Richardson's Bay Regional Agency

Ecologically-based Mooring Feasibility Assessment and Planning Study

Prepared for:

Richardson's Bay Regional Agency

c/o Marin County Community Development Agency,

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PREFACE

Merkel & Associates, Inc. (M&A) was retained by the Richardson's Bay Regional Agency (RBRA) to prepare an ecologically-based mooring feasibility and planning study to evaluate the nature and scale of ecological impacts associated with moorings and anchor-outs and to determine if there are feasible means to ameliorate the conflicts while retaining moorings. In submitting this mooring feasibility and planning study, our objective has been to provide defensible data on which to base actions and recommendations, or ranges of recommendations, for actions.

Over time there has been considerable contention related to moorings in Richardson Bay and we do not expect unanimous agreement as to the best course of action when all factors presented in this study are considered. Further, there are many factors that must be weighed beyond those within the scope of the requested planning study such as social considerations, culture and heritage, environmental justice, regulations and policy, as well as land-use, planning, and available services.

For these reasons, it is important to advise that authors have taken a narrow role in exploration of means of reducing or eliminating existing ecological conflicts associated with moorings. This effort has been informed through interviews and interactions with affected representatives of varying interests, field investigations, and document research. Through these efforts, we have developed strategies that we believe provide workable solutions to ecological conflicts. The recommendations also integrate insights into the factors constraining various options. However, the solutions are not all encompassing in that they are very explicitly focused on one aspect of vessel mooring and anchor-out issues.

There has been considerable effort put into development of a self-governance system for the waters of Richardson Bay. This effort has been mainly, but not exclusively, invested as an effort of self-preservation by a community that is diverse and generally poorly represented and which fears future actions that may result in the demise of the anchor-out community in Richardson Bay. However, we believe that such a self-governing system cannot be successful without greater shared interests within the community and adequate enforcement tools and on the ground resources. Notwithstanding trepidation about the ability to effectively police management activities with current allocated resources, the self-governance concepts provide many elements of the structure and commitment of the engaged parties that can, and should, play an important role in ensuring effective management of moorings, should moorings be retained in the bay. Further, success of any management measures would require effective long-term implementation efforts and enforceable regulations.

Having completed the study, it is the authors' opinions that the solutions proposed are technically workable, would resolve ecological conflicts, and would allow continued presence of moorings while substantially or fully eliminating ecological impacts associated with the anchor-out moorings. We are equally convinced that there are things about the solutions posed that will be disliked by all, but that the dislikes will vary across different slices of the community.

The present study is an informational document rather than a decision document. This means that it provides information to end users on which to base further actions. Truth be told, resolving ecological conflicts while maintaining moorings and anchor-out opportunity is a far easier task than obtaining consensus on an ultimate action to be undertaken. With the conclusion of this study, there remains considerable need for planning, regulatory and policy consideration and potential conflict resolution, environmental review, and ultimately decision making on the part of many entities. It is also important to keep in mind that the recommendations made in this document rely on vigilant management and enforcement to be successful which is why the recommendations seek to embrace a community involvement in implementation of the management process.

Richardson's Bay Regional Agency

Ecologically-based Mooring Feasibility Assessment and Planning Study

TECHNICAL APPROACH

Purpose

The overall purpose of this mooring feasibility and planning study is to provide informed recommendations regarding the feasibility of retaining moorings, resolving conflicts between moorings and natural resources, and determining the sustainable capacity, suitable locations, and design for moorings in Richardson Bay that will avoid or minimize damage to natural resource values. In addition to the broad questions of where moorings should and should not be located, there are logistical considerations of what shore access, shoreline infrastructure, services, and mooring management activities would be recommended to facilitate the purpose of protecting natural resources in the context of mooring establishment and uses in the bay.

Overall Approach

The overall approach to the planning study is one of spatial analyses wherein data are accumulated and digested down to spatial data layers that may be used to investigate, identify, and quantify existing conflicts and opportunities for conflict resolution between natural resources and moorings. From this evaluation process, the locations and magnitude of existing conflicts was identifiable and opportunities for both spatial and design resolution of conflicts have been identified. It was anticipated that gaps in existing data or knowledge about conflicts would be identified and as much as practical, filled through additional information gathering. Where data gaps remain, these have been acknowledged and the relative importance of the gaps to the study conclusions and management recommendations has been discussed.

The area evaluated in this study included the waters within the RBRA Special Area Plan Boundary excluding the Richardson Bay Audubon Sanctuary, the federal navigation channel, and developed marinas (Figure 1). The waters within the study area fall under the RBRA member agency local jurisdictions of the County of Marin and cities of Belvedere, Tiburon, and Mill Valley. The study area also includes waters within the City of Sausalito.

The study area extends from waters that are too shallow to support moorings within the waters of Mill Valley and east and west of the Strawberry Peninsula out to deeper waters of San Francisco Bay at the west end of Raccoon Strait.

This study has been structured around a data collection phase, analyses and conflict identification between ecological resources and moorings, and conflict resolution seeking to identify means and opportunities to resolve conflicts through changes in mooring locations, changes in mooring methods, and identification of operational and management needs. This planning study identifies recommended management actions based on known information and identifies recommended actions based on general ecological, physical, engineering, planning, and regulatory principles.

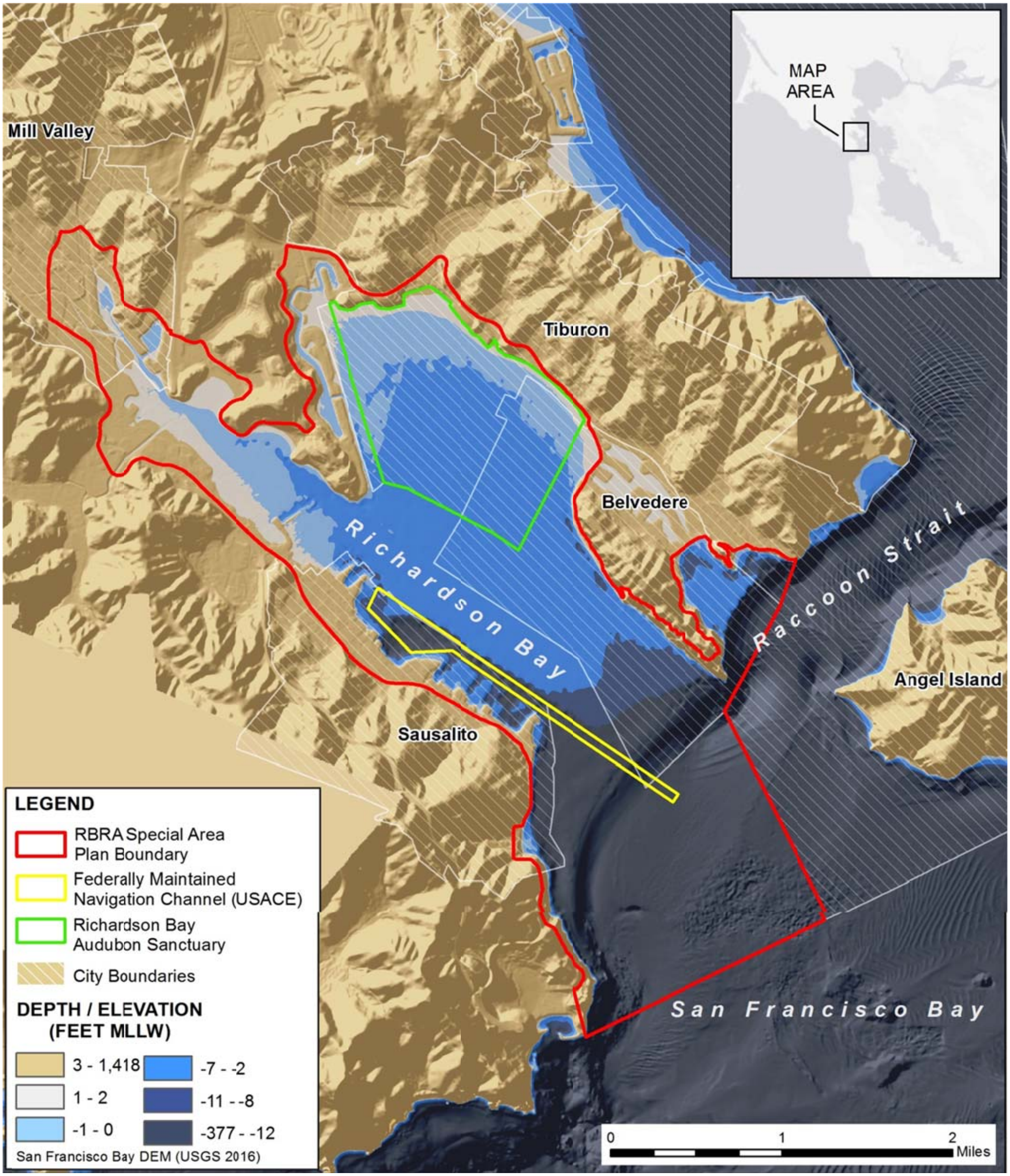


***Figure 1. Richardson's Bay Regional Agency Special Area Plan**. The study area is bounded by deepwater of Raccoon Strait, shallow water of the Mill Valley western finger of the bay, and closed waters of the Audubon Sanctuary. In addition, the federal navigation channel and developed waterside lands further constrain the operative study area*

Some of the most salient operating assumptions that have been defined in the study are:

- Existing shoreside landings would remain unchanged in Sausalito; however, other potential landings elsewhere should be evaluated if they can be identified;
- The study excludes evaluation of suitability or adequacy of shoreside support facilities, but rather evaluates potential issues of impact from transit to and from shoreside landings as well as distances of travel between moorings and landings;
- The study is intended to answer questions related to whether ecological resource protection can be achieved concurrently with mooring retention. However, there is no specific number or scale of moorings that should be targeted for accommodation;
- If moorings may be accommodated in a manner protective of ecological resources, the study should make recommendation as to where moorings could be situated and what mooring tackle would be appropriate for the moorings;
- The study should seek to identify the mooring carrying capacity of the RBRA Special Area;
- The study explicitly does not intend to address whether moorings should or should not be retained, and finally;
- The study does not address land-use, regulatory, social, or political issues associated with mooring elimination, retention, relocation, or scaling.

STUDY METHODS

Information Gathering

Outreach for Ecological and Mooring Information

From February through April 2019 interviews were held with many individuals representing diverse backgrounds and providing varied insights into the moorings. The subject matter of interviews ranged from ecological observations including eelgrass, marine mammal, bird, and herring spawning activities in and around the moorings to mooring life. Interviewees included residents of vessels on moorings, agencies administering waters (RBRA and City of Sausalito), social welfare representatives, and concerned environmental groups (Audubon California and Marin Audubon Society). Over 20 individuals were interviewed, some on multiple occasions. Tours of the moorings were also taken separately with environmental advocates, enforcement agencies, and research scientists. However, the interview process should not be considered exhaustive but the interactions do provide a good perspective on life on moorings, systemic challenges faced by those on and off moorings as well as issues resulting from the moorings. In addition, the interviews provide insights into governance and enforcement efforts and the complexity of issues associated with both.

Interviews were either coordinated directly by M&A with stakeholder parties, or were advertised to the anchor-out community by RBRA as a means to seek information through informal sit-down discussions at the local Sausalito waterfront restaurant, Taste of Rome.

Ecological and Physical Data Collection

Ecological and physical data collection included multiple avenues of information gathering. These were:

- Collection of previously released study information;
  - Many years of bird survey data from the Richardson Bay Audubon Sanctuary, Audubon Christmas Bird Counts, eBird, and Point Blue data base records
  - Baywide eelgrass survey data from 2003, 2009, and 2014
  - Areas specific eelgrass surveys from 2013 and 2018
  - Herring spawning information from California Department of Fish & Wildlife
  - Marine mammal data from Golden Gate Cetacean Research
  - Water quality data from the Regional Water Quality Control Board
  - Physical wave field model data from Our Coast Our Future (OCOF)
  - Other data garnered from reports of various types focused on conditions of Richardson Bay as discussed in this study document

- Collection of information through interviews of stakeholders;
  - Data collection included accumulation of anecdotal observation data on marine mammals and birds, herring spawning
  - Data on mooring designs in use within the anchorage and specific as well as general issues with moorings related to cost, mooring effectiveness, failure points, and frequency of vessel breakaway
  - Data on the nature of vessels on the moorings including ownership, seaworthiness, waste management strategies
  - Information on dinghy travel routes and use, vessel distribution on moorings, and logic behind mooring location selection
  - Effectiveness of community support and policing on the water

    - Perspectives on the limitations and constraints to effective management and servicing of anchor-outs

- Original data collection and data mining from previously collected data
    - Completion of a 2019 comprehensive survey to collect eelgrass and bathymetric data
    - Reprocessing of prior eelgrass survey data to extract higher resolution eelgrass distribution information than incorporated in baywide and regional survey reporting
    - Aerial imagery review and extraction of data on the number and locations of moored vessels on the bay through time
    - Digitizing of historic bathymetric chart data, boundaries, and survey features and resources for spatial analyses purposes

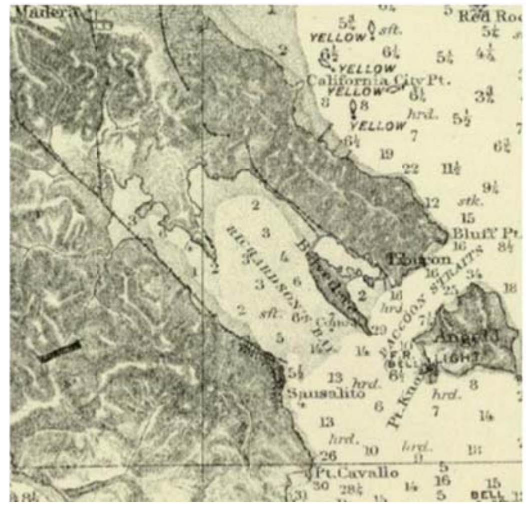
Wherever practical, accumulated data were geographically plotted to allow for the spatial analysis. This included plotting of biological and physical features, vessel moorings and landings, land and water use constraint areas, etc. In addition, temporal elements of the data were also captured by segregating information by time steps so that conditions could be viewed as a function of time.

Planning Process

Existing Setting Characterization

Bay Nomenclature

Richardson Bay is named after Captain William Anthony Richardson, an English whaling captain that married the daughter of the Commandant of the Presidio of San Francisco, Ygnacio Martinez, in 1826. Richardson was an important figure in the San Francisco bay maritime ventures and even served as the Captain of the Port of San Francisco. In 1838, Richardson received a 19,500-acre Mexican land grant over Rancho Saucelito. A significant portion of what is now called Richardson Bay fell within this land grant and the bay was given the name of Richardson's Bay with a possessive tense. This name was the common period vernacular and was present on some but not all historic maps of the bay. For instance the Alden chart of San Francisco Bay drafted in 1856 uses Richardson Bay while the 1908 Earthquake Investigation Commission chart uses Richardson's Bay to describe the area. As a convention, United States Board on Geographic Names created in 1890 adopted a convention of omitting the possessive tense from place names and thus more current period maps and place name reference recognize the bay as Richardson Bay. The RBRA has retained the traditional nomenclature of the Bay. This study follows the applicable conventions used for proper names, published references, and published maps. The possessive and non-possessive nomenclature is intended to be synonymous.



Richardson's Bay remained in some use on maps in the early part of the twentieth century as indicated in this 1908 Earthquake Investigation Commission map.

Physical Setting

Geomorphology and Bathymetry

Richardson Bay is a shallow soft bottom embayment of San Francisco Bay. The bay supports principally marine deposited sediments of silts and clays with a sandy sediment transition to deep waters of Raccoon Strait along the southern margin of Richardson Bay. The mud deposits are young Bay Muds of the Holocene Age (less than 10,000 years). Cone Rock is the single rocky protrusion rising through the bay muds to the surface of the water. However, the margins of the bay are defined by similar rocky features including the Strawberry Peninsula, Peninsula Pt. at Belvedere and Saucelito Pt. in Sausalito.

San Francisco Harbor surveyed by Lt. James Alden, U.S. Navy 1856 (published by British Admiralty, London). Soundings are in fathoms.

- Historic Conditions

Richardson Bay has historically been a shallow soft bottom embayment of the Bay bounded on the south by deep waters of Raccoon Strait and surrounded by the hills of Marin County. The embayment was surrounded by coastal salt marsh that extended from Richardson Bay into Belvedere Cove resulting in an isolated Belvedere Island of what is now western Belvedere connected to the remainder of the Tiburon Peninsula by a narrow sand tombolo crossing the marsh lands (Figure 2). A circuitous channel crossed through the bottom of the bay flats extending bayward from the small western creeks of Arroyo Corte Madera del Presidio and Coyote

Creek. The channel, while not easy to detect from the point sounding map of 1859 curved around Strawberry point and extended slightly northward and then south to the bay within the eastern lobe of the bay where it crossed the bay to the east and hugged Belvedere Island traveling to the deeper waters of the bay in Raccoon Strait. This channel formed during a period when sea level was lower and the creek crossed a shallow flat valley.

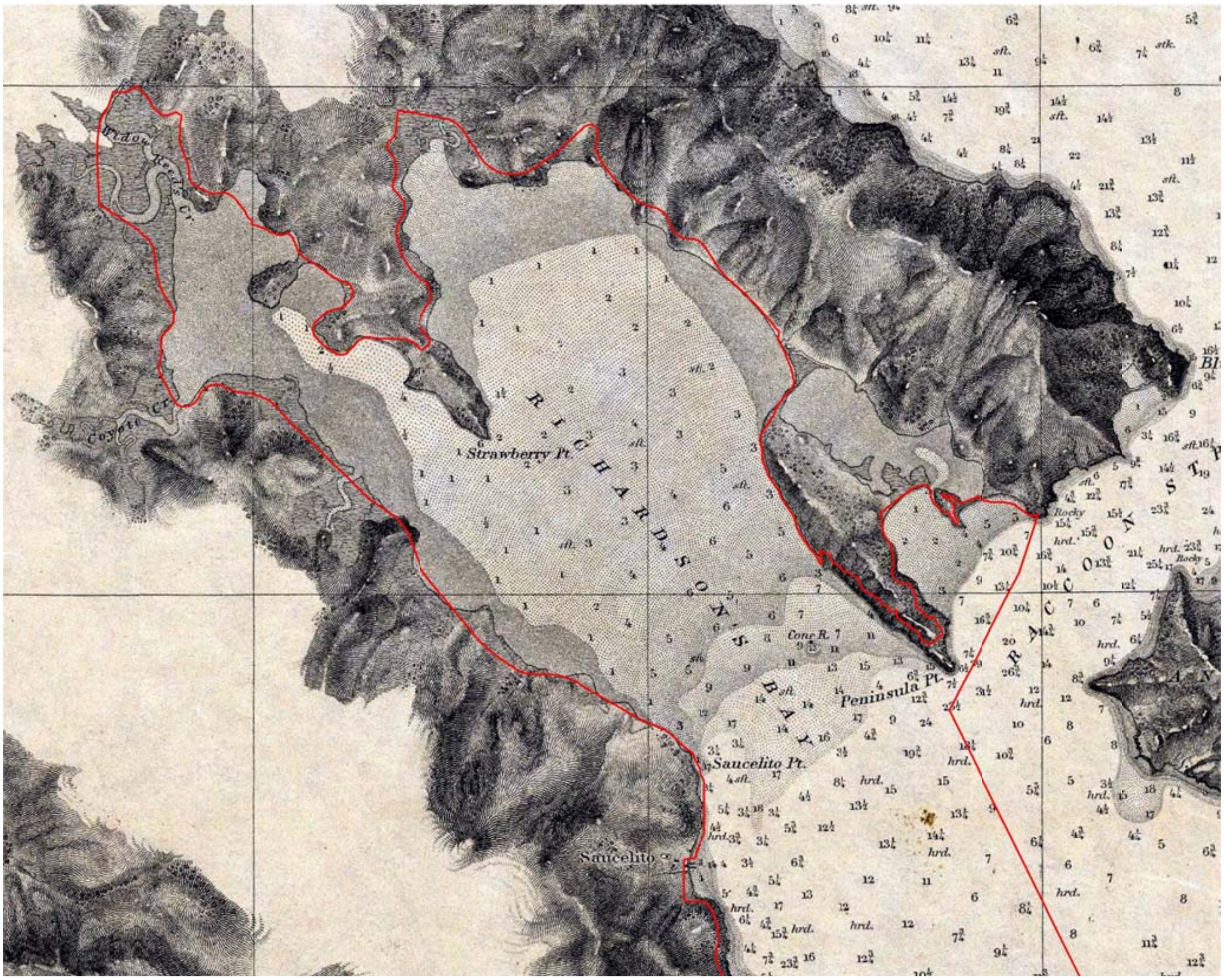


Figure 2. 1859 Richardson's Bay bathymetry.

