bathymetry for the bay, and allometric modelling for biomass, analyses should be added to the monitoring program to estimate the eelgrass canopy biomass and distribution throughout the Bay. This will greatly assist in understanding how the Bay's eelgrass beds differ geographically and eventually temporally, as functional habitat, generators of detrital organic matter, and relative to carbon storage and cycling. These data will also be useful in assessing how different environmental stressors affect beds in different portions of the Bay.

3) As advances in understanding carbon sequestering capacity, cycling, and plant-sediment contributions to managing environmental carbon stores develops, it would be beneficial to incorporate module connections between the eelgrass inventories and carbon management values of eelgrass throughout the Bay. While it is premature to fully integrate these two elements at this time, it is valuable to start working on crossover tools to quantify eelgrass functions for carbon management, and to better understand how the eelgrass dynamics within the bay affect carbon storage, and cycling. Recommendation 2 above will advance this effort significantly, but it would need to be further developed and tested further to make full use of this as a carbon tracking tool.

LITERATURE CITED

Bernstein, B, K. Merkel, B. Chesney, and M. Sutula. 2011. Recommendations for a Southern California Regional Eelgrass Monitoring Program. Southern California Coastal Water Research Project. Tech. Report 632 – May 2011.

Environmental Science Associate (ESA), Merkel & Associates, and Dave Tomasko. 2023. San Diego Bay Eelgrass Blue Carbon Study 2021-2023. Prepared for Port of San Diego under funding provided by the Maritime Administration (MARAD).

Lockheed Center for Marine Research. 1979a. Biological Reconnaissance of Selected Sites of San Diego Bay. March 1979.

Lockheed Center for Marine Research. 1979b. Preliminary Report on Spatial Distribution of *Zoobotryon verticillatum*, *Zostera marina*, and *Ulva spp*. in South Bay. September 1979.

Merkel, K.W. 1988. Mission Bay Eelgrass Inventory and Marine Habitat Survey, September 1988. Prepared for the City of San Diego, San Diego, California. December 1988.

Merkel, K.W. 1992. Mission Bay Eelgrass Inventory, September 1992. Prepared for the City of San Diego, San Diego, California.

Merkel & Associates. 2000. Environmental Controls on the Distribution of Eelgrass (*Zostera marina L.*) in South San Diego Bay: An Assessment of the Relative Roles of Light, Temperature, and Turbidity in Dictating the Development and Persistence of Seagrass in a Shallow Back-Bay Environment. Prepared for Duke Energy South Bay, LLC. San Diego, California.

Merkel & Associates. 2005. San Diego Bay 2004 Eelgrass Inventory. Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California.

Merkel & Associates. 2008a. Mission Bay Park Eelgrass Inventory and Bathymetric Change Analysis October 1988, 1992, 1997, 2001, and 2007. Prepared for: City of San Diego. San Diego, California.

Merkel & Associates. 2008b. Baywide Eelgrass (*Zostera marina L.*) Distribution and Status within San Francisco Bay: Program Development and Testing of a Regional Eelgrass Monitoring Strategy. Prepared for California Department of Transportation and NOAA National Marine Fisheries Service. December 2008.

Merkel & Associates. 2009. 2008 San Diego Bay Eelgrass Inventory and Bathymetry Update. Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California.

Merkel & Associates. 2011a. 2011 San Diego Bay Eelgrass Inventory Update. Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California.

Merkel & Associates. 2011b. Eelgrass Distribution and Status within San Francisco Bay – 2011 Regional Eelgrass Monitoring Results. Prepared for National Marine Fisheries Service, Southwest Region Habitat Conservation Division. November 2011.

Merkel & Associates. 2013. Eelgrass Distribution and Status within San Francisco Bay – 2013 Regional Eelgrass Monitoring Results. December 2014.

Merkel & Associates. 2014. 2014 San Diego Bay Eelgrass Inventory and Bathymetry Update.

Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California.

Merkel & Associates. 2017a. Humboldt Bay Eelgrass Comprehensive Management Plan. Prepared for Humboldt Bay Harbor, Recreation, and Conservation District and U.S. Environmental Protection Agency (October 2017).

Merkel & Associates. 2017b. 2017 Tomales Bay Eelgrass Inventory, Tomales Bay, CA. Prepared for NOAA Greater Farallones National Marine Sanctuary (December 2017).

Merkel & Associates. 2017c. 2016 Southern California Bight Regional Eelgrass Surveys. Prepared for: NOAA National Marine Fisheries Service, West Coast Region Protected Resources Division. (March 2017).

Merkel & Associates. 2018a. Eelgrass Distribution and Status within San Francisco Bay – 2017 Regional Eelgrass Monitoring Results.