- Current Conditions

A bathymetric survey was completed within Richardson Bay concurrent with completion of a 2019 eelgrass inventory. The survey was limited to waters of Richardson Bay and Belvedere Cove and did not extend outward to deeper waters of Raccoon Straits or San Francisco Bay within the RBRA study area located to the south of the two embayments. At the upper end of Richardson Bay within the Richardson Bay Audubon Sanctuary, eelgrass was mapped using an Unmanned Aerial Vehicle (UAV)-based aerial imagery and thus bathymetric data collection was not practical. However, bathymetry for this upper intertidal portion of the bay was completed using a combination of aerial imagery-based interpretation of edge-of-water calibrated to image acquisition time stamps and local tidal water level observations derived from the San Francisco (Golden Gate Station) station - Station ID: 9414290 and corrected to the Sausalito Corps of Engineers Dock, - Station ID: 9414819; as well as interpolation of the 2016 USGS San Francisco Bay Digital Elevation Model (DEM) that provided supplemental shoreline elevation information.

Bathymetric surveys reveal an extremely shallow and flat bottom embayment over most of the bay with a gentle slope to the southern end of the bay where the bay falls abruptly to the deeper waters of San Francisco Bay. Dredged channels are the most notable topographic features followed by scour pits at the western side of Strawberry Point and those derived from moorings on the otherwise featureless flats (Figure 3). Within the inner portions of the bay, some areas have a slope ratio of less than 1 foot of fall in more than a half mile of distance.

Figure 3. 2019 Richardson Bay bathymetry.

- Evolving Conditions

To evaluate how the bay bathymetry has changed, the sounding points and elevation relatable boundary information (e.g., marsh edge, upland boundaries) depicted in the 1859 Entrance to San Francisco Bay Chart were used to develop a bathymetric raster of the bay. The lower edge of salt marsh was interpreted to be approximately coincident with MSL and assigned elevation of +3 ft MLLW. The lowest upland contour was interpreted at the shore transition where stippling transitions to hash fill. This area was assigned a value of +7ft. MLLW. The topo to raster tool in ArcGIS was used to surface the point and contour data at 5-m resolution coincident with the 2019 topobathy DEM.

The 1859 bathymetry was subtracted from the 2019 bathymetry using math algebra to determine how the elevation of the bay floor has changed between the two survey periods. Confounding the observed changes, there has been a 0.8-foot sea level rise across eight tidal epochs during the 160-year period between surveys. The general rate of sea level rise over this period has been approximately 0.005 feet/year (Smith 2002). Accompanying this rise has been an upward shift in the mean lower low water (MLLW) tidal datum on which the two charts are based. To correct for changes in the tidal epoch between 1859 and 2019, a tidal datum correction was applied by lowering the 1859 bathymetric surface by 0.8 foot. This adjustment allows for an assessment of the true change in bay floor elevation after removing the tidal datum shift (Figure 4).

Over the 160 year period between 1859 and 2019, the water depth within Richardson Bay has changed with the bay becoming gradually shallower. However, the rate of change has been remarkably slow. In general, sediment has accreted over much of the bottom of the bay raising the bay floor by approximately 1.5 feet over much of the central portion of the bay; however, the 0.8-foot sea level rise during this period has resulted in an effective change in water depth of only approximately 0.7 feet since 1859. Bathymetric change has been extremely gradual with the principal areas of accretion being along the historic channel system that historically snaked through the bay floor. In deeper waters, a greater difference in infill has been noted. However, it is uncertain as to the extent of error that may have existed in the deeper swift moving waters that would have been very difficult to accurately sound in 1859.

In addition to areas of natural bay deposition, there are areas of bay fill that are associated within shoreline development, areas of no detectible elevation change, and areas where the bay is presently deeper than was depicted in the 1859 charts. Most of the areas of deeper water are the results of prior excavations for channels and borrow sites for shoreline fill sediments. It is highly likely that the dredging along the Sausalito side of the bay resulted in an enhanced conveyance of water along the western bay margin and accelerated the infill of the circuitous channel that previously extended through the center portion of the bay.

Along the western and northwestern shorelines of Sausalito and Mill Valley there was historically a gradual upland transition with lower gradient valleys transitioning to intertidal marsh. The heavy development of the Sausalito waterfront during the early part of last century resulted in a combination of dredging and filling in support of maritime commerce. This was significantly expanded during World War II with the Marinship shipyard development along with supporting ship and boatyards and channel infrastructure improvements being undertaken. In these areas, substantial infilling/reclamation of former tideland (salt marsh) to support development occurred along the waterfront. Dredging of the channel to facilitate navigation and shoreline reconfiguration occurred substantially along the Sausalito side of the bay. After the end of the war, waterfront development transitioned from a working waterfront to a more gentrified recreational, tourism, and residential focused waterfront. This spawned the replacement of industrial and commercial fishing focused development to recreational boating marinas. Often the conversion to recreational uses from prior industrial uses has been through partial retrofit rather than full infrastructure replacement. This has given rise to the oddly formed convoluted shoreline configuration of narrow peninsulas and oversized piers supporting small slip marinas.

The most extensive change in the eastern portion of Richardson Bay associated with the development of the Belvedere Peninsula and Lagoon from what was Belvedere Island and the saltmarsh and mudflats that historically connected the island to the Tiburon Peninsula. In addition, Belvedere Cove was deepened to navigable depths from very shallow intertidal and subtidal flats. Marsh lands along the eastern shore were filled to support roadway. However, surprisingly most of the core of Richardson Bay has remained relatively unmodified from its natural conditions with only slow sediment accretion altering the bay conditions.

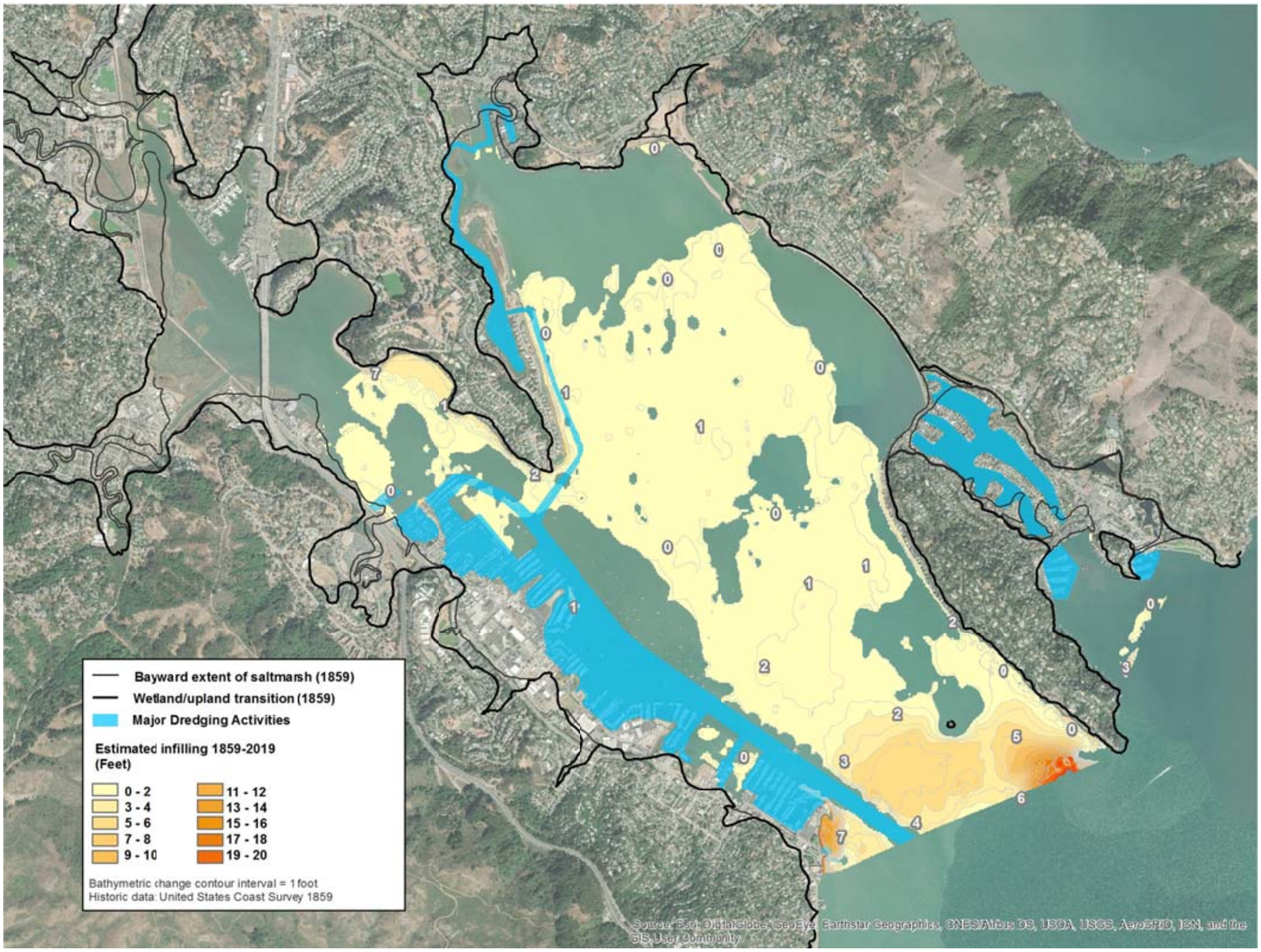


Figure 4. Richardson Bay sediment accretion from 1859 to 2019. *Bathymetric change has been extremely gradual with the principal areas of accretion being along the historic channel system that historically snaked through the bay floor. In addition to areas of natural bay deposition, there are areas of bay fill for development, areas of no detectible elevation change and areas where the bay is presently deeper than was depicted in the 1859 charts. Most of the areas of deeper water are the results of prior excavations for channels and shoreline fill sediments.*

Hydrology (Waves, Currents, and Freshwater Flows)

- Wind and Wave Environment

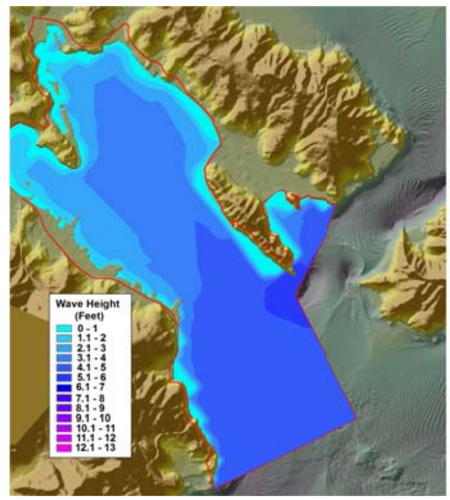
Richardson Bay is a relatively protected embayment, sheltered from winds from the west by hilly terrain of the Marin Peninsula. The bay is further sheltered from propagation of waves into the bay from the deeper waters of the entrance of San Francisco Bay by the pronounced concavity of the bay shoreline and the shallow waters of the bay that preclude large swell from penetrating into the bay.

No new modeling of the wind and wave environment was completed for this study; instead, data was drawn from prior modeling efforts completed by the Our Coast Our Future (OCOF). OCOF is a collaborative project focused on providing California coastal resource managers and planners locally relevant, online maps and tools to help understand, visualize, and anticipate vulnerabilities to sea level rise and storms. The modeling is based on the USGS Coastal Storm Modeling System (CoSMoS), version 1.5. For analysis purposes the available modeled maximum wave heights generated under 1-year, 20-year, and 100-year return event frequencies were evaluated throughout Richardson Bay (Figure 5).

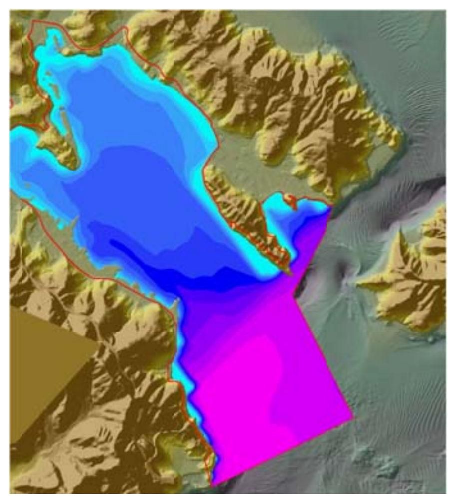
As anticipated the results of the OCOF modeling suggest that the annual peak wave environment within Richardson Bay is of a relatively low amplitude with the maximum annual (1-year) wave heights of 3 feet being reached near the eastern shoreline of the southern end of the bay where wind fetch, water depth, and wave penetration from the deeper waters to the south are at their maximum. Similar to the conditions of the 1-year wave environment, the 20-year and 100-year maximum wave conditions follow the same pattern with the greatest wave conditions being expressed at the south end of the bay. Within Richardson Bay a 20-year event produces a maximum modeled wave height of 5 feet. A 100-year event produces a maximum modeled wave height of 8 feet. However with the 100-year wave environment, the deeper Army Corps dredged channel is modeled to promote a greater penetration of large waves along the Sausalito side of the bay. This is a condition not seen in the 1-year and 20-year model results. In all modeled scenarios an erroneous anomaly exists in the model at the upper end of the bay near the Highway 101 Bridge.

What is not depicted in the OCOF modeling and which is of high importance in understanding wave environments is that all of the modeled waves are of a short-period wind-generated variety. This means that the waves travel fast and the space between waves is short. As a result, waves slap vessels and can inflict considerable force on mooring tackle, anchors, and vessel cleats unless moorings are designed to effectively absorb such energy.

1-year maximum wave model results



20-year maximum wave model results



100-year maximum waves model results

Figure 5 Richardson Bay wave field model from Our Coast Our Future (OCOF) modeling developed by USGS using Coastal Storm Modeling System (CoCMoS) version 1.5.

- Currents

Richardson Bay is a flat shallow and principally subtidal basin that is subject to full tidal circulation with the deepwater entrance channel of San Francisco Bay. The configuration of the basin would tend to support efficient tidal flushing of the southern portion of the bay and substantially lesser flushing of the northern portions of the bay where waters would move in an oscillatory manner with the tides, moving southward with the ebbing tide and northward with a flooding tide. This would result in greater residence of waters at the north end of the bay, particularly within the Mill Valley northwesterly arm of the bay and within the northeastern arm of the bay dominated by the Sanctuary. Adding to the controls on tidal circulation are inefficiency of water movement over the shallow flats, particularly where the roughness of the flats is dramatically increased by the presence of eelgrass, and efficiencies added by the deepened channel system extending along the Sausalito shoreline and on up to the eastern side of the Strawberry Point. There is a slight gyre to the circulation as a result of winds and passing tidal waters through Raccoon Strait. Currents along the dredged federal channel can be strong at times during spring tide exchanges, but current velocities over the central bay flats are generally slow to the north end of the bay and increase towards the south end as greater exchanged volume is added.

- Freshwater Influences

Richardson Bay is a highly marine influenced embayment within the San Francisco Bay estuary. Its position near the Golden Gate places it in a position where oceanic waters predominate in the bay significantly more so than do the Sacramento-San Joaquin River Delta discharges that can strongly influence other areas of the bay.

Local freshwater discharges to Richardson Bay are limited to small local drainages of Arroyo Corte Madera del Presidio, Coyote Creek, and unnamed drainages from Warner Canyon, Homestead Valley, and a number of smaller urban drains. Nearly all of the fluvial discharge is derived from the collective discharge to the bay from the northwestern Mill Valley arm of Richardson Bay (USGS Topographic Map San Francisco North and San Rafael Quadrangles). The local urbanized environments of Sausalito, Tiburon, Belvedere and unincorporated Marin County lands contribute mostly minor storm drain and sheetflow discharge to the bay and thus discharge events are of short duration and of limited volume.

The geographic position in the San Francisco Bay estuary and the small scale of the watersheds draining to Richardson Bay tend to result in a stabilizing influence on salinities that is unique to the area. Even during major freshwater floods during spring of 2017 that had devastating effects on eelgrass and marine invertebrate communities of the North Bay and East Bay, Richardson Bay was principally spared and did not suffer detectible effects of depressed salinities (K. Merkel, pers. obs.).

Water Quality

- Bacterial Contamination

Over the years, waters within Richardson Bay have suffered from multiple sanitary sewage spills in the watershed (2013-2014 Marin County Civil Grand Jury, 2014) that have continued through the present period with a May 17, 2019 spill of 670 gallons of sewage into the bay near Blackie's Pasture (The Mercury News, Tiburon beaches closed amid bay contamination probe, July 27, 2019). Quoted to The Mercury News, Bill Johnson San Francisco Bay Regional Water Quality Control Board (SFRWQCB) noted that sewage spills into the bay are a common occurrence and when inspected on the State Water Resources Board Sewage Spill Map (https://www.waterboards.ca.gov/water_issues/programs/sso/sso_map/sso_pub.shtml) it is clear that Category 1 spills reaching surface waters or not fully collected, regularly occur around Richardson Bay from sanitary sewer system failures. While most of these are small, they do occasionally lead to elevated bacteria levels in the bay near the waste entry points.

The SFRWQCB prepared staff report supporting a Total Maximum Daily Load (TMDL) for pathogens in Richardson Bay (SFRWQCB 2008) summarized bacterial monitoring data for many years within Richardson Bay. Data reported on extends back to 1973; however, the most useful data are from widespread sampling completed from 1994 through 2004, subsequent sampling by RBRA from 2004 to 2006 for *Escherichia coli* (*E.coli*) and Enterococcus bacteria, and fecal coliform sampling in 2006 and 2007. Sampling revealed regular exceedance of bacterial indicator levels within marina basins along the Sausalito shoreline with increasing exceedances of shellfish harvesting water quality standards and the higher threshold water contact recreation thresholds being exceeded at the upper Clipper Basin and further up the bay gradient past Waldo Point and into the Kappas Houseboat Marina. However, notably two control stations (Stations B and C) selected as reference conditions were generally low with Control B, an inner channel station off Clipper Yacht Harbor regularly exceeding the shellfish harvesting standards but being well below the contact recreation standard, and Control C, located on the shallow subtidal flats of Richardson Bay, typically being well below both standards (SFRWQCB 2008). Most notable in the control stations is that both of these stations are much closer to the moored vessels than are the shoreside sampling stations and showed a much lower level of fecal coliform, Enterococcus, and *E. coli* throughout the sampling than observed along the waterfront shore stations.

The TMDL staff report references various potential sources of pollutant discharge including sanitary sewer system overflows and leaks, stormwater runoff, houseboats, vessels at marinas, and anchor-out boats. The TMDL further outlines plans, policies and prohibitions intended to curb bacteriological discharges from the various sources (SFRWQCB 2008). While the various potential sources of bacterial pollutant discharges are all very likely contributors to one degree or another, it is likely that the concentration of discharge associated with sanitary sewer spills and storm water discharges are a primary culprit to the greatest exceedances of standards, while the concentrated vessels, including houseboats, in shoreline marinas are the most likely source of chronic exceedances. The observed increasing levels of indicator bacteria counts with increasing distance up bay along the Sausalito shoreline is also suggestive of a potential strong roll in tidal flushing to maintain lowered pollutant loads. The test results from control stations compared to monitoring stations as well as the diffuse generation of vessels within the anchor-out areas suggests that these areas may also benefit from tidal flushing.

Notwithstanding intermittent discharges and a history of water quality concerns in the bay, the water quality overall in Richardson Bay has improved through time. The County of Marin Environmental Health Services monitors water quality throughout the County and has a permanent weekly station at Schoonmaker Beach. This beach has received an A+ grade for Summer Dry Weather conditions from the non-profit environmental group Heal the Bay that scores beach conditions relative to bacterial pollutants. In spite of the fact that the beach was impacted by a 750 gallon sewage spill during the 2018-2019 monitoring period (Heal the Bay 2019).

- Temperature

Temperatures in Richardson Bay exhibit significant geographic, seasonal and daily variation due to a dominance of ocean water sources over bay water sources feeding the bay, and the extremely shallow and low circulation conditions of the inner bay flats that allow for atmospheric temperatures and solar heating of the bay floor to play major roles in dictating water column temperatures. Notably, the waters of the upper Richardson Bay Audubon Sanctuary can become very warm during hot summer days when wind does little to lower water temperature and long-periods of solar heating affect the water temperature. The water temperatures under such conditions have been measured to be within the high 70 and mid-80˚F range at times within the Audubon Sanctuary (K. Merkel, pers. obs., K. Boyer, pers. comm.). Further south in the bay where waters are deeper, the temperature range is more dampened.

While the shallow flats promote high atmospheric influence on water temperature, so too do wind waves that aid in heat dissipation to the atmosphere. As a result, the prevailing winds, solar angle, atmospheric temperature, tidal circulation, and ocean temperatures all play roles in dictating the prevailing water temperatures and temperature fluctuations in Richardson Bay.

Ecological Setting

Eelgrass

- Ecological Importance

Eelgrass is a marine flowering plant and the most widely distributed and abundant of the seagrasses in the world with a global north temperate range. Common eelgrass (*Zostera marina* L.) is a marine flowering plant and the most widely distributed marine angiosperm in the Northern Hemisphere (den Hartog 1970). It is a native plant indigenous to the soft-bottom bays and estuaries and occurs along the Pacific coast of North America from the Bering Strait down to lower Baja California. Eelgrass is considered to be a habitat forming species that creates unique biological environments when it occurs in the forms of submerged or intertidal aquatic beds or larger meadows. Eelgrass is considered to be a "foundation" or habitat forming species as it provides three dimensional structure to an otherwise two dimensional soft bottom seafloor and contributes disproportionately to defining the physical, chemical, and biological character of the local ecology within and around the eelgrass beds and can also have far reaching influences beyond the eelgrass beds and even outside of the systems within which eelgrass occurs. Eelgrass provides significant physical, chemical, and biological services (Orth et al. 2012, Waycott et al. 2009, Cole and Moksnes 2015).

Eelgrass is recognized as an ecosystem engineer, providing protection against coastal erosion, increasing water clarity through the reduction of wave energy, trapping of particulates, and stabilizing of sediments (Orth et al. 2012). Dense rhizome mats of eelgrass meadows stabilize sediments near channel banks against surficial slides, while the leaf canopy dampens wave energy, traps sediment, and stabilizes sediment against wave resuspension. These functions result in clarifying the water column and reducing shoreline and mudflat erosion.

From a chemical standpoint, eelgrass provides a high degree of function in nutrient uptake and cycling and influences multiple water column properties including dissolved oxygen, temperature, turbidity, total dissolve solids, and pH. It also serves a role in nutrient trapping and cycling (McGlathery et al. 2012), sequestration of atmospheric carbon (Duarte et al. 2005, Fourqurean et al. 2012), and buffering against the effects of ocean acidification (Shaughnessy and Tyburczy; in progress).

Eelgrass is a major source of primary production in many bay and estuary marine systems, underpinning detrital-based food webs both locally and in areas where dead leaf matter accumulates. In addition, several organisms directly graze upon eelgrass or consume epiphytes and epifauna supported by eelgrass plant structures, thus contributing to the system at multiple trophic levels (Phillips 1984, Thayer et al. 1984). Eelgrass beds function as habitat and nursery areas for commercially and recreationally important open ocean marine fish and invertebrates, and provide critical structural environments for resident bay and estuarine species, including abundant fish and invertebrates (Hoffman 1986, Kitting 1994, Simenstad 1994). Besides providing important habitat for fish, eelgrass is considered to be an important resource supporting migratory birds during critical migration periods. Eelgrass is particularly important to waterfowl such as black brant that feed nearly exclusively on the plants and to a number of other species that make a diet of both eelgrass and the epiphytic growth that occurs on the leaves. Beyond direct habitat functions, eelgrass benefits nearshore benthos through detritus export, producing significantly greater secondary production than mudflats, marshes and sandflats (Heck et al. 1995) and supporting much greater species richness than other habitats of shallow marine embayments (Orth et al. 1984, Zieman and Zieman 1989).

Notwithstanding the high importance of eelgrass to structuring and enriching nearshore marine environments, eelgrass abundance, and that of seagrasses in general, has declined worldwide over the past four decades due to increased anthropogenic as well as climatic shifts (Short and Wyllie-Echeverria 1996). As a result of the vulnerability of seagrasses, the noted declines, and the multifaceted benefits provided, eelgrass habitats and other vegetated shallows, are considered special aquatic sites under the 404(b)(1) guidelines of the Clean Water

Act (40 C.F.R. § 230.43). Eelgrass is given special status as submerged aquatic beds under the Clean Water Act of 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." In addition, pursuant to the Magnuson-Stevens Fishery Conservation and Management Act (MSA), eelgrass is designated as a habitat area of particular concern (HAPC) within essential fish habitat (EFH) designated for various federally-managed fish species within the Pacific Coast Groundfish Fishery Management Plan (FMP) (PFMC 2014). An HAPC is a subset of EFH that is rare, particularly susceptible to human-induced degradation, especially ecologically important, and/or located in an environmentally stressed area. HAPC designations are used to provide additional focus for conservation efforts. As a result of concerns over the protection of eelgrass, additional policies for eelgrass conservation and mitigation of impacts have been adopted in California in the form of the California Eelgrass Mitigation Policy (CEMP) (NMFS 2014).

- Historic Conditions

In the late 1920s eelgrass was reported as an abundant species along the shores of San Francisco Bay (Setchell 1929). In 1987, about 60 years later, a survey of the Bay, relying principally on aerial surveys and single-beam sonar surveys was completed by the National Marine Fisheries Service (NMFS). This survey revealed only 316 acres of eelgrass throughout the Bay, with much of the existing habitat exhibiting conditions of environmental stress (Wyllie-Echeverria and Rutten 1989, Wyllie-Echeverria 1990). A decade later, surveys of the San Pablo Peninsula, documented over 400 acres of eelgrass, suggesting extremely dynamic conditions within the existing beds, an underestimation in the 1987 studies resulting from limited survey techniques, or a combination of factors may have influenced earlier surveys (SAIC and Merkel & Associates 1997a, 1997b).

In 2003, a comprehensive inventory of San Francisco Bay eelgrass habitats was completed using a combination of survey methodologies, predominantly relying on sidescan sonar that allows detection and mapping of eelgrass within waters that are too turbid to allow effective aerial mapping and in eelgrass beds too sparse to allow effective mapping by single-beam sonar methods (Merkel & Associates 2004). This survey yielded the first comprehensive inventory of eelgrass in San Francisco Bay. The survey was followed up by other baywide eelgrass inventories in 2009 and 2014 (Merkel & Associates 2010, 2015). In addition to these baywide inventories, several smaller segments of the bay have been mapped over multiple years in an effort to investigate eelgrass dynamics. In Richardson Bay additional comprehensive surveys have been completed in 2013 and most recently in 2019 in association with this current study. When evaluating the results of these inventories, eelgrass has been noted to expand and contract over time and varies by bottom coverage (Figure 6). Low bottom coverage within an eelgrass bed is typically associated with seedling recruitment events and young plants that have not yet coalesced. However, where intact beds are on the decline, they are generally characterized by a greater proportion of higher cover classes even though the margins of the beds may be deteriorating.

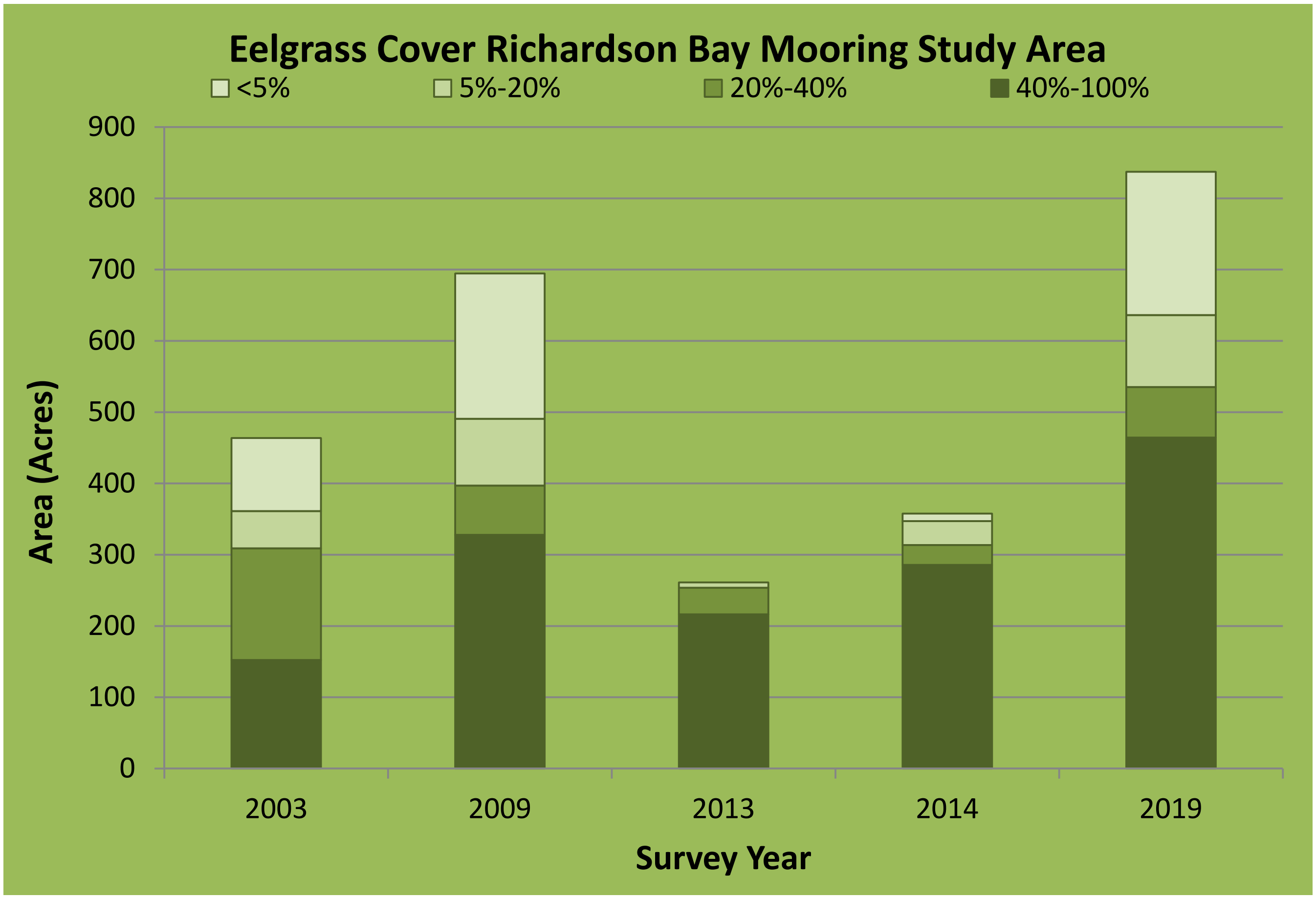


Figure 6. Eelgrass distribution within Richardson Bay Mooring Study Area inclusive of Richardson Bay and Belvedere Cove for comprehensive survey years. *Eelgrass bottom coverage is defined as the openness of the eelgrass plants distributed across the bayfloor. A 20%-40% eelgrass bed means that within this portion of the beds a random sampling by dropping a 1 meter quadrat would be expected to hit eelgrass 20-40% of the time.*

It is likely that eelgrass was once more widespread within Richardson Bay as well as Belvedere Cove. When the maximum extent of eelgrass (2003-2019) is overlain on the 1859 it appears that additional depths and exposure conditions suitable to support eelgrass once occurred along much of the Sausalito shoreline and inner Belvedere Cove in areas now occupied by shoreside fills and marinas (Figure 7). However, it should also be noted that the presence of deeper channels plays an important role in circulating water and maintaining cooler conditions in shallow water embayments. In 1859 channel definition was poor compared to the present navigation channels that extend along the western bay margin. As a result, it is uncertain whether eelgrass today extends over a greater or lesser extent of Richardson Bay than was the historic condition. Also notable is that while the Sausalito shoreline undoubtedly was suitable to support more eelgrass historically than during post-urbanization, the bathymetry of 1859 also suggests that eelgrass was unlikely to be more extensive elsewhere due to unsuitably shallow or deep waters.

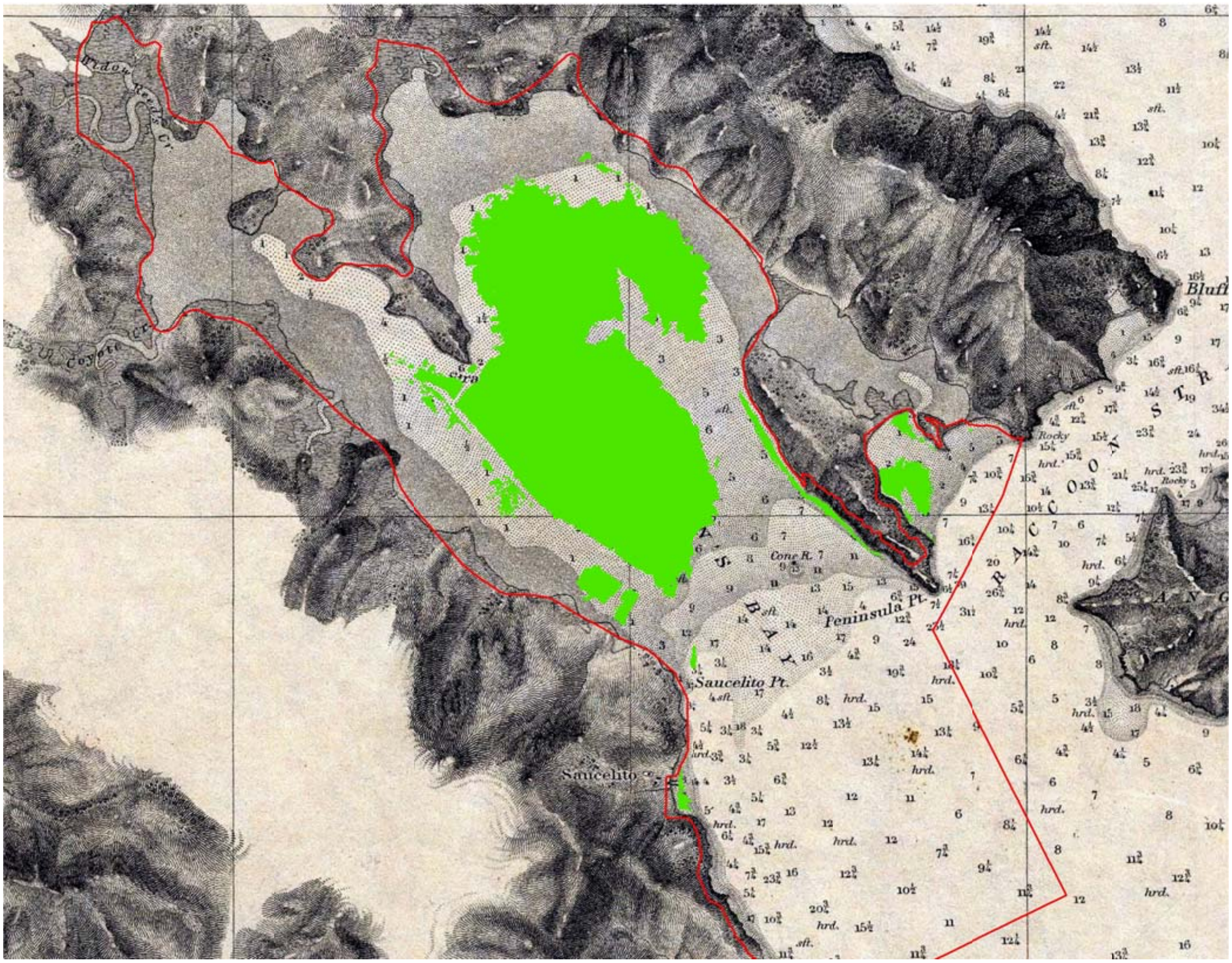


Figure 7. Maximum extent of eelgrass (2003, 2009, 2013, 2014, and 2019) overlain on 1859 bathymetric chart *(depth in fathoms) suggests that greater eelgrass habitat suitability likely once existed along the Sausalito waterfront and within Belvedere Cove. Similar suitability of deeper and shallower margins of the bay is not suggested by current distribution patterns and bathymetric ranges occupied by eelgrass.*

Considering the individual survey year conditions of the beds it is possible to examine the frequency of occurrence of eelgrass across the bay through time. This is helpful in understanding the dynamics of the beds and the distribution of the most and least stable eelgrass beds within the study area (Figure 8). Alternatively, it is also possible to refine the frequency distribution mapping further by integrating the bottom cover class data from the regional mappings into the overall frequency analyses. This approach uses the mean eelgrass bottom coverage within each of the cover classes (i.e., 70% represents 40-100%, 30% represents 20-40%, 12.5% represents 5-20%, and 2.5% represents less than 5%) as a weighting factor for each inventory year. The results of this scoring produce a cover weighted frequency distribution wherein higher bottom cover results in greater weighting in the analyses (Figure 9). The outcome provides a graphically meaningful presentation of eelgrass on the basis of persistence and maturity of beds through time. Note that beds that have historically always been within the highest cover class and persistent in every survey year can only reach a value of 70%, while rare occurrences of low bottom cover beds are severely penalized in the analysis with the lowest cover weighted eelgrass frequency being 0.5%.