Merkel & Associates. 2018b. 2017 San Diego Bay Eelgrass Inventory Update. Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California

Merkel & Associates. 2020. 2020 San Diego Bay Eelgrass Inventory and Bathymetry Update. Prepared for: U.S. Navy and San Diego Unified Port District. San Diego, California.

Merkel & Associates. 2022a. 2022 Eelgrass Surveys to Support National Marine Sanctuary Management, Tomales Bay, Marin County, CA. Prepared for: Greater Farallones and Cordell Bank National Marine Sanctuaries. San Francisco, California.

Merkel & Associates. 2022b. Evaluation of Temporal and Spatial Changes of Eelgrass Beds within San Diego Bay using Permanently Monitored Transects. Prepared for: Naval Facilities Engineering Command. San Diego, California.

Merkel & Associates. 2024. San Diego Regional Eelgrass Surveys. Prepared for San Jose State University Research Foundation and San Diego Regional Water Quality Control Board. San Diego, California.

NOAA Fisheries, West Coast Region. 2014. California Eelgrass Mitigation Policy and Implementing Guidelines. October 2014.

SDUPD (San Diego Unified Port District). 1979. San Diego Bay Eelgrass Distribution 1975-1979. *In*, Draft Environmental Impact Report, Master Plan San Diego Unified Port District. September 1979.

SDUPD (San Diego Unified Port District) and California State Coastal Conservancy. 1990. South San Diego Bay Enhancement Plan. 4 volumes. Prepared by Michael Brandman Associates, Inc.

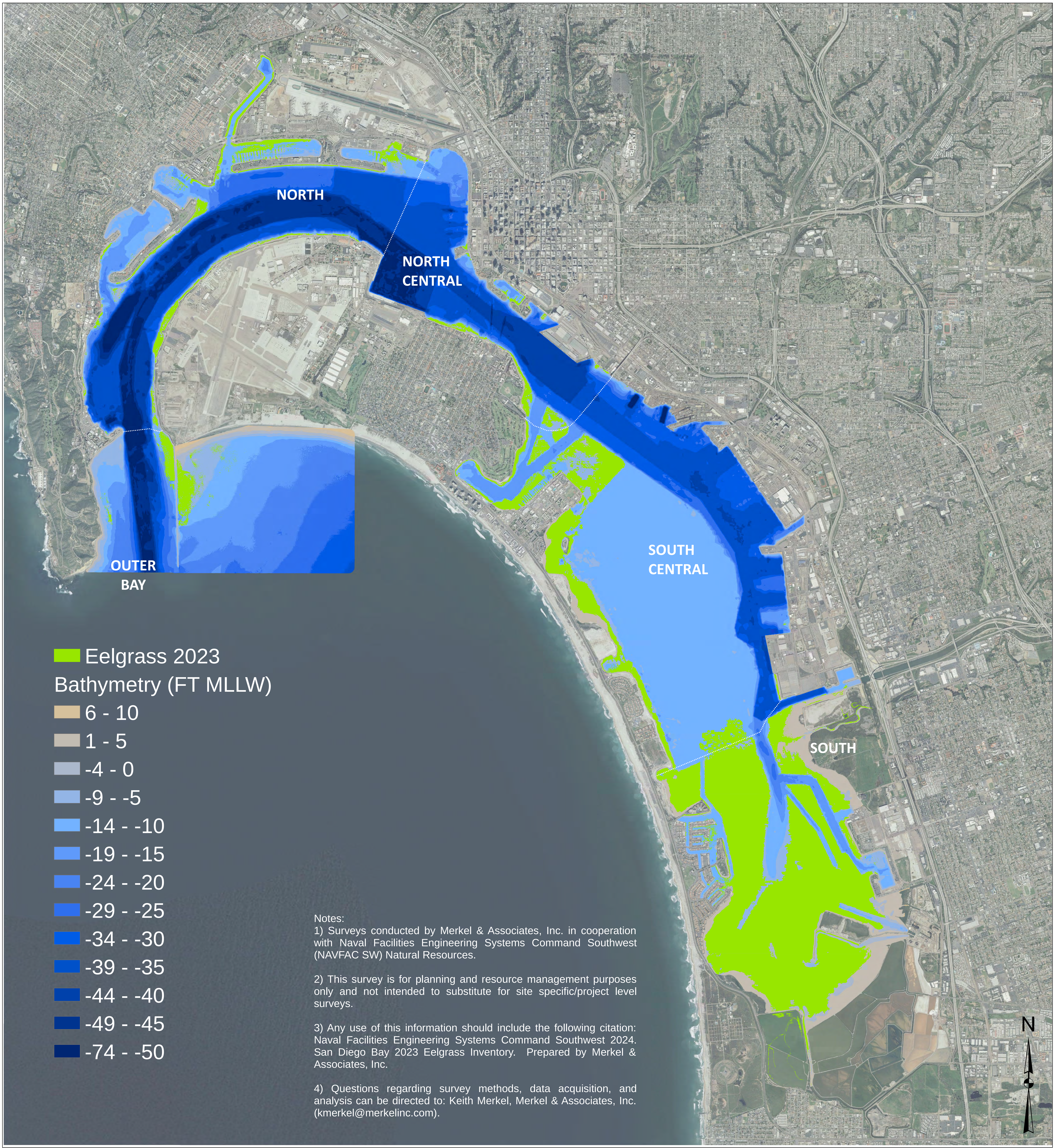
[USFWS] United States Fish and Wildlife Service. 1998. Proposed South San Diego Bay Unit, National Wildlife Refuge. Draft Environmental and Land Protection Plan.