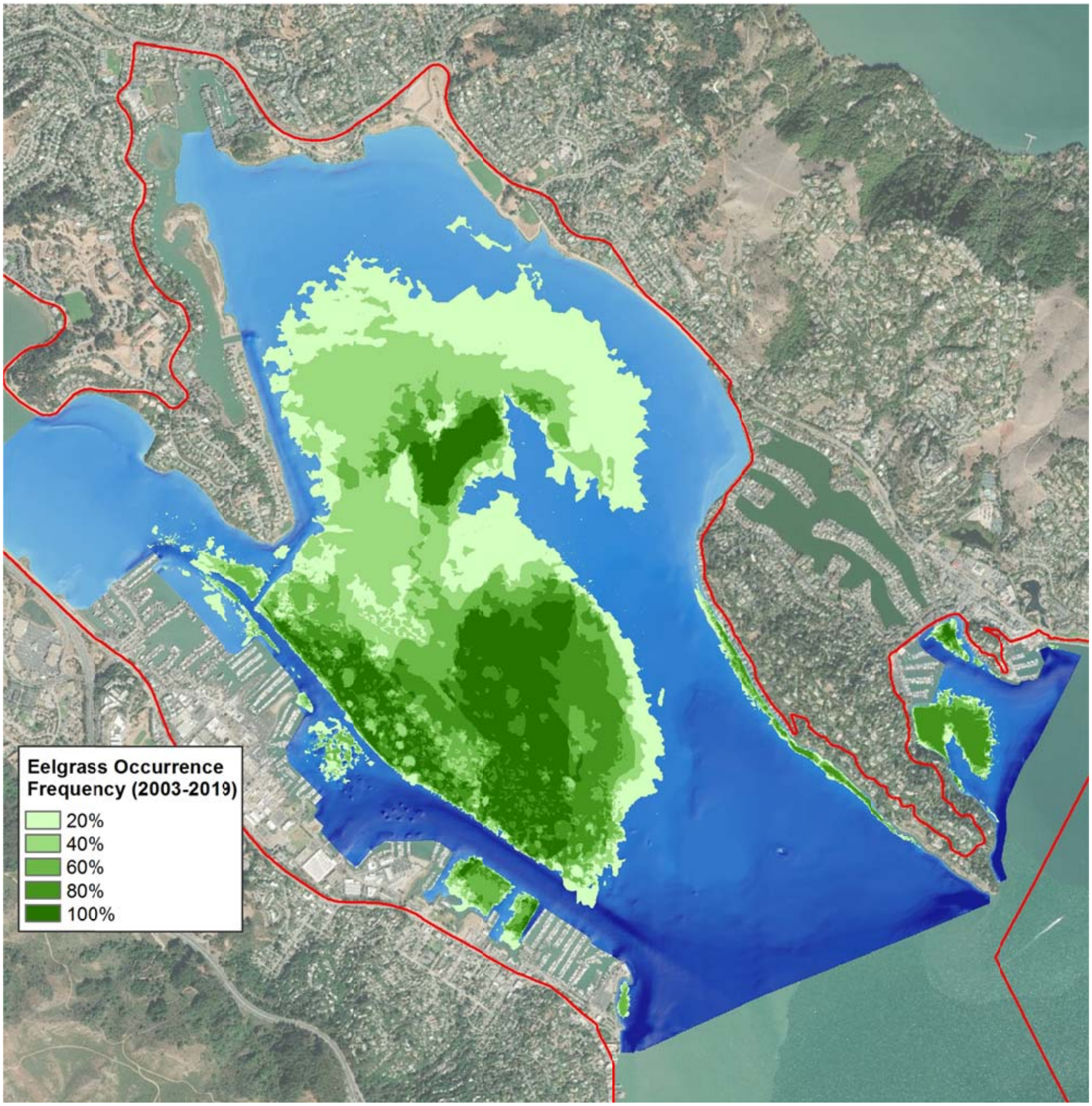


Figure 8. Eelgrass frequency distribution based on surveys conducted 2003, 2009, 2013, 2014, and 2019. *The data layer exhibits the average extent of mapped eelgrass, regardless of bottom cover class present during the contributing years.*

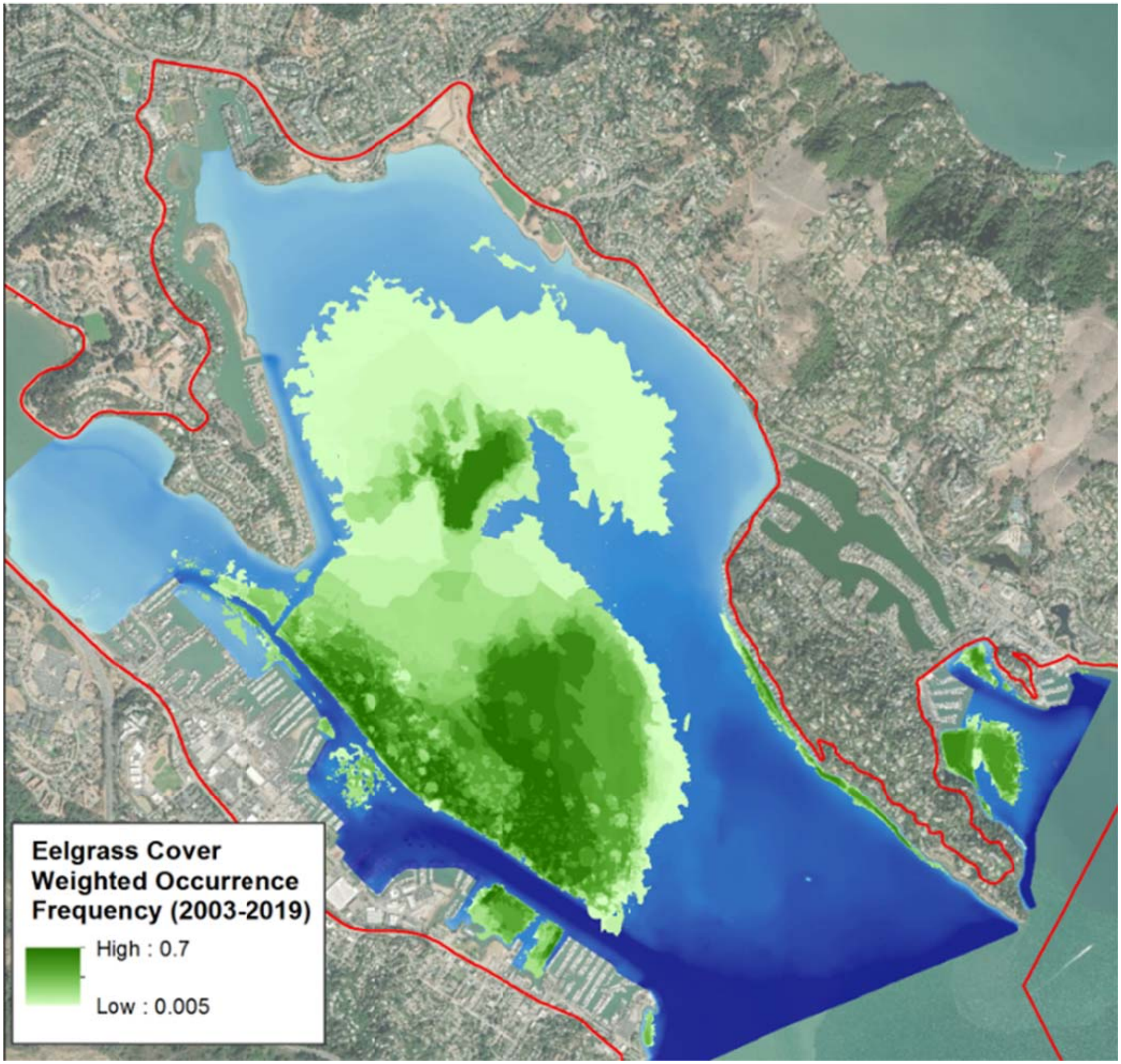


Figure 9. Bottom coverage weighted eelgrass frequency distribution based on surveys conducted 2003, 2009, 2013, 2014, and 2019. *The data layer exhibits the average extent of mapped eelgrass, weighted by the mean eelgrass bottom cover class from the contributing survey years.*

- Current Conditions

From a planning perspective, the long-term frequency distribution of eelgrass is more valuable than a single survey result; however, it is notable that the 2019 eelgrass survey found more eelgrass present within the study area than any of the prior surveyed years (Figure 6). In fact, 2019 held more than three and two times the extent of eelgrass than mapped in either 2013 or 2014, respectively. Both 2013 and 2014 were considered to be extremely poor years for eelgrass in Richardson Bay. Eelgrass in 2019 extended significantly further northward into the Richardson Bay Audubon Sanctuary than has historically been the case, although most of this extension has been due to seedling recruitment at sparse densities (Figure 10). As has been the case in prior surveys, eelgrass areas along the federal navigation channel continues to show substantial evidence of damage from vessel and mooring scarring. Expansion of eelgrass within the Audubon Sanctuary near the tip of the Strawberry

Peninsula and west of the northern core bed has been fostered by active restoration which accounts for the higher bottom coverage than seen elsewhere in the upper lobe of the bay.

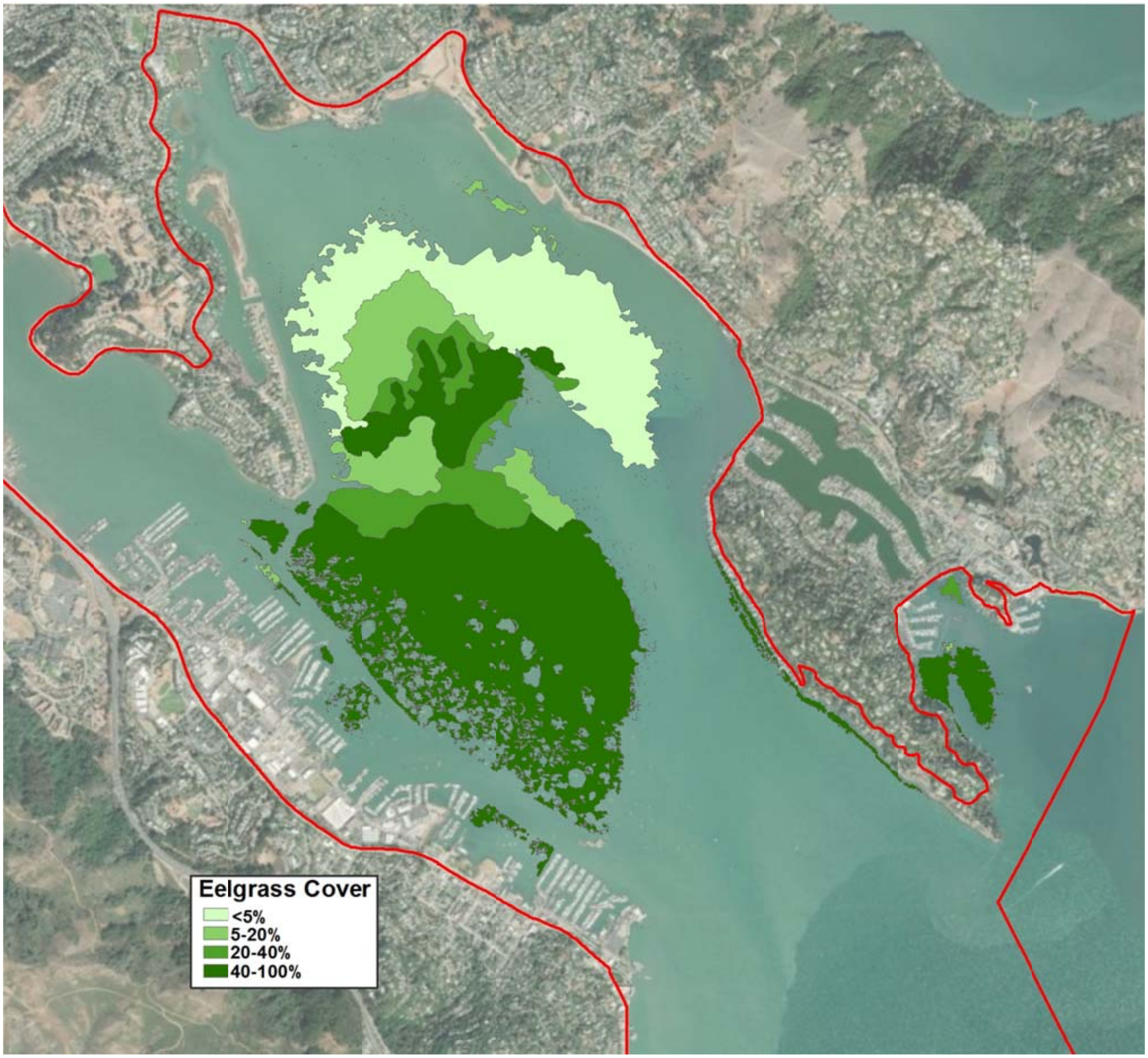


Figure 10. 2019 eelgrass distribution by bottom percent cover class. *The data layer exhibits the distribution of eelgrass based on a hybrid of interferometric sidescan sonar and UAV based aerial photographic survey with surveys being completed in June and July 2019.*

- Stressors on Richardson Bay Eelgrass

As discussed previously, Richardson Bay is uniquely situated within San Francisco Bay to support relatively stable eelgrass beds. The controlled input of freshwater, the limited sedimentation and predominance of marine waters, and the position of the bay adjacent to deepwater channels all favor physical environmental conditions conducive to eelgrass. However, Richardson Bay is prone to other factors that are stressful to eelgrass. Most notably, these include broad intertidal mudflats and shallow waters that are subject to considerable solar radiation and atmospheric heating that can result in thermal stress to eelgrass. This stress is exacerbated by dense eelgrass beds within shallow waters that trap waters in the shallows and calm wind waves, resulting in reduced heat dissipation during some periods. The extreme heating that can occur in inner Richardson Bay is illustrated by water temperatures measured near the tip of the Strawberry Peninsula of 25.3°C (77.5˚F) on June 13, 2019, and sustained temperatures in excess of 24°C (75°F) during eelgrass restoration in Richardson Bay in 2015. While it is not certain, it is believed that significant die-offs of eelgrass noted between the 2009 and 2013 period may be substantively attributed to thermal stress and resultant cumulative factors.

Secondary to thermal stress, for which the magnitude of effect is uncertain and the influence is manifested most substantially in the shallows of the Audubon Sanctuary, the second greatest and very documentable stressor on eelgrass in Richardson Bay is damage due to mooring of vessels within eelgrass beds and associated ground tackle dragging, vessel dragging, and damage from vessels transiting through the eelgrass beds during low tide conditions. While the large scale of mooring scars in Richardson Bay has been known for some time, dating back to at least the late 1980s when eelgrass monitoring in San Francisco Bay was initiated, explicit quantification of impacts was not undertaken. During the 2003 eelgrass inventory and subsequent inventories the damage to eelgrass from moorings in Richardson Bay was noted, but again not explicitly quantified (Merkel & Associates 2004, 2009, 2015a). A localized pilot assessment of eelgrass damage from moorings was undertaken to evaluate how moorings were affecting both eelgrass and the underlying topology of the bottom (Merkel & Associates 2015b); however, again no attempt was made to systematically quantify the magnitude of the impacts, although quick analyses based on estimating the average mooring scar area and counting the visible moorings suggested that impacts likely fell between 20-40 acres (K. Merkel, unpublished data).

In 2017, California Audubon undertook a rigorous process of quantifying eelgrass impacts by mooring tackle and moored vessels (Kelly et al. 2019). This included low altitude, low tide aerial surveys flown on July 23, 2017 that were subsequently mosaicked to an orthorectified image of the moorings and subject to high resolution mapping using GIS software. Because the photography is not capable of distinguishing eelgrass at depth with the greatest level of accuracy, and thus impacts may be over-estimated using purely photographic tools, Audubon developed both high (84.01 acres) and low (49.42 acres) estimates of eelgrass impacts for 2017. This approach provided a very robust estimate of eelgrass impact albeit establishing a wide range of uncertainty. To apply these results in the present study, the mean of the high and low impact assessment (66.72 acres) was used for the 2017 impact level.

Following up on the Audubon assessment, six additional survey years were analyzed to assess mooring and vessel damage in Richardson Bay. This work included revisiting sidescan sonar mosaics prepared to support the 2003, 2009, 2014, and 2019 San Francisco baywide eelgrass inventories in order to more explicitly map eelgrass in and around moorings and to identify physical evidence of bottom scarring by moorings and vessel transit through the eelgrass. In addition, two additional surveys were evaluated; these included a 2018 partial interferometric sidescan sonar survey of the moorings within Richardson Bay and a 2013 NOAA high resolution aerial photographic survey of Richardson Bay. The results of the eelgrass impact assessments from these various years are illustrated in Figure 11. In all cases, eelgrass impact was determined where surrounding bottom supported eelgrass at the time of the survey and impacts were not quantified if bottom scarring occurred outside of eelgrass beds present at the time of the survey.

In addition to mapping of the spatial extent of eelgrass impacts (Figure 11), a quantification of eelgrass impacted by vessels was undertaken (Figure 12). This chart illustrates an increasing trend of greater eelgrass impacts from vessel activities over time. In 2003 impacts to eelgrass were quantified at approximately 22 acres and by the present 2019 survey eelgrass impacts were quantified to be nearly 74 acres.

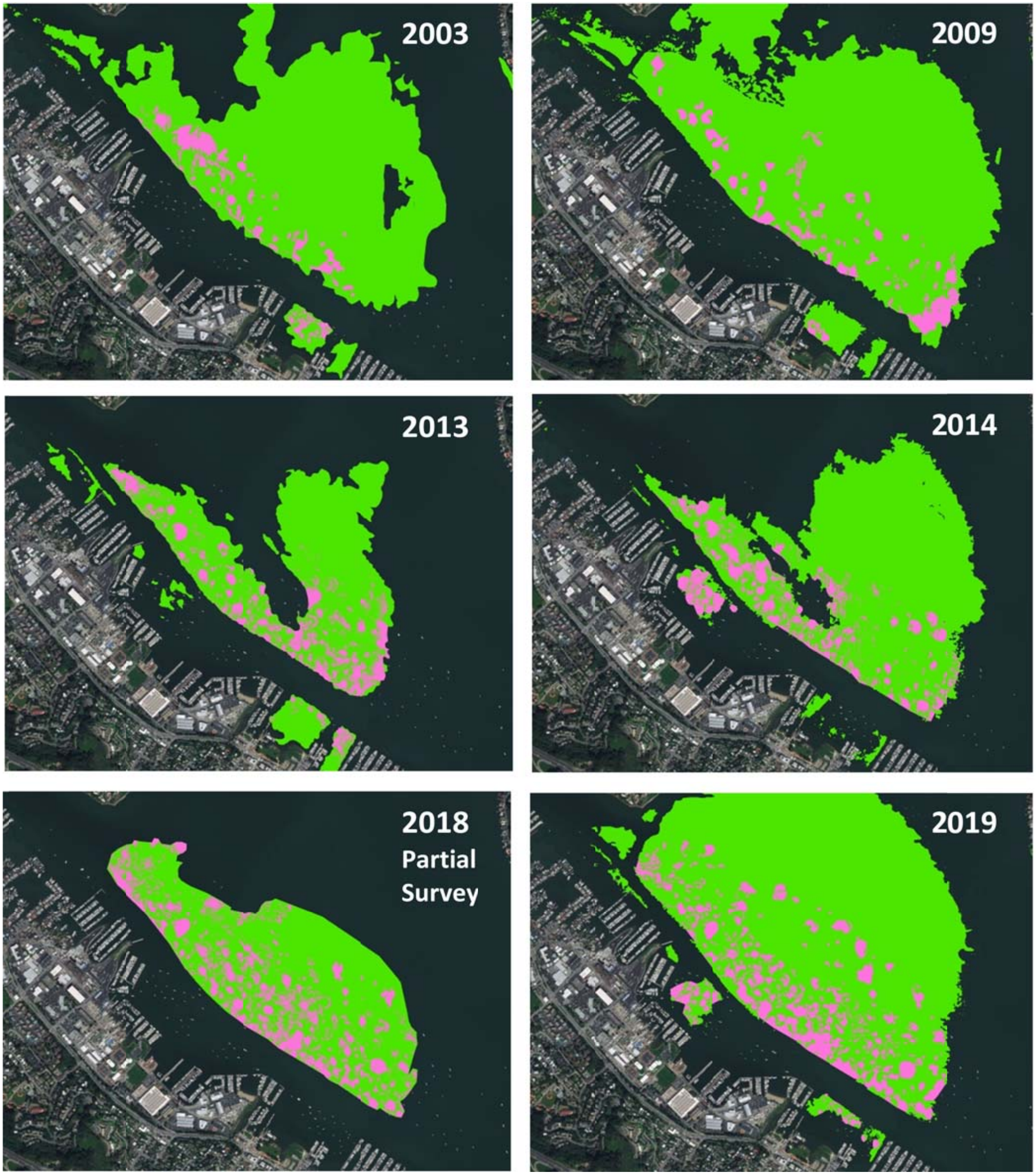


Figure 11. Eelgrass impact by moorings, vessel grounding and propeller wash over multiple years. Images depict eelgrass absence as a result of mooring and vessel damage (pink) along with adjacent eelgrass (green) existing during the analyzed year. Note bottom scarring that occurs outside of eelgrass beds existing during the analyzed year was not considered to be an eelgrass impact.

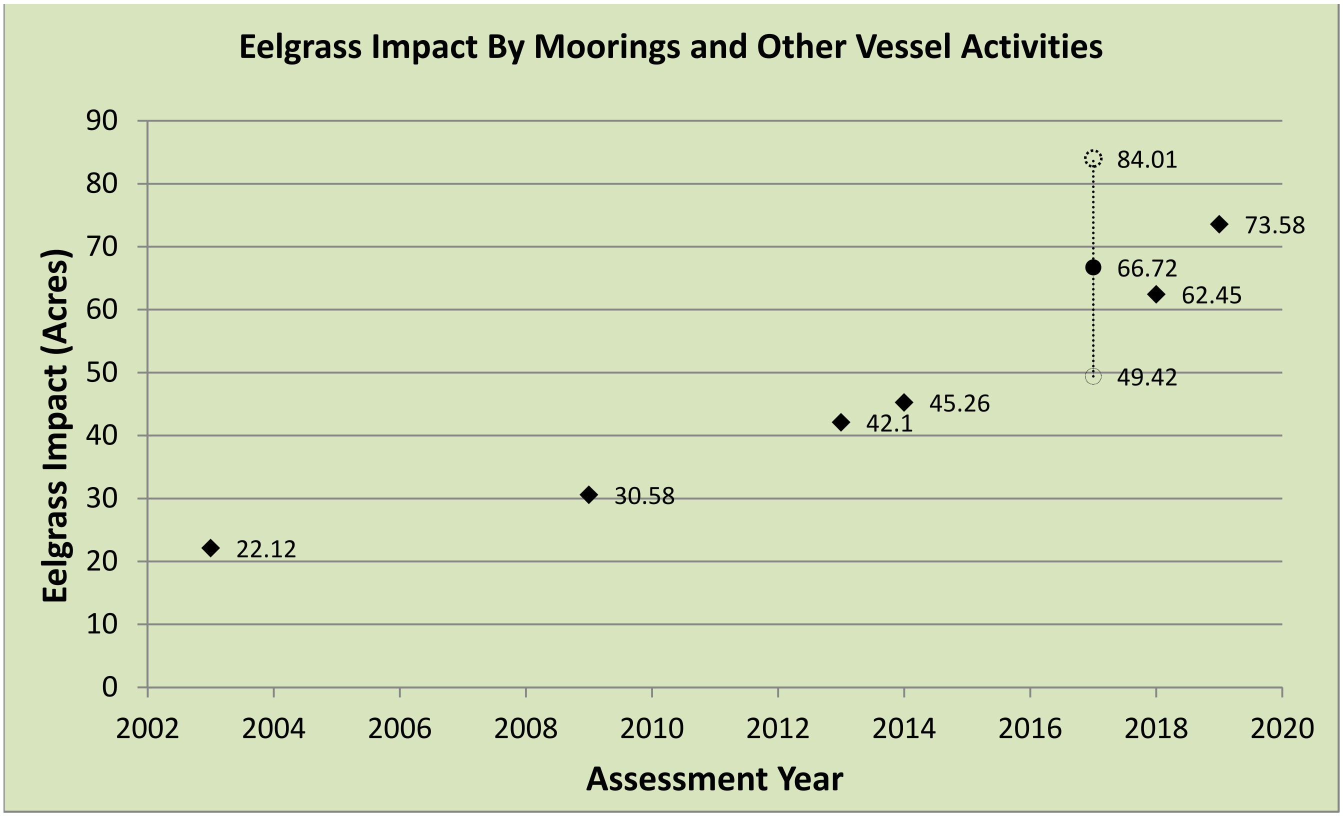


Figure 12. Change through time of eelgrass impact area as a result of moorings, vessel grounding and propeller wash. *Data are derived from eelgrass surveys and mapping using acoustic sonar and aerial photographic interpretation completed under this study with an additional estimate for 2017 derived from work by Audubon California (Kelly et al. 2019).*

The trend toward increasing eelgrass damage in recent years is the result of many factors including expanding numbers of vessels on moorings, changing make up of vessels on moorings, and changing distribution of vessels and eelgrass. It is also possible that sediment accretion and reduction of water depths within the inner portions of the Bay is playing a role in increasing damage; however, this is not clear since the history of accretion over time has not been ascertained.

The nature of eelgrass damage from moorings is often viewed as simple scouring of the bottom by mooring tackle dragging. However, in truth the damage is more complex within Richardson Bay. Most moorings in Richardson Bay are single point moorings with a gravity mooring weight and chain mooring tackle that rises to a mooring ball from which a pendant attaches the vessel to the ball. Conventional wisdom is that the longer the chain the less risk of dragging the mooring anchor or pulling cleats and the smoother the ride on the boat due to energy absorbed by lifting the chain. However, the more chain on the bottom, the greater the damage due to vessel rotation around the anchor in response to wind and currents. As the chain sweeps the bottom, it stirs up the fine sediments creating turbidity plumes that drift away from the points of disturbance. Over time the suspension of sediment and export by currents generates a pit around the mooring anchor. The depth and shape of the pit depends upon many factors; however, within Richardson Bay there are many such mooring scar pits that are as much as 2-3 feet below the surrounding bottom elevations. The pits are regularly scoured by the chain and as they deepen they become traps for algal detritus and other drift debris. The high frequency of disturbance and accumulation of debris makes the pits unsuitable to support eelgrass. Macolino et al. (2019) has also demonstrated that ecological effects seen on macro-habitat scales can also be detected in the infaunal communities as a diminishing signal with increasing distance from moorings.

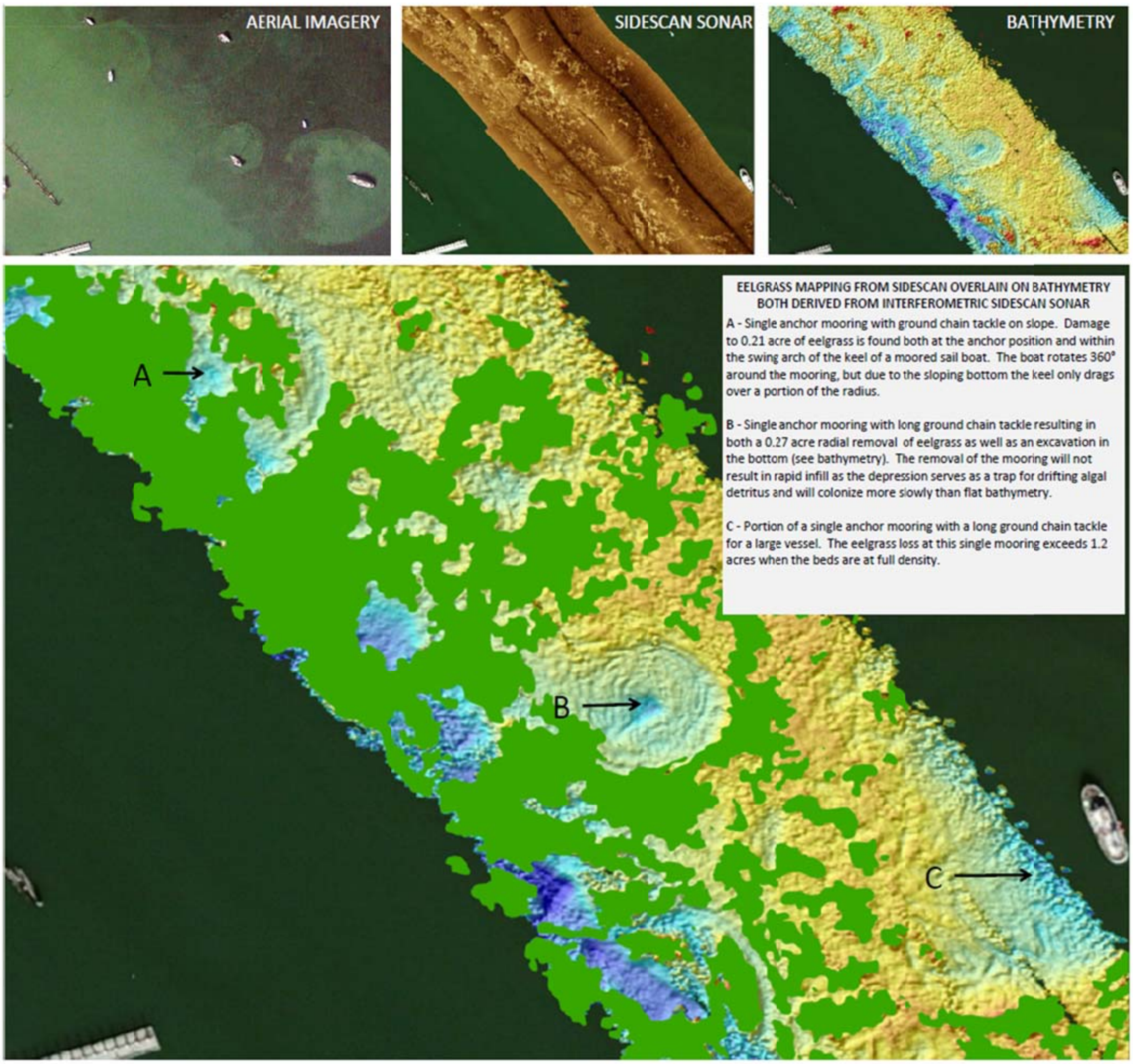
In addition to ground tackle damage, most of the vessels within the bay are in waters too shallow for the vessels moored in them. As a result, vessels drag keels and or motors on the bottom. This also cuts into the bottom and liberates fine silt clouds. Where vessels don't actually drag bottom, the vessels and stern tied dinghies drag deeply through the eelgrass and can, over time reduce the extent of eelgrass within the swing radii of the vessels.

Eelgrass damage from mooring ground tackle dragging and vessel grounding drags at low tides. The dark mottling is eelgrass, the brownish tinge is a diatom film on the bottom and the bluegreen color is unvegetated silt and clay from recent disturbance. (Photograph taken June 2019)

Moored vessels supporting live-aboard residents make frequent trips to and from vessels and the shore. As a result the trips account for substantial low tide traffic through eelgrass beds. Eelgrass can be damaged by vessels running through the beds. However, vessel transiting to and from moorings are principally small dinghies and likely accounts for some but not the majority of the bottom damage in the eelgrass beds attributed to propeller wash and trenching. When the actual physical scars are examined in sidescan imagery, the scale of the scars and the frequency of twin propeller scars makes it more likely that the principal eelgrass damage from vessels underway is derived from larger vessels such as commercial salvage vessels, law enforcement, and vessel rescue boats that are either deep draft, or operate at inopportune tidal levels by necessity.

Finally, there is a secondary effect of moorings on eelgrass that is not completely understood but may be the result of a variety of factors. That is the fact that many of the moorings have generated "crop circles" in eelgrass beds that are of a greater radius than can be accounted for by the mooring taken and vessels alone. This can be seen in aerial photographs as well as interferometric sidescan data. These larger areas of impact can raise a single mooring scar to be greater than 1.2 acres in size. Often the larger radius beyond direct mechanical impact supports a diatom film across the bottom. The absence of eelgrass in these areas has been hypothesized to be the result of prior larger mooring system arcs on the same anchor, the localized halo area affected by regular suspension of sediment by ground tackle and vessel d ragging, or some other, as yet identified factor.

Mooring and vessel damage within Richardson Bay unquestionably accounts for the greatest extent of direct and ongoing anthropogenic impact to eelgrass in San Francisco Bay. In 2014, mooring damage suppressed eelgrass extent by an estimated 13.5 percent in Richardson Bay or 1.6 percent baywide. This is a highly significant effect in the context of the resource. Notably, it is the reversible and incomplete nature of the impacts to eelgrass associated with the moorings that make the circumstances here unique. It is likely that many times more acres of eelgrass were lost along the margins of San Francisco Bay in association with filling and dredging projects to support upland development, marinas and navigation; however, those losses are generally viewed as permanent.



A multi-media presentation of conditions along the east margin of the channel at the entrance of Clipper Yacht Harbor (July 2015). The imagery identifies the central scour pits around single point moorings as well as vessel keel drag scars on the bottom and expanded halos of eelgrass loss beyond the reach of the mooring tackle and vessels. With close inspection of the various image products, scarring of the bottom by twin and single propeller vessels can be seen.

Pacific Herring

Pacific herring (*Clupea pallasii*) is an important and historically significant commercial fishery in California (CDFW 2019). Over 90 percent of California's herring landings come from San Francisco Bay. Herring, a pelagic species moves into bays and estuaries as early as October and departs from the bays as late as April.

In San Francisco Bay, eelgrass is used as spawning substrate by Pacific herring with the most abundant herring spawning through time being in Richardson Bay. Since the California Department of Fish & Wildlife (CDFW) commenced tracking herring spawning locations within San Francsicso Bay in 1973, Richardson Bay has been the area of most predominant spawning by herring with 80 percent of the 45 years from the 1973-1974 to 2013-2014 having recorded spawning activities on eelgrass and other substrates (CDFW unpublished data). When parsed further by spawning events, 65.3 percent of observed spawns have been in areas around the Marin shoreline, principally within Richardson Bay. This is more than 3.5 times more spawning events than occurring within the San Francisco waterfront, the next most prolific spawning region (CDFW 2019). Based on the level of historic use, CDFW has suggested that the spawning grounds in and around Richardson Bay provide critical spawning habitat for the San Francisco Bay herring population (CDFW 2019). Further, many of the persons interviewed for this study noted a high societal value and cultural atmosphere associated with the seasonal herring runs in Richardson Bay.

Pacific herring eggs on eelgrass San Francisco Bay (photo by CDFW Marine Region)

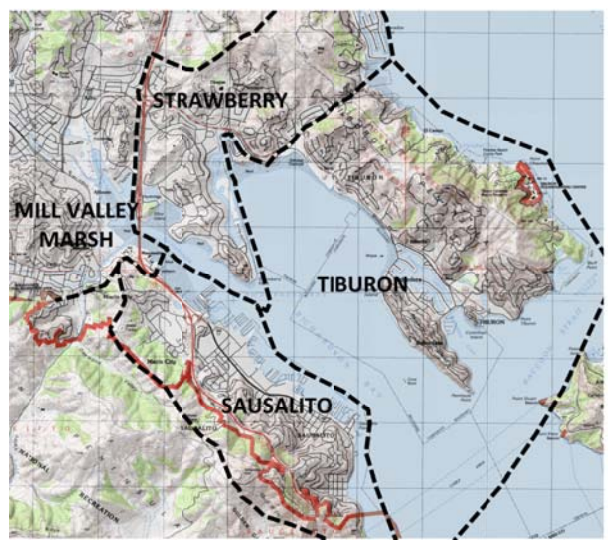
Richardson Bay is considered a herring conservation area and has never been open to commercial gill net herring fishing activity. The CDFW notes that this closure protects herring during spawning in one of the most important spawning areas in San Francisco Bay. Herring eggs on kelp (HEOK) fishing is allowed in specified areas of Richardson Bay. CDFW's management of the herring fishery focuses on controls to protect the viability of the fishery and damage to important habitats that are both intrinsically important to the marine environment and which benefit the herring fishery sustainability. Prohibition on gill netting in the shallows of Richardson Bay protects against net drag and anchoring damage to eelgrass. It further limits propeller wash and scour damage to eelgrass and unvegetated soft bottom from fishing vessel operations. However, the CDFW regulations are specifically restricted to the fishing activities and do not extend over similar types of disturbances that may influence the bay's habitats and the herring fishery.

Marine Birds

Perhaps the best summary of avian resources and constraints associated with data application is derived from the PRBO Waterbird Census at Richardson Bay Audubon Sanctuary 1982-2006 (Shuford 2008). This document does a very good job of placing the Richardson Bay avian community into the broader regional and global context and identifies clearly the constraints to existing data sets. As such, the present study relies heavily on this document for the present analysis. Richardson Bay is recognized as an Important Bird Area in California, yet little prior information has been compiled on the abundance of birds in this bay. A summary of waterbird censuses conducted at the Richardson Bay Audubon Sanctuary irregularly from 1982–83 to 2006–07 and in the Tiburon subarea of the Marin County (southern) Christmas Bird Count (CBC) from 1978 to 2005 documents thousands to tens of thousands of wintering waterbirds in Richardson Bay. Numbers of waterbirds in this bay are typically dominated by a few species or species groups of diving birds, mainly scaup, Ruddy Ducks, large *Aechmophorus* grebes, Double-crested Cormorants, Buffleheads, and gulls. Numbers of the most numerous waterbirds in the Tiburon subarea were high during the late 1970s and early 1980s, and declined in the mid-1980s. The numbers have been low since this time. Reportedly abundant in the late 1970s, American Wigeons, Canvasbacks, and American Coots are currently uncommon to rare in Richardson Bay. Authors have noted that limitations in census methods affect the ability to make substantial links between bird numbers and influencing factors; however, it has been suggested that fluctuations in spawning herring and the density and extent of subtidal plants (principally eelgrass) may be the most important local factors influencing waterbird numbers in Richardson Bay in winter (Shuford 2008). Additionally, wintering numbers of waterbirds on Richardson Bay may be strongly affected by factors elsewhere in their range at other seasons.

Marine birds on herring in Richardson Bay moorings (top February 2019 photo by CDFW Marine Region, bottom date unknown photo by Chad Carvey, Anchor-out resident)

Annual regional Christmas Bird Counts are compiled by survey areas that are too broad to provide adequate insight into avian distribution patterns within or near the mooring areas or adjacent portions of the bay. The entirety of Richardson Bay falls within four different count areas with one of the count areas capturing approximately 80 percent of the bay. Further, the scale of the Tiburon survey area is untenable with respect of fully capturing and recording avian distribution patterns with respect to moorings.



Audubon Christmas Bird Count area map. Note that the bird count survey and reporting zones cover wide expanses of the bay and are not aligned in a manner that support analytical application to mooring influence on avian distribution, diversity, or abundance questions.

Trends in waterbird numbers at Richardson Bay vary across avian species. Because movements of waterbirds in and out of surveyed waters of the Richardson Bay Audubon Sanctuary are strongly influenced by the distribution of herring spawning, census data is again hard to interpret when spawning is occurring either within our outside of Richardson Bay (Shuford 2008).

Present avian survey data includes various point observation methodologies, survey zone census methods, and efforts at saturation surveys. However, all of the existing data is constrained in its application to evaluation of avian resources beyond primary ecological metrics in diminishing accuracy of species richness, abundance, diversity, and coarse spatial distribution. As a result, application of existing avian survey data to questions of ecological impact of moorings on avian resources of Richardson Bay is limited and absolute conclusion regarding mooring and bird interactions would be well informed by more focused behavioral studies targeting this specific question.

Vessel disturbance of birds has been previously evaluated in Richardson Bay specifically with respect to the Richardson Bay Wildlife Sanctuary (Zitney 2000). This study "Richardson Bay Dock and Boat Study: The Cumulative Effects of Dock Development and Boat Traffic on Wildlife and the Richardson Bay Wildlife Sanctuary" was not precisely applicable to the present question since the study tended to focus more on shoreline development and constrained environments in the northeastern portion of the bay. However, it does point to a few important factors. First, the effect of boat traffic and docks, in the present case moorings, is complicated and not readily addressed by a singular issue such as intensity of features, but rather the extent to which bird use will be influenced by boat impacts is tied to habitat resource distribution, species specific behavior, disturbance acclimation, and variable factors of forage availability, tidally influenced resource availability, wind and wave conditions, and landside disturbance patterns.