[U.S. Navy] U.S. Department of the Navy, Naval Facilities Engineering Command Southwest. 1994. Bathymetric and Eelgrass Survey of San Diego Bay, California 1993. Southwest Division Natural Resource Branch.

U.S. Navy. 2000. 1999 San Diego Bay Eelgrass Survey. Southwest Division Natural Resource Branch.

U.S. Navy and Port of San Diego. 2013. San Diego Bay Integrated Natural Resources Management Plan, Final September 2013. San Diego, California. Prepared by Tierra Data Inc., Escondido, California.

APPENDIX 1. EELGRASS DISTRIBUTION - 2023



Notes:

1) Surveys conducted by Merkel & Associates, Inc. in cooperation with Naval Facilities Engineering Systems Command Southwest (NAVFAC SW) Natural Resources.

2) This survey is for planning and resource management purposes only and not intended to substitute for site specific/project level surveys.

3) Any use of this information should include the following citation: Naval Facilities Engineering Systems Command Southwest 2024. San Diego Bay 2023 Eelgrass Inventory. Prepared by Merkel & Associates, Inc.

4) Questions regarding survey methods, data acquisition, and analysis can be directed to: Keith Merkel, Merkel & Associates, Inc. (kmerkel@merkelinc.com).

0 0.5 1 2 3 4 5 6 Kilometers

0 0.5 1 2 3 4 Miles

Navy Region Southwest — One Team, One Voice, One Mission

PORT of SAN DIEGO Environment