Within the widely spaced moorings, water-birds are commonly observed making use of the waters between vessels, as well as boat decks, railings, and rigging of vessels that are principally not occupied, or do not support high levels of activity. The vessels on the mooring are a relatively static feature in the context of avian use patterns; however, transit by dinghies as well as dogs and people on deck can produce discrete nodes of disturbance. During high wind and wave conditions, more birds are often noted within the moorings where the fetch length is shorter, some wind and wave protection is derived from vessels, and waves don't build as high as occurs on the east side of the bay. However, on calm days, avian distribution patterns are more diffuse and tend to be focused wherever foraging, loafing, or other resources are best represented. During herring spawning runs, habitat selection for many of the water-bird species is overwhelmingly driven by available food resources and normal behavioral response to lessor stressors break down. During these periods, it would be illogical to evaluate effects of moorings on avian resources.

While studies that explicitly evaluate the influence of moorings and mooring associated activities are lacking, it is not believed that the present moorings contribute substantially to bird abundance, diversity, or distribution patterns within Richardson Bay. This is based on anecdotal evidence of avian uses within the moorings, abundant similar habitat within the central Richardson Bay environment, and patterns of use that are driven by variable factors influencing birds. This is a different conclusion than would be made relative to the more developed and limited shoreline margin habitat where a similar low effect conclusion, especially on the western shoreline margin could not be supported. More investigation into moored vessel and avian interactions is certainly warranted, but beyond the scope of this effort.

Marine Mammals

- Cetaceans

To investigate marine mammals in Richardson Bay data were collected on mammal occurrence from multiple sources. Golden Gate Cetacean Research (GGCR) was contacted, as were California Audubon, RBRA staff, and members of the anchor-out community regarding marine mammal activities in Richardson Bay. In addition, mammal observations were made by M&A staff while conducting eelgrass surveys in June and July 2019.

Bill Keener from GGCR provided information on sightings of cetaceans within the RBRA Special Area Plan boundary (Figure 13). The data reveals four species: harbor porpoise (*Phocoena phocoena*), bottlenose dolphin (*Turisops truncates*), humpback whale (*Megaptera novaegliae*), and gray whale (*Eschrichtius robustus*) that make regular use of the deep bay environment but which do not venture into the shallows of Richardson Bay. Bill Keener also noted that several years ago a minke whale was also spotted in the area. The harbor porpoises have only been back in the San Francisco Bay in any numbers (after a multi-decadal absence) since around 2008 (Stern et al. 2017). The bottlenose dolphins have been entering San Francisco Bay for about the same period of time. GGCR noted that humpback whales have come in to feed since the summer of 2016, so the use pattern for these whales is based on only three years of data. The gray whales typically enter the bay in small numbers during their northward migration. However in 2019, gray whales were more active in the bay with three or more animals being present in the bay in March and February, including an animal working the mouth of Richardson Bay and areas off the tip of the Tiburon Peninsula.

According to all respondents to inquiries, cetaceans including whales, porpoise, and dolphins make almost no visits into the shallow waters of Richardson Bay.

- Pinnipeds

However, the bay does host a large number of harbor seals (*Phoca vitulina*) and a smaller number of California sea lions (*Zalophus californianus*). Historically harbor seals commonly hauled out on Aramburu Island in the late 1960s and 1970s. In 1975, an estimated 30 percent of San Francisco Bay's harbor seal population took refuge on the island (George 2011). However, the number of seals on the island began to seriously decline in 1976. In 1984-1989 surveys, only two seals were observed hauled out on the island in 1985 and were not observed hauled out subsequently (Zitney 2000). The last occurrence of seals meaningfully hauling out on the island has been reported as 1985 (George 2011). It is reported that seals stopped using the island, likely due to human and dog disturbance, including from land and vessel encroachment. This is probably true; however, there is certainly more to the story than vessel disturbance. A particularly notable demonstration of this point is the more recent establishment of a seal haul-out along the primary navigation channel in Richardson Bay on the pile wave break of the Clipper Yacht Harbor. At this location, seals are exposed to intermittent disturbance by vessels transiting in and out of the marina and along the navigation channel. Seals in this area continue to exhibit inherent skittishness and often enter the water as vessels pass, but also will ignore vessel traffic regularly when the vessels exhibit no particular threat.

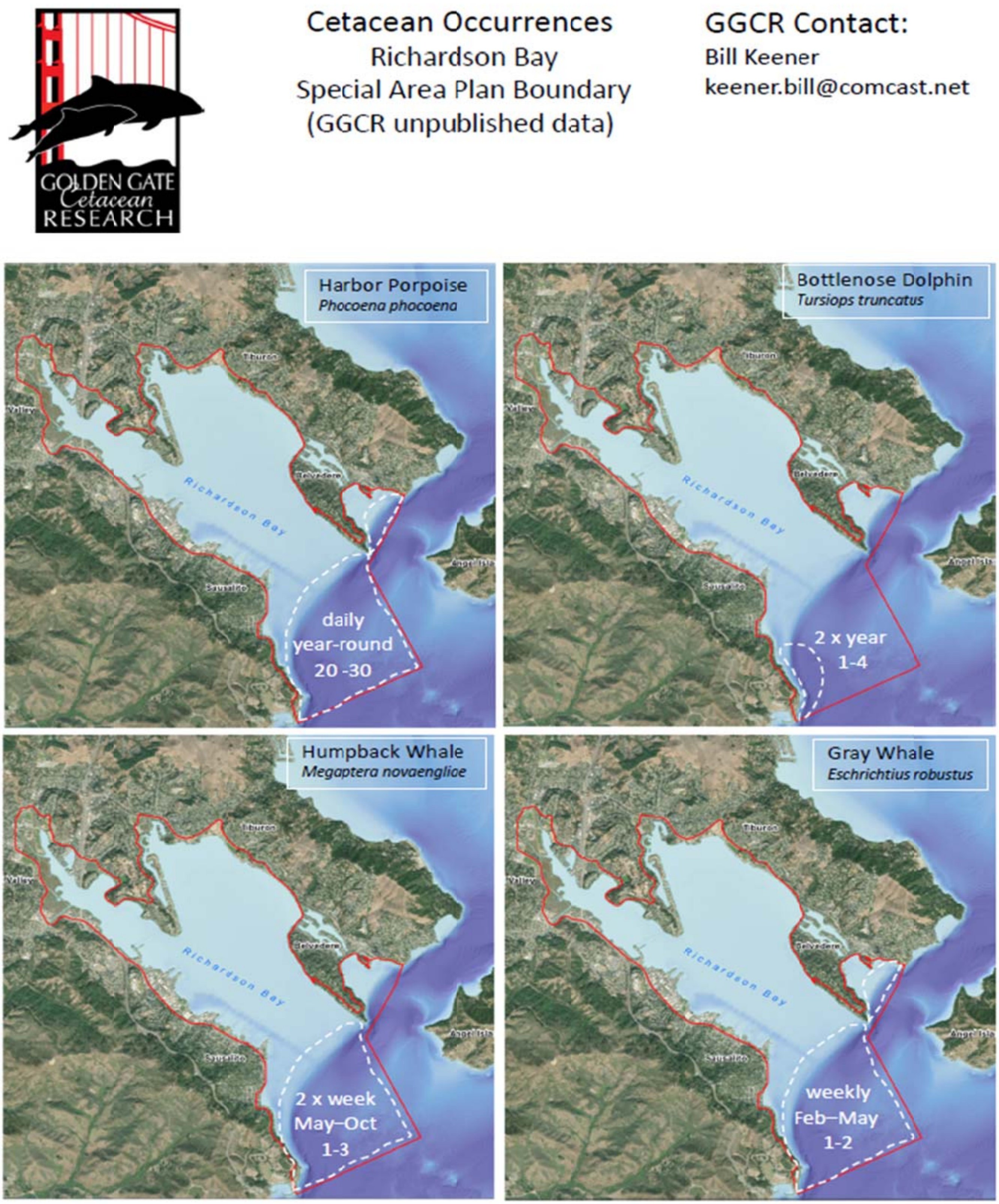


Figure 13. Cetacean records within the RBRA Special Area Plan (provided by GGCR)

The observed habituation of seals and sea lions to low-speed and non-threatening maritime activities has been seen in many areas and is not at all unexpected. Harbor seals forage commonly along the main channel of the harbor and within the deeper portions of Sausalito waterfront. To a lesser extent they also forage over the shallow flats of the broader bay. Approximately 30 seals are often times hauled out on the wooden pile wave break located along the eastern boundary of the Clipper Yacht Harbor.

Harbor seals hauled out on wooden pile breakwater adjacent to Clipper Yacht Harbor with the main navigation channel adjacent to the east and the marina channel adjacent to the west. Docked vessels are within 50 feet of the haul-out.

Sea lions are less common in the bay and generally found towards the mouth of the Bay near the deeper waters along the outer Sausalito waterfront. Why sea lions are not more common along the Sausalito waterfront is somewhat of a mystery. California sea lions have become prevalent within developed marina areas up and down the coast as populations have increased and off-shore fisheries have declined. The result has been an aggregation of animals around fishing harbors or public marinas where they can more readily garner food. Notably, some of the long-term anchor-out residents report that sea lion populations appear to have declined from earlier years when a fishing fleet was present in the waters of the western bay.

During herring runs in the bay, both harbor seals and sea lions follow spawning herring wherever they go. In addition, the spawn events attract animals from outside of the local area such that the numbers of sea lions and harbor seals observed often exceeds the regular bay population. Video provided by anchor-out resident Chad Carvey shows the influence of a herring spawning event within the moorings with both pinnipeds and birds foraging prolifically amongst the moored vessels. In addition, similar observations have been reported by others in the anchor-out community, RBRA and City of Sausalito staff, and Audubon representatives.

- Fissipeds

A more recent occurrence within Sausalito is the North American river otter (*Lontra canadensis*). At least one family of otters now occurs along the Sausalito waterfront being observed most frequently north of the Army Corps of Engineers Bay Model, but being encountered regularly in the area. While the use of the bay by otters has been generally reported to be along the Sausalito waterfront by anchor-out residents, including Greg Baker and Chad Carvey, it is assumed that otters would use other areas if the population increases, although otters generally forage on hard structure environments rather than in soft bottom areas.

None of the marine mammals present in the bay are expected to be particularly sensitive to mooring activities and their presence is not considered to be a factor in evaluating moorings in the Bay.

Moorings and Life on Moorings

Richardson Bay May 1958 shows different distribution of moorings than occurs today. The northwestern end of the bay has a number of moorings, assumed to be houseboats, Belvedere Cove had considerable moorings, the Sausalito waterfront had moorings where many marinas are present today, and a few moorings occurred in the central portion and near the far southern end of the bay.

Within the anchor-out residents that were interviewed many have a long history on the waters of Richardson Bay. The longest tenure on the waters includes residents with 50 and 34 years on the shore and waters of the bay with much of that time being within the anchor-out community. Several additional interviewees ranged from 10 to 4 years' experience as anchor-outs. As a result, the residents on the water provided a very unique and in-depth perspective on many aspects of Richardson Bay that can barely be appreciated by those with less interconnection to the waters. The interviewed residents on the water provide insights relative to transient ecological resources, storm conditions influencing moorings and on-water safety, mooring tackle design and demands, waste management, and shore landing logistics. They also provide keen insights into the make-up of the mooring community.

What is notable in the interviews is that there was widespread recognition that there were a number of members of the anchor-out community that were not represented in the section of the community interviewed. Several of those not represented were described as being very distrustful of the study process and its motivations. Some anchor-out residents, agencies, and social welfare interviewees noted that mental illness and drug abuse affects a substantial portion of this group not represented in the interviews.

- Mooring Resident and Vessel Population

Moorings have been an established use within Richardson Bay with vessels holding in the shallow waters of the bay for as long as navigation in the bay has occurred. In early years ships would await suitable tide or weather conditions to leave the bay and smaller vessels would moor offshore of south Sausalito. As the waterfront developed to include fishing operations and boatyard uses, vessels at dock and moored along the waterfront were common.

Richardson Bay May 1916 showing a history of vessel mooring at the extreme southern portions of Richardson Bay between Anchor Street and South Street, Sausalito. (Derived from Kelly et al. (2019) originally referenced to the Anne T. Kent Room of the Marin County Library)

With the meteoric growth in shoreline development in association with war time industrial manufacturing of ships and support vessels, large numbers of laborers moved to Sausalito and people living on the water rose. After the war, cheap barges and other vessels were readily available and the beginnings of a maritime anchor-out community had its origins.

During interviews, multiple anchor-out residents estimate the total number of individuals living aboard anchored vessels to be approximately 100 individuals. The anchor-out residents have noted that the number of live-aboards has increased substantially over the past several years as anchorages are being closed elsewhere in San Francisco Bay and Delta areas and cost of housing in the Bay Area rises. While it is difficult to get a precise count of residents within the anchorage, more extensive estimates have been made as to the number of vessels.

In recent years systematic inventories of vessels have been made by RBRA and the City of Sausalito. These surveys have carefully sorted vessels from tending dinghies and have recorded additional information regarding vessel condition, registration, etc. To support the present study, historic photographs were reviewed and vessels on moorings were mapped and counted by year to determine how vessel moorings have changed over time. In total 15 separate counts were made between the years of 1987 and 2019. For this investigation the vessel count did not distinguish vessels within waters of Sausalito from those within the RBRA or federal channel turning basin. The counts show high variability in the number of vessels present in earlier years hovering around 150 boats during a given year. However, between 2011 and 2013 the number of vessels increased substantially approaching 250 by 2016 (Figure 14). Note that the recent counts are generally higher than various counts made by local agencies and are based on rectified aerial image counts of vessels excluding dinghies. This is likely due to several factors including potential inclusion of very larger tender dinghies or stationary but unmoored vessels in the counts from aerial photographs. In addition, it is clear that a small number of vessels in the aerial counts were cruisers present in the bay for only brief periods. The City of Sausalito reports that the peak in vessels on the anchorage was about 250-260 in 2015. This is roughly comparable and a slightly higher estimate than obtained in the present study by aerial photo reviews.

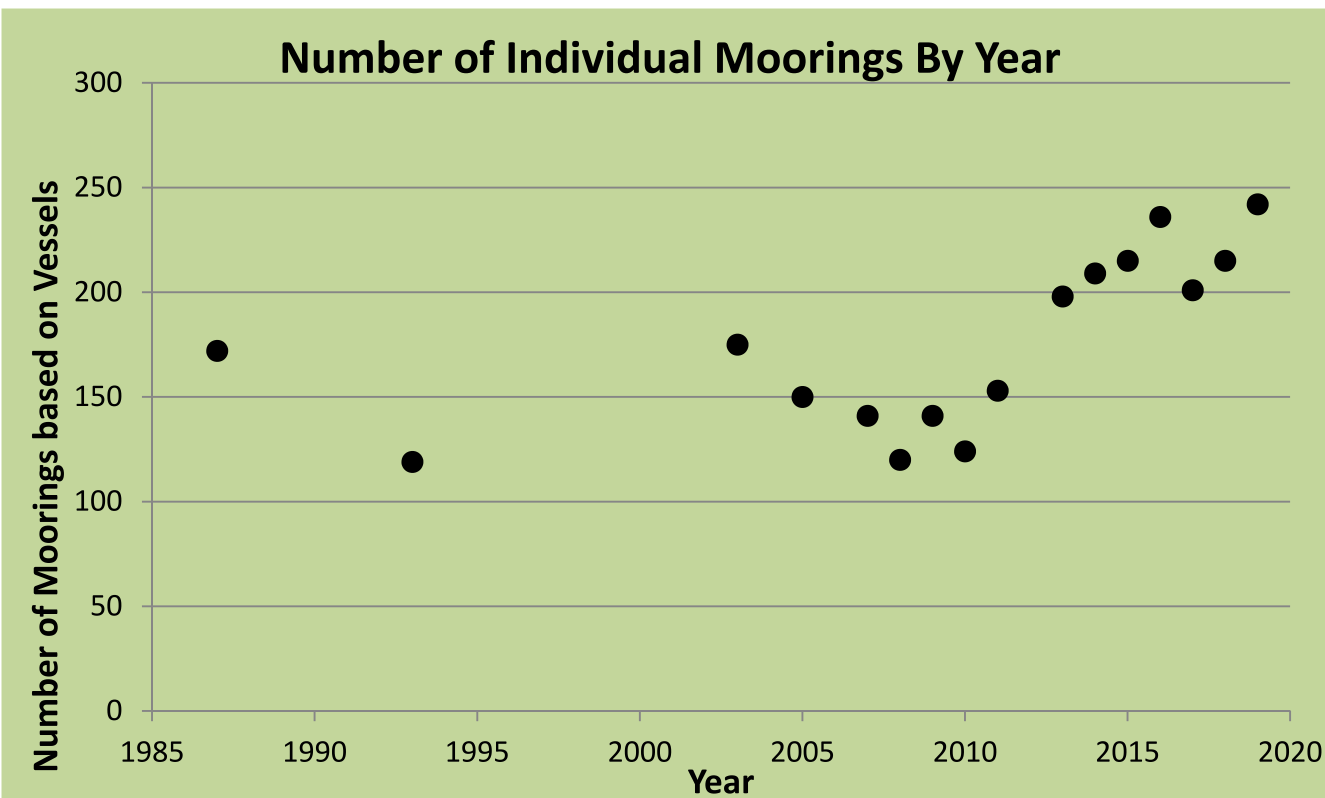


Figure 14. Vessel count within the Richardson Bay moorings over time.

An RBRA vessel survey summary covering surveys conducted in October 2018, March 2019, and June 2019 showed substantial fluctuations in vessel numbers located within County waters and a continued high rate of vessel infusion into the Bay. The study also found new vessels observed during each of the studies to account for a large percentage of the total vessel population, with 62, 33, and 54 new vessels being noted in October 2018, March, and June 2019, respectively (RBRA 2019). As a result of these observations, it is clear that any given count should be considered a snapshot in time and thus there is some imprecision in the vessel population. Further, vessels within the moorings move around from time to time making tracking the status of individual vessels more complex. This is especially true with limited resources and technology available to the local jurisdictions.

- Nature of Vessels on Moorings

The tremendous increase in moored vessels in recent years has been reported to be both the result of displacement of live-aboards from other areas as well as the recent rampant availability of free to nearly free vessels as other anchorages are closed down and agencies and marinas charged with disposal of derelict vessels have allowed vessels to be hauled away in lieu of being removed from the waters. The result of these two factors has been that the number of vessels on Richardson Bay greatly exceeds the number of residents on the water.

Many of the vessels are not registered, nor are they even titled to the parties claiming ownership. This creates some inherent stewardship and accountability issues. In a 2019 vessel survey, RBRA found that 46 percent of the vessels in County waters had expired or no vessel registration (RBRA 2019). Bill Price, previously of RBRA noted that most of the vessels that break free of their moorings or sink at the moorings do not have current registrations.

When queried about the nature of vessels on the water, some of the long-time residents noted that there are six different classes of vessels on the water:

- cruisers
- commercial boats
- pleasure boats
- live aboard boats
- storage boats
- trash

Cruisers are generally well kept larger vessels that make transitory mooring within the bay for days to months in association with long-range excursions. Commercial vessels operate along the Sausalito waterfront both within Richardson Bay and elsewhere in San Francisco Bay. Most commercial vessels staged in Richardson Bay are small vessels berthed at marinas, or moored near the waterfront. Pleasure boats are generally found in marinas, on private docks, or come into Richardson Bay for day trips. These boats occasionally anchor out in the bay.