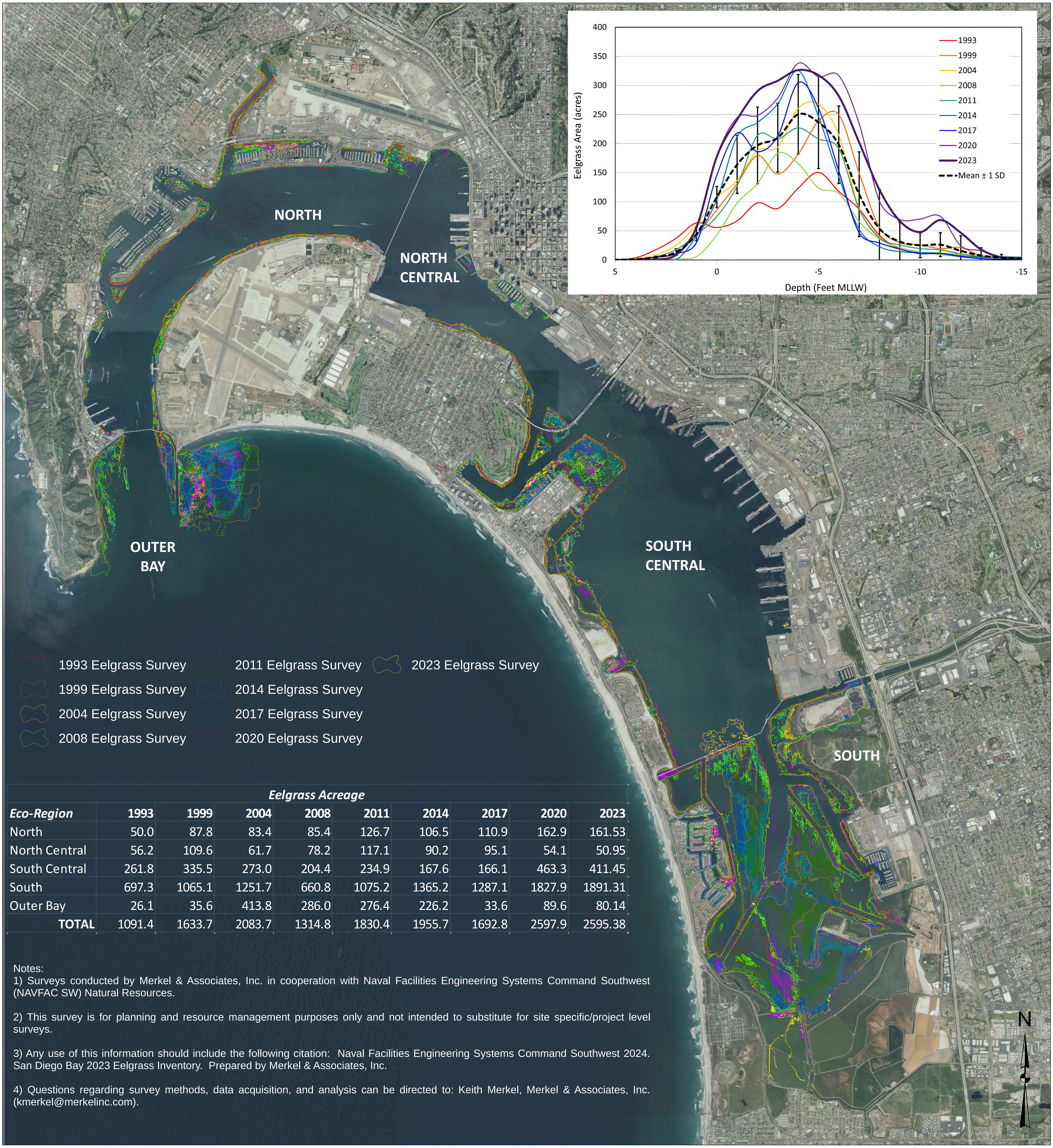
SAN DIEGO BAY

2023 EELGRASS INVENTORY

NAVFAC Naval Facilities Engineering Systems Command

Merkel & Associates

APPENDIX 2. EELGRASS DISTRIBUTION MAP - 1993-2023



Eelgrass Acreage									
Eco-Region	**1993**	**1999**	**2004**	**2008**	**2011**	**2014**	**2017**	**2020**	**2023**
North	50.0	87.8	83.4	85.4	126.7	106.5	110.9	162.9	161.53
North Central	56.2	109.6	61.7	78.2	117.1	90.2	95.1	54.1	50.95
South Central	261.8	335.5	273.0	204.4	234.9	167.6	166.1	463.3	411.45
South	697.3	1065.1	1251.7	660.8	1075.2	1365.2	1287.1	1827.9	1891.31
Outer Bay	26.1	35.6	413.8	286.0	276.4	226.2	33.6	89.6	80.14
TOTAL	1091.4	1633.7	2083.7	1314.8	1830.4	1955.7	1692.8	2597.9	2595.38

Notes:
1) Surveys conducted by Merkel & Associates, Inc. in cooperation with Naval Facilities Engineering Systems Command Southwest (NAVFAC SW) Natural Resources.

2) This survey is for planning and resource management purposes only and not intended to substitute for site specific/project level surveys.

3) Any use of this information should include the following citation: Naval Facilities Engineering Systems Command Southwest 2024. San Diego Bay 2023 Eelgrass Inventory. Prepared by Merkel & Associates, Inc.

4) Questions regarding survey methods, data acquisition, and analysis can be directed to: Keith Merkel, Merkel & Associates, Inc. (kmerkel@merkelinc.com).