Live aboard vessels comprise the majority of the boats on moorings in the bay. These boats are occupied by residents. Residents on the moorings describe a common progression of boats from live aboards to storage boats, which are used somewhat as floating garages on which possessions are stored to provide adequate living space on live aboard boats. As vessels fall into disrepair, are abandoned, or begin to sink, they are considered trash. Several of the residents on the moorings have noted that proliferation of vessels and the ease to which they are acquired, exchanged, and discarded has resulted in the accumulation of storage and trash vessels. One anchor-out resident noted that 30 percent, or perhaps fewer vessels, may have no known owner. This creates difficulty in administering moorings as there is limited capacity for enforcement on several vessels. However, when it becomes clear that a vessel does not have a known owner, multiple parties on the anchorage will sometimes claim ownership. This uncertainty of ownership and variable claims of ownership add complexity to the administration of the waters within Richardson Bay.

Commercial boats and pleasure boats are classes of vessels that are either temporarily anchored in the bay, un-occupied as live-aboard vessels, or are considered to have live aboard aspects that are incidental to their commercial activities. This is not to say that there are not vessels that once operated commercially that have become live aboard boats.

- Seaworthiness

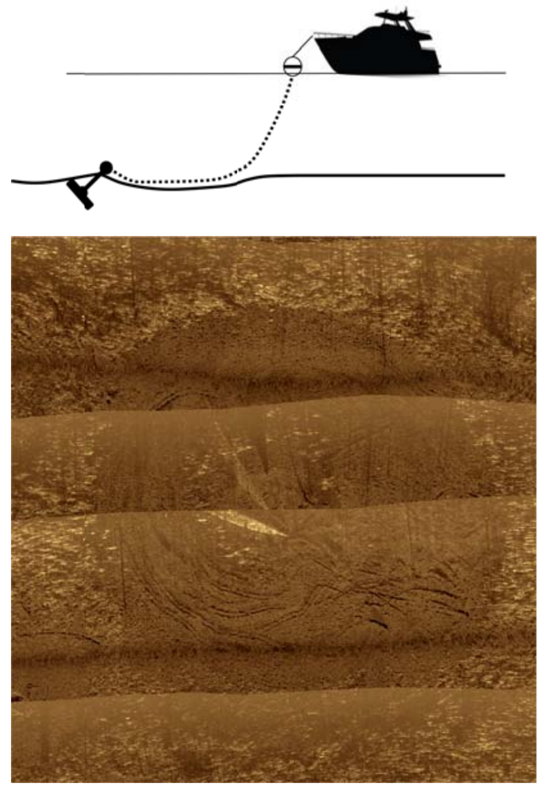
In 2019, the RBRA adopted Ordinance No. 19-1 An ordinance of the Richardson's Bay Regional Agency Updating Definitions, Providing for Vessel Conditions Required for Mooring and Anchoring in Richardson' Bay, and Amending the Location of Appeal Hearings (RBRA 2019). This ordinance defined more explicitly requirements for seaworthiness of vessels, provision of vessel sanitary facilities, and minimum conditions that a boat must be maintained at within Richardson Bay. Under the ordinance, seaworthy is defined as "Operational thru hulls, hoses and sea cocks; bilge pumps are operational and bilges are free of oil; no loose debris or materials on deck; hull, keel, decking, cabin and mast are structurally sound and vessel is free of excessive marine growth, excessive delamination or excessive dry rot that compromises the vessel's integrity to stay intact and afloat without extraordinary measures; capable of operation to avoid striking vessels, persons, and or property should it break free from its anchor." Vessels anchored or moored in Richardson Bay must also possess current and valid registration with the California Department of Motor Vehicles or current and valid documentation with the United States Coast Guard.

Ordinance No. 19-1 also provides clarity with respect to Harbor Master discretion and lack thereof with respect to various aspects of the ordinance and reiterated state and federal regulations.

Non-seaworthy vessel removed for disposal as marine debris (February 2019).

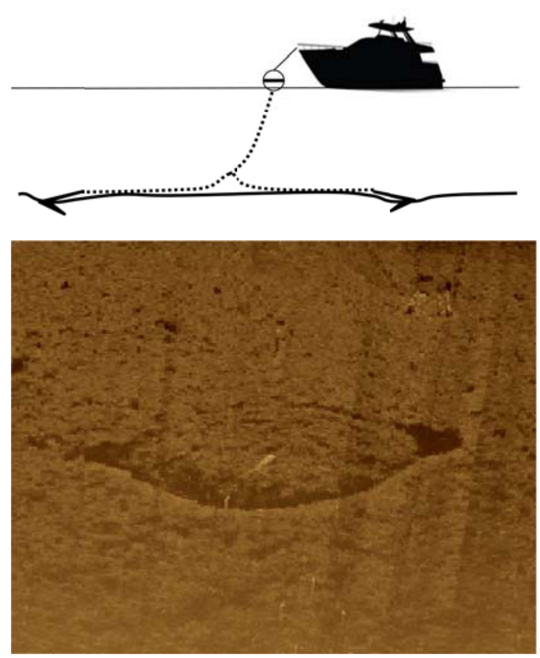
- Mooring Methods

Vessel mooring within Richardson Bay varies as the majority of the vessel moorings are privately installed and maintained. However there are two primary designs of mooring anchors in use. The details of the anchors vary considerably, but the basics are shared. The first is a single point mooring design with a central mooring anchor of either a mushroom anchor or clump weight design. There may also be standard claw anchors deployed with single point moorings in the bay. The anchor is attached to a heavy ground chain that extends to a shackle and lighter chain, cable, or line that then attaches the ground chain to the mooring ball or buoy. From the ball, a single or double pendant is used to connect the mooring to cleats on the bow of the moored vessel. Dinghies are generally stern-tied to the vessel. The lift of the ground chain accommodates tidal range and provides elasticity to the mooring dampening wave energy on the vessel and strain on the cleats. In some cases elastic pendant lines are also used. These further dampen the pull on the vessel hardware and soften the ride on the vessel.



Typical configuration for single point mooring and bottom scarring generated from such a mooring.as depicted in interferometric sidescan sonar mosaic.

The moored vessel on a single point anchor swings around the center point anchor dragging the ground chain across the bottom. This carves away at the bottom suspending the fine sediments allowing them to drift away from the mooring. In addition the mooring chain often creates ruts on the bottom. At most of the moorings within Richardson Bay the vessel keel also hits bottom during low tides and creates additional scarring. To illustrate this point, an interferometric sidescan sonar mosaic shows a single point mooring in an eelgrass bed. The image is akin to monochromatic photograph produced by sound. Eelgrass produces a bright return due to air in the leaves having a high acoustic reflectivity. The deeper scars on the bottom of the “crop circle” pattern are the result of keel dragging during low tide. Single point ground tackle moorings have the greatest capacity for seabed damage and are the most common moorings used in Richardson Bay.



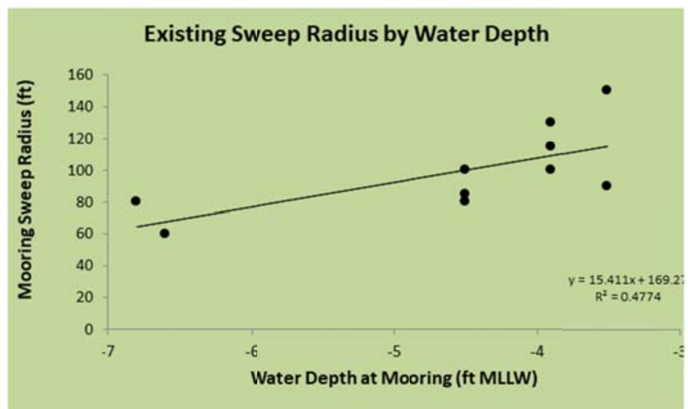
Configuration of two point swing mooring and bottom scar from mooring configuration.

Two point mooring configurations are the second most common moorings in the bay. In these moorings, claw anchors are situated facing each other and a tight chain is stretched between the anchors. A swivel is then connected to the chain and a riser chain, cable, or line extends upward to a mooring ball with the rest of the mooring tackle and configuration being the same as for a single point mooring. The elasticity of the mooring is derived from lifting the two chain legs off the bottom and bowing between the anchors. The results of this design are a lesser footprint of impact due to the elimination of the full radial swing. However, bottom scarring, while dependent on many factors is generally reduced by about two thirds or more over the single point mooring system.

The two point moorings are principally in use on larger vessels that are anchored in slightly deeper waters of the bay than most vessels. While the two anchor design has some merits over the single point anchor in terms of safety against break-away at ground tackle, and reduction in bottom disturbance, the design also has some weaknesses as well in that certain orientations of the vessel to the tackle can reduce the elasticity of the tackle and put more stress on cleats. As such, correct construction of these systems takes some consideration beyond that of a single point design. Further, recognizing potential for increased stress warrants use of elastic shock pendants and good cleats.

Vessels pivoting around the mooring, whether a single point or two point swinging mooring design rotate around the mooring center point within a swing radius of the mooring, vessel, and associated dinghies. The swing radius is useful in designing moorings to ensure that one moored vessel does not impact an adjacent vessel. However, for the present analysis of ecological injury, the sweep radius is of primary concern. The sweep radius is the radius within which a vessel and the mooring tackle affect the seafloor around the mooring. In many cases for moorings this radius is distinguished by a circle cut into the bottom around a mooring anchor. However, in the case of moorings in Richardson Bay, more often than not, the sweep radius is dramatically expanded by damage from chain dragging through eelgrass in the water column and damage caused by dragging of keels and or motors in the mud. In some instances the vessel keel drag and the ground tackle drag are discontinuous resulting in survival of some eelgrass within concentric sweep radii on the same mooring.

The sweep radius in a properly designed mooring is related to the tides, water depth, anchor type, vessel type, and loading anticipated from wind, waves, and currents. In general, a typical single point mooring has a rode scope of 2.5:1 to as much as 4:1 (rode length to high water depth) resulting in a sweep radius that increases with water depth. Further, the sweep radii generally increase with vessel size meaning a greater scope is played out for larger vessels. In the case of Richardson Bay, 10 moorings sampled at random were investigated to analyze sweep radii relative to water depth and also vessel size. The results of these analyses indicate that the sweep radii tended to be inversely related to water depth while the sweep radii were related to vessel length (Figure 15). However, what is missing from this analysis is that in every case investigated, the sweep radius in shallow water was defined not only by ground tackle drag, but also vessel drag. Only vessels in slightly deeper water had bottom scour driven only by ground tackle.



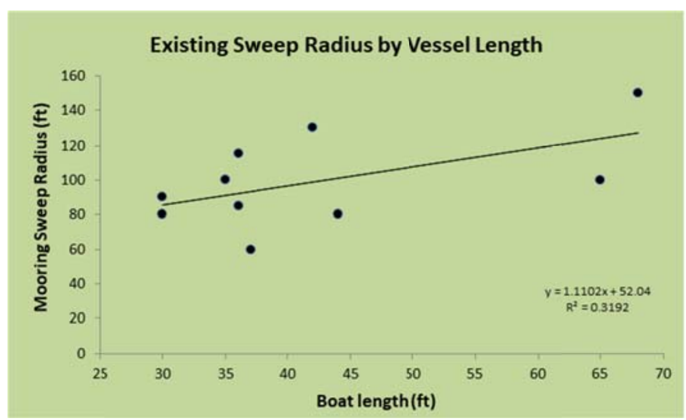


Figure 15. Relationship between sweep radius water depth and vessel lengths within Richardson Bay mooring sampling

In addition, many moorings have an expanded circular influence beyond physical indication of vessel or mooring tackle dragging that is not readily explainable by mechanical damage to the bottom. This is a halo around the mooring that is also principally devoid of eelgrass but which shows no indication of bottom dragging and which is generally beyond the radius of the mooring rode, pendant, vessel, and dinghies. It is possible that this halo affect around the moorings is the result of earlier changes in vessels or tackle on the mooring and represent prior disturbance, or it may be related to turbidity influence from chronic bottom disturbance within the mooring sweeps. Typically near sources of high turbidity, sediment settles on leaves and smothers eelgrass or otherwise impairs photosynthesis. This can be an issue around dredging projects in

Sweep radius illustrating concentric impact areas of ground tackle on the inner portion of the sweep and keel drags on the outer portion of the sweep (left). Low tide turbidity plume generated from vessel grounding at the outer margin of the sweep radius. Note the vessel keel drag scar on the bottom above dinghies in photograph (right).

shallow waters adjacent to eelgrass beds.

- Evolving Conditions

Within the last year, Sausalito has move forward with aggressive enforcement within moorings in Sausalito waters. This includes enforcement of 72 hour anchoring, removal of vessels designated as marine debris, and a stepwise progression of enforcement starting with least compliant to most compliant vessels. Legacy, long-term anchor-out residents with seaworthy vessels have been placed at the lowest priority of enforcement actions. Concurrently Sausalito has been working with various local and regional social services organizations to provide land-side assistance to those requiring it. The result of Sausalito's waterside enforcement actions have led to a shift of vessels into RBRA waters from Sausalito waters. However, the extent to which this has occurred is a matter of some disagreement among different agencies and the anchor-out community.

In recent months, the RBRA has similarly stepped up action to curb the number of vessels identified as marine debris and to implement enforcement actions under its recently adopted Ordinance No. 19-1. The work also includes a focus on curbing the influx of new boats into Richardson Bay. This activity is underway, but principally shouldered by a very small staff with limited resources, supported intermittently by available law enforcement to the extent resources can be provided.

On a broader basis, multiple agencies, marinas, and other parties are coordinating efforts in an attempt to curb the availability of cheap or free vessels that feed the supply chain of new vessels entering various areas throughout San Francisco Bay and the Delta.
In addition to the governmental shift towards greater enforcement of existing rules and regulations, as well as provision of expanded social services to support both on-water residents and displaced residents moving off of the water. This includes actions of local ministries.

Also from the non-governmental perspective, there are on-going and active efforts on the part of the anchor-out community to reduce the issues and impacts associated with the anchor-out population and vessels through the Richardson Bay Special Anchorage Association (RBSAA, 2016). This includes working on self-governance elements to reduce the burden of enforcement by understaffed government agencies. The anchor-out community has partially implemented a “self-help” system where vessel rescues and retrievals are implemented to a great degree by able-bodied mariners in the anchorage, vessel inspections and repairs are sometimes undertaken as a collaborative effort, vessel and mooring tackle inspection and shipshape stewardship is promoted along with mariner training,, and on-water security is achieved through an ad hoc neighborhood watch. Finally, as environmental impacts have been identified, the RBSAA has sought to identify and support means of addressing these concerns to the extent practicable. The RBSAA representatives have noted that the organization is seeking to both engage in conflict resolution while defending and lobbying for persistence of anchor-out use within Richardson Bay. Readers are encouraged to visit anchoredout.org for greater depth of review of community coordination towards sustaining moorings and conflict resolution.

The evolving synergy amongst public and private parties is seen as a good, but a fledgling and somewhat flawed model because parties are aligned in many respects, but pursuing often opposing goals. Further, the anchor-out community is not a unified community that can be expected to operate cohesively. This makes it difficult to fully trust in self-governance on the water and absent enforcement tools being both in place, and applied as needed, any actions to address ecological impacts and retain moorings will eventually unravel. This concern has been recognized widely within those interviewed in the anchor-out community, and recommendations as to governance structures have been put forward that would make use of community-based enforcement, assistance, and self-regulation backed up by governmental regulatory and law enforcement support.

In practice, the inaccessibility and greater resource demands to effectively police the waters where access is all by vessel to respond to social, emergency, law enforcement and regulatory functions creates a necessity to have greater reliance on the on-water residents, or an increase in resource allocation to governmental agencies expected to conduct the required work.

Notable in the interviews across a broad strata of stakeholders was the degree of commonality in concerns and recognitions of problems. Concurrent with this was a collective desire to resolve conflicts with the major departure being perspectives on where the resolution ends with respect to moorings and anchor-outs remaining or being fully removed from the water. The anchor-outs, agencies, and other stakeholders interviewed all share a common understanding that a portion of the anchor-out community is nearly unregulatable due to mental health issues, drug abuse, or efforts to maintain a lifestyle outside of the regulated society. This portion of the community is also the principal complication to development of an effective management strategy to deconflict anchor-outs and ecological resources.

Ecologically Suitable Mooring Areas and Mooring Design

Restrictive Spatial Modeling

The approach to evaluating the potential for curtailing impacts to ecological resources while retaining moorings was application of an unweighted spatial model. A spatial model is a means to combine many metrics that vary across the landscape into an objective output reflecting the degree of suitability or unsuitability to a particular purpose.

The modeling approach was designed as a restrictive model rather than an opportunity model. This means that the model was approached through documenting constraints to moorings rather than being constructed based on factors favoring moorings. However, the effect of the modeling approach makes little difference to the ultimate outcome. An additional element of the model is that it is a multiplicative rather than an additive model. This means that any factor that drives a single screening metric to zero suitability eliminates suitability within the model, irrespective of how suitable other metrics may be. To avoid a weighting bias across model parameters, all parameters were scored within a range from 0 to 1.

For the model five metrics were included as they facilitate distinctions between areas of suitability to support moorings (Figure 16). These metrics were:

- **Water Use** – Areas of the Sanctuary, navigation channels, existing marinas, and land-locked waters were considered unsuitable as were the waters of Dunphy Park in Sausalito where mooring is excluded by an adopted park plan. The area of The Marinship Launching Basin (part of the Marinship Turning Basin) was considered to be intermediately impaired due to the fact that it historically was maintained as part of the federally maintained channel, likely a wartime condition, and is privately owned with an unclear maintenance dredging future.

- **Wave Environment** – The wave environment screening was based on the modeled 20-year storm maximum wave height scenario. In the model, maximum wave heights of less than 4 feet received a score of 1.00 while waves in excess of 4 feet and less than 4.5 feet received a suitability score of 0.75, waves in excess of 4.5 feet and less than 5 feet received a suitability score of 0.5, and waves in excess of 5 feet but less than 5.5 feet received a score of 0.25. Larger 20-year storm wave conditions were considered unsuitable for mooring of vessels. Note that suitability scores within the wave climate are based on assumptions of seaworthy vessels of an approximately 24-foot and larger size on a proper mooring configuration. The comfort within individual vessels through such an extreme weather event would be expected to vary. The 20-year storm condition was adopted over a 1-year maximum wave environment or a 100-year event with the thought that smaller vessels may need to relocate to more sheltered areas in the face of very extreme events and 1-year events were more suited to defining comfort levels than distinguishing mooring acceptability levels. Finally, it should be noted for this parameter, that many of the vessels within the interior portions of Richardson Bay are not believed to be in a condition suitable to sustain the identified lower suitability scored 20-year event maximum wave conditions as they are not likely to be seaworthy.