0 0.5 1 2 3 4 5 6 Kilometers

0 0.5 1 2 3 4 Miles

Navy Region Southwest — One Team, One Voice, One Mission

NAVFAC Naval Facilities Engineering Systems Command

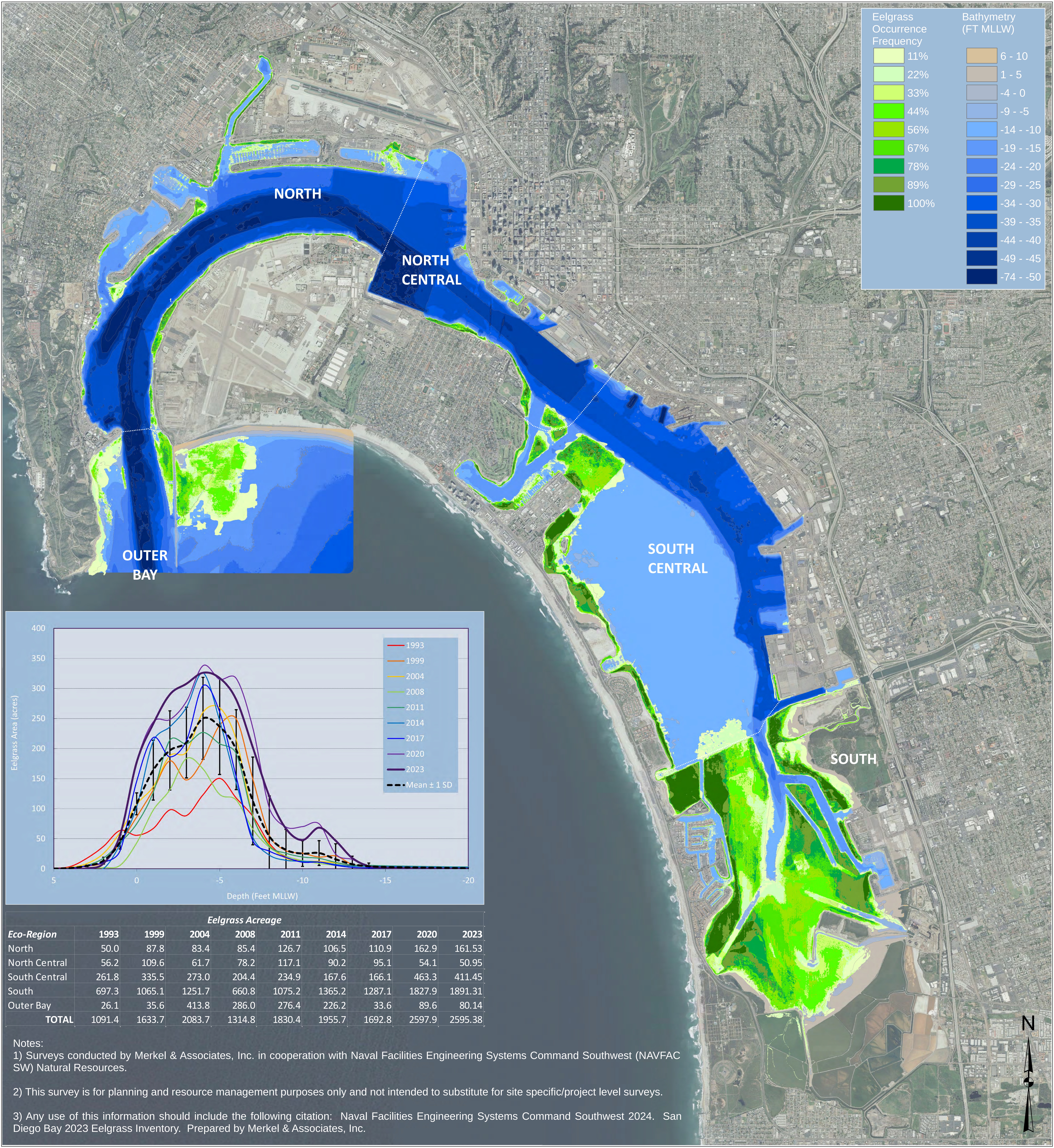
PORT of SAN DIEGO Environment

SAN DIEGO BAY

2023 EELGRASS INVENTORY

Merkel & Associates

APPENDIX 3. EELGRASS FREQUENCY MAP - 1993-2023



	Eelgrass Acreage								
Eco-Region	**1993**	**1999**	**2004**	**2008**	**2011**	**2014**	**2017**	**2020**	**2023**
North	50.0	87.8	83.4	85.4	126.7	106.5	110.9	162.9	161.53
North Central	56.2	109.6	61.7	78.2	117.1	90.2	95.1	54.1	50.95
South Central	261.8	335.5	273.0	204.4	234.9	167.6	166.1	463.3	411.45
South	697.3	1065.1	1251.7	660.8	1075.2	1365.2	1287.1	1827.9	1891.31
Outer Bay	26.1	35.6	413.8	286.0	276.4	226.2	33.6	89.6	80.14
TOTAL	1091.4	1633.7	2083.7	1314.8	1830.4	1955.7	1692.8	2597.9	2595.38

Notes:
1) Surveys conducted by Merkel & Associates, Inc. in cooperation with Naval Facilities Engineering Systems Command Southwest (NAVFAC SW) Natural Resources.

2) This survey is for planning and resource management purposes only and not intended to substitute for site specific/project level surveys.

3) Any use of this information should include the following citation: Naval Facilities Engineering Systems Command Southwest 2024. San Diego Bay 2023 Eelgrass Inventory. Prepared by Merkel & Associates, Inc.

SAN DIEGO BAY

2023 EELGRASS INVENTORY