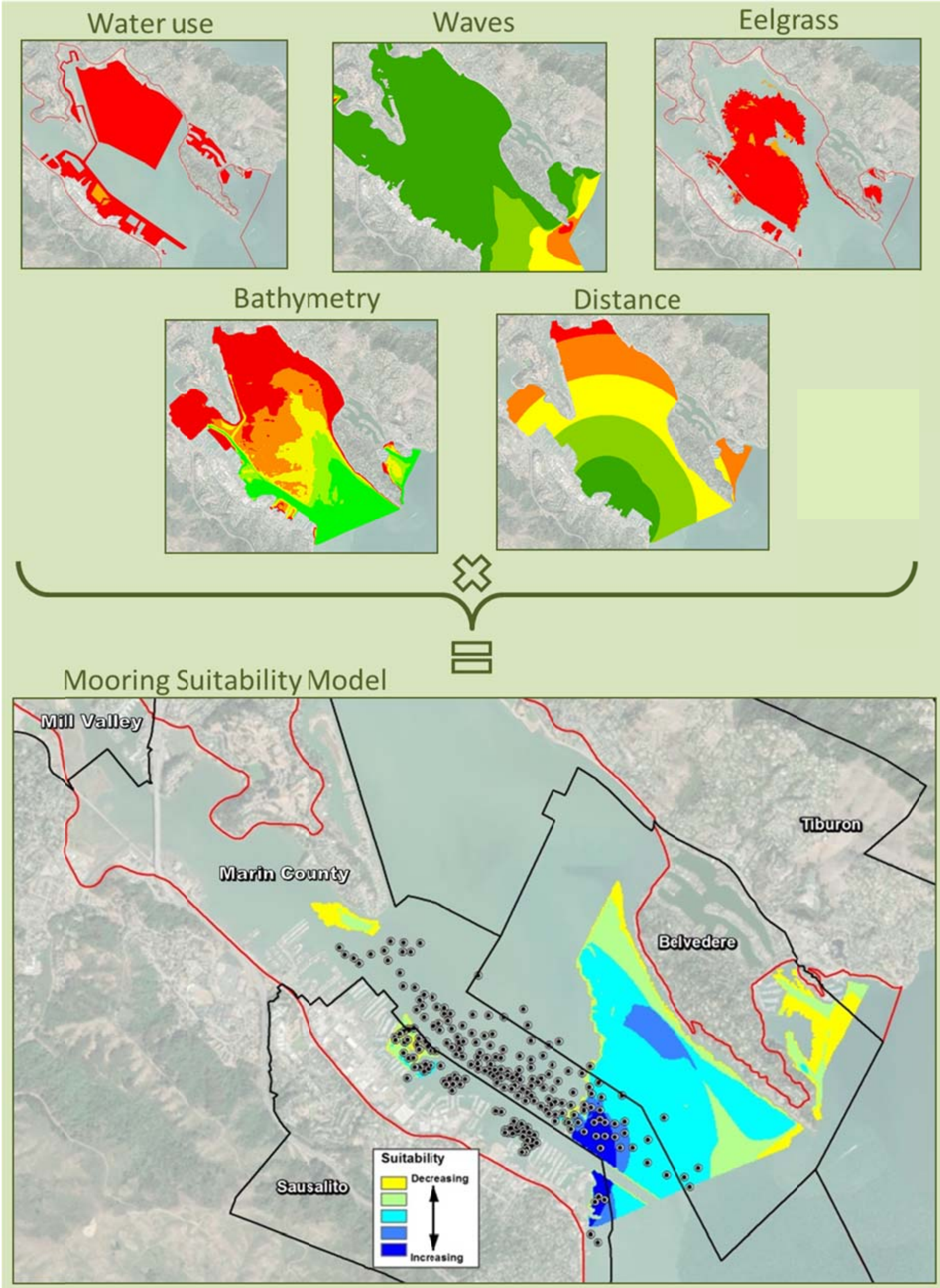


Figure 16. Mooring Suitability Model. *Yellow to Blue indicates increasing suitability. Black dots are 2018 mooring distributions.*

- **Eelgrass Habitat** – The most explicit ecological resource for which spatial definition exists and impacts can be identified is eelgrass. While less substantial or localized impacts may occur for avian resources, there is not adequate information to suggest water bird impacts within any anchorage areas and shallow flats where shorebird impacts may occur are screened out by bathymetric analyses. For the eelgrass consideration was given to both the frequency of eelgrass presence over time and the bottom cover class of eelgrass (Figure 9). Eelgrass was assigned to ether a zero suitability for moorings or 0.25, very low suitability where eelgrass occurrence through time and bottom coverage were both low. The results of this classification were limited distributions of marginally suitable conditions at the deeper and shallower margins of the beds.

- **Distance to Shoreline Landings** – The distance to shoreline landings factors into consideration of safe and effective mooring locations. Shorter distances are favored over longer distances. In discussions within the anchor-outs there was a wide mix of perspectives regarding suitable distance from shore. With most of the dinghies present on the water having small gasoline motors travel distance issues are relatively mitigated. However, in general, greater distance from shoreline landings is less desirable. The scoring of this parameter used a value of 1.0 for transit distances less than 0.5 miles, 0.75 for distances of less than 1 mile, 0.5 for distances of less than 1.5 miles and 0.25 for distances of less than 2 miles. Consideration was given to potential for alternative shoreline landings, although no logical alternatives to the existing landing locations were identified without consideration of additional infrastructure such as adding a dinghy dock. Shoreline areas within Belvedere Cove, specifically off of Beach Road, might be suited to accommodate an additional landing geometrically and could substantially alter the scoring of this metric if such a landing were incorporated.

- **Bathymetry and Vessel Draft** – The impact analysis of vessel damage to existing benthic resources includes bottom scarring, eelgrass loss, and sediment suspension in association with both mooring ground tackle dragging and vessel keel and motor dragging on the shallow bottom of the bay. While changing mooring tackle may be able to curb damage from the moorings themselves, it would not address vessel dragging damage. Further vessels that drag within eelgrass canopy can damage the eelgrass beds, irrespective of whether the vessels actually ground on the bay floor. Vessel dragging not only results in a degree of environmental effect that may range from minor to major, it also has the potential to damage the vessel hull, plug water intakes on engines, and alter movement patterns of vessels subject to wind and current shifts, and thus can result in increased risk of fouling moorings of adjacent vessels. The extent to which vessels drag is a function of draft and tidal stage. Moored and anchored vessels should not ground, even at the lowest tides and moored vessels should not bounce on the bottom as a result of wave passage. For this parameter, most of the northern end of the bay is extremely shallow and not well suited to moorings. However, some of the moored vessels are small and consist of flat bottom or semi-vee hull power boats with very shallow draft of less than a foot. At the lowest annual tides reached in the bay (approximately -1.5 to -2.0 feet MLLW during any given year), a vessel drafting more than 1.0 foot would likely ground if waters were shallower than -3 feet MLLW. It is unlikely that any of the moored vessels presently on the waters of Richardson Bay draft less than 1.0 foot.

  Conventional wisdom suggests that moorings should be placed in waters of at least 6 foot of depth below the lowest tides to allow safe mooring depths for most recreational vessels (McAllister 2018). This also ensures that vessels do not damage the bottom with low tide drag or damage the vessels by bottoming out on anchors or other hard debris on the bottom. For larger sailboats additional water depth is required to accommodate deep keels. In areas of higher wave climates, clearance should also account for water depths when vessels are in wave troughs. Waters deeper than 25-30 feet become expensive and require larger radii. In Richardson Bay this is not a particular issue since the bay does not reach these depths until the steep slope at the bay entrance that is unsuited for any moorings.

Given the makeup of the vessels on the water and conventional wisdom guidance, the ideal mooring depths in the bay are waters deeper than -8 feet MLLW. Unsuitable bathymetry was defined as shallower than -3 feet MLLW, a low suitability of 0.25 was assigned to waters shallower than -4 feet MLLW, waters of -6 feet MLLW were scored as a 0.5, and waters shallower than -8 feet MLLW were scored as 0.75. Deeper waters were given a full score of 1.0. Note that even though very shallow water still has some degree of suitability, the vessels for which mooring depths are suited are still limited by the true vessel draft. Further, the suitability scoring for bathymetry does not address shallower conditions due to eelgrass canopy as this concern is considered addressed by the eelgrass parameter.

The screening mooring suitability model identifies areas of mooring suitability from decreasing suitability to increasing suitability (Figure 16). Areas that are not colored are not considered to be suitable to support moorings. The basic premise of the suitability model is one intended to identify areas suitable to support moorings that do not conflict with ecological resource conservation within Richardson Bay. The model does not address any metrics beyond those including in the model parameters as discussed above and thus does not explore factors of appropriateness of land or water uses outside of the specifically excluded water use constraints included as a parameter in the model, nor does the model address the individual suitability of any particular vessel presently on Richardson Bay to be located within areas identified as suitable for moorings. This is a very important point in that several of the vessels on the water are not likely to be seaworthy and suitable mooring locations identified in the model principally favor areas further to the south than the central mass of vessels presently occupied. A shift in center mass would move vessels from locations that experience lower overall wave and wind energies and thus some of the vessels in the bay could likely not be suited to elevated wave exposure conditions.

Mooring Types

Moorings presently used in Richardson Bay are of a classical design of one or two point configurations with heavy chain ground tackle. There may also be other mooring configurations present as well. These have been discussed previously. Irrespective of the mooring types presently in use, due to the shallow nature of the bay and the use of bottom dragging ground tackle, impacts to eelgrass do occur when vessels are moored in eelgrass. Further, these impacts may be expanded by vessel grounding during low tides. Conventional ground tackle moorings result in scarring of the bottom associated with anchor rode dragging during changing tide and wind conditions with more or less of the rode dragging based on the tidal height and extent of tension on the anchor tackle at any given time. Except where vessel drag exacerbates benthic scarring, the pattern of damage is reduced with reducing tackle dragging. With a one-point mooring reliant on lifting of a ground-chain for surge reduction, the damage is defined by a radial scar with the central region receiving more damage and the outer radii receiving less impact. Often times the scar also reflects a bias based on predominant wind and current directions (Figure 17). With a two point system, the scarring is reduced and extends along the axis of the opposing anchors with the broadest extent of damage being towards the center of the array. Finally, with a three point anchoring system most of the lateral movement of tackle is controlled by opposing anchors and thus the bottom damage is further reduced to narrow trenches where the anchor lifts and falls in response to tides and wave motion. Greater numbers of points further reduce the lateral movement, but not significantly.

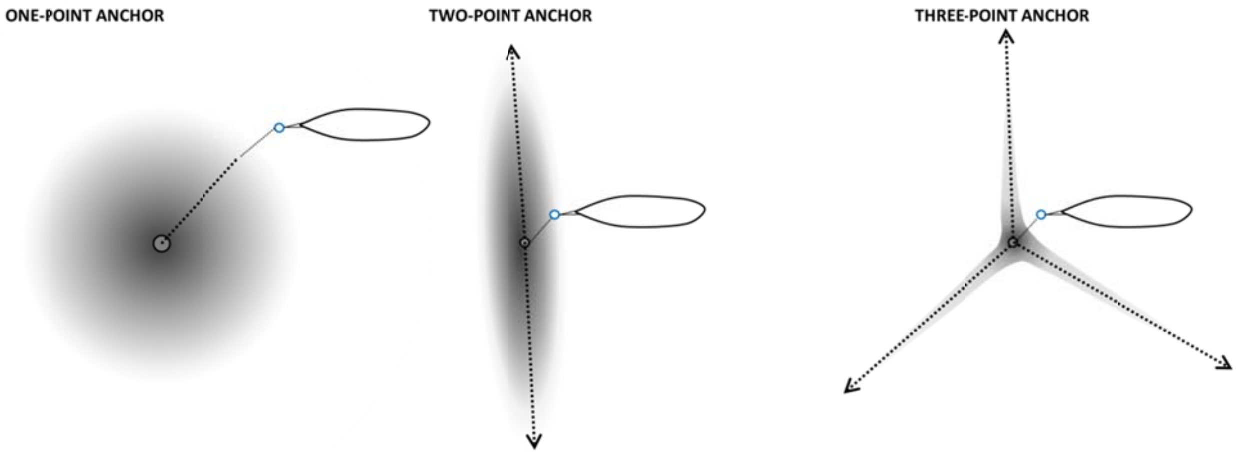


Figure 17. Conventional ground tackle anchor scarring. *Typical configuration of conventional ground tackle anchors result in diminishing benthic ecosystem damage with increasing points of anchoring.*

Vessels moored in deeper waters outside of eelgrass and employing classical mooring tackle generally are not likely to generate impacts to eelgrass; however, they may contribute to local elevation of turbidity as ground tackle drags around the anchors. This impact is lessened with two point moorings and is further lessened with three point conventional ground tackle moorings. Alternatives to conventional moorings include a suite of moorings that are marketed as "conservation moorings", "eco-moorings", "ecologically-friendly moorings", etc. As a group, these moorings typically employ either a helical anchor or very heavy gravity anchor, a means to suspend the mooring tackle above the bay floor, an elastic anchor line, a mooring buoy, and a pendant line (Figure 18). The conservation moorings were initially developed as a means of reducing ecological impacts from ground-tackle dragging on the seafloor; however, they have also been used as a means of increasing mooring packing density since the required radii for moorings using an elasticized anchor line over a standard chain mooring can be substantially reduced.

The elimination of ground tackle in conservation moorings has been identified as providing benefit to previously damaged eelgrass habitats. In Maine a replacement of conventional moorings with conservation moorings resulted in a slow recovery of damage with 13 percent recovery over a 3 year period (Swan 2012). Swan noted that some continuing effects of vessel shading may have contributed to limited recovery over the 3 years post mooring transition. This observation may suggest that active restoration of mooring scars may be suitable to accelerate eelgrass recovery.

There are several manufacturers of conservation moorings and such moorings have been used in many areas around the world for many years. In general, the moorings have been time tested and demonstrated to be suitable for most mooring uses and environments when properly sized, installed, and maintained. For this reason, no particular conservation mooring is recommended in this investigation, but rather the suite of moorings is discussed and some of the various manufacturers' information and photographs are provided. This is not to be construed as a particular product endorsement, nor is the information presented considered to be exhaustive. Several of the manufacturers have posted information on line and many of the products have been reviewed and evaluated in different studies (Massachusetts Division of Marine Fisheries 2019, Swan 2012, Outerbridge 2013).

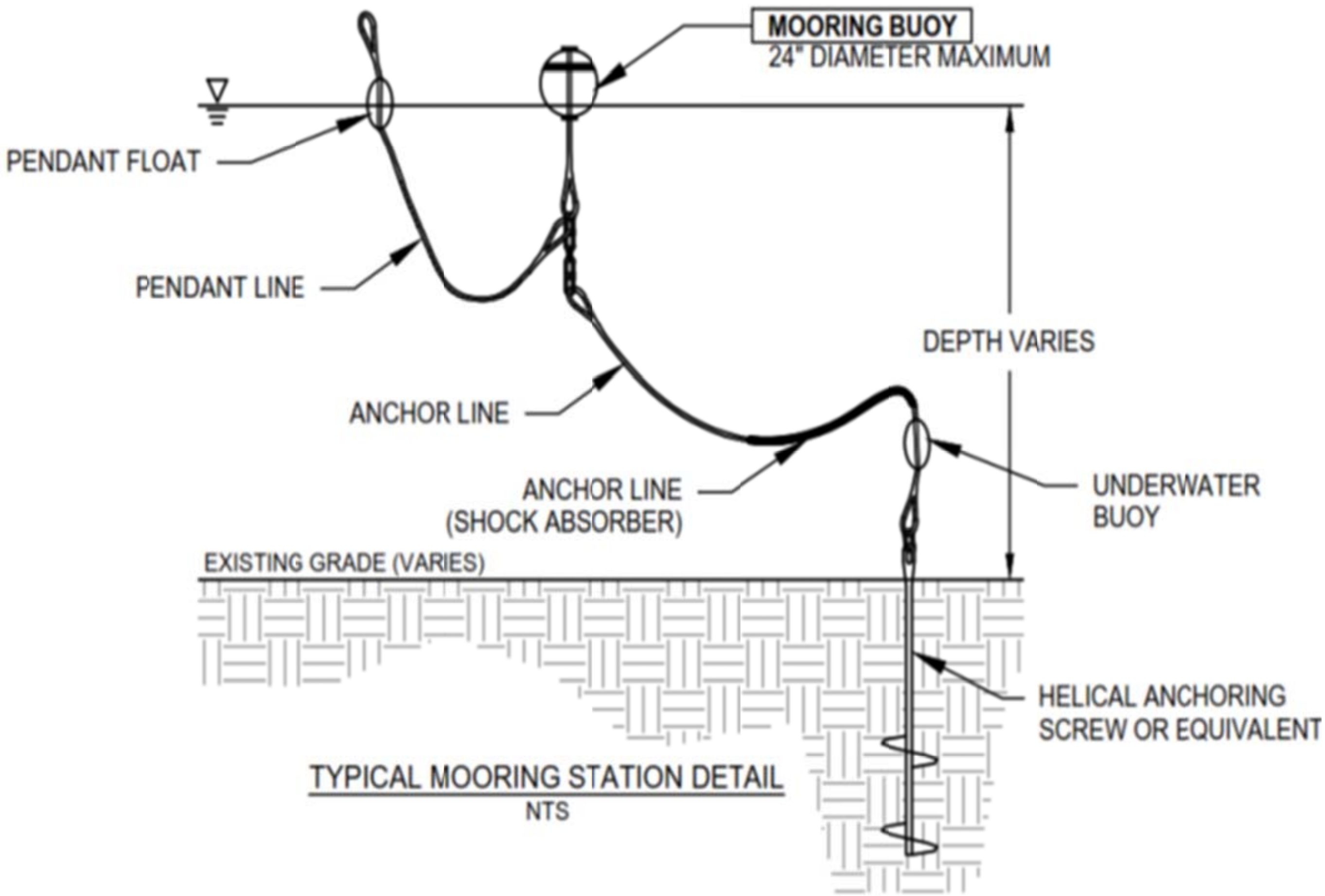
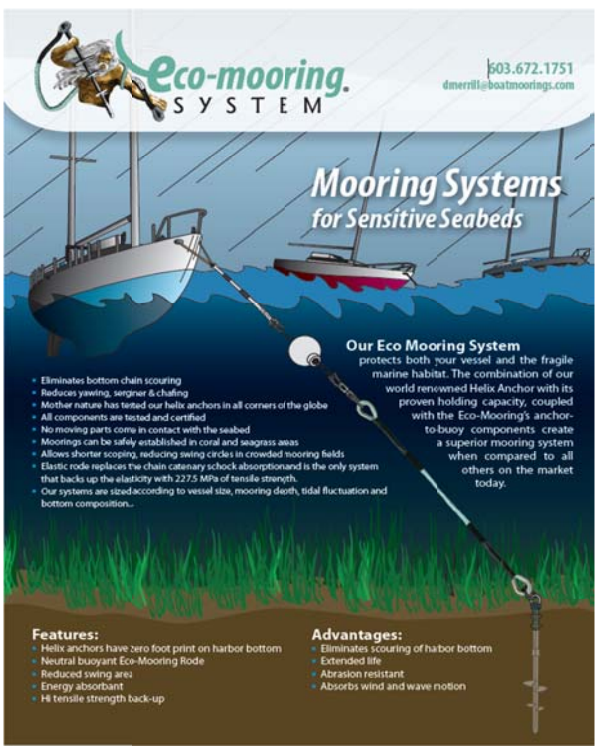


Figure 18. Conservation mooring components. *Typical configuration of various conservation moorings are similar to conventional moorings within the near surface element.*

Examples of differing systems and components are displayed in this section. Manufacturers, distributers, and installers often interchange different system components to meet particular application needs. This interchangeability of parts, as with conventional moorings provides flexibility in design; however, it also creates potential for untested pairings and potential points of failure. For this reason, any mooring system considered, of a conventional or conservation mooring type, should be engineered for the particular application and installed and maintained by a qualified party. Common manufacturers or vendors of conservation moorings, mooring systems, and mooring components include, but are not limited to the following:

- Big-e Storm Pendant (boatmooring.com)
- Eco-mooring System (boatmooring.com)
- Elastic Mooring Systems (ecomooringsystems.com)
- Hazelett Marine (hazelettmarine.com)
- Helix Mooring Systems (helixmooring.com)
- Marine Flex (marineflex.com)
- Sea-flex (seaflex.net)
- StormSoft (jwilburmarine.com)



Differing mooring systems and system components from manufacturer advertising information and evaluation reports available. Examples are provided for information only and are not a particular product endorsement.

Conservation moorings have several potential benefits beyond conventional catenary system moorings. In addition to eliminating ground tackle scour impacts in benthic environments, elastic rode moorings can be situated with tighter packing ratios (i.e., smaller mooring radii). Conventional moorings with adequate anchors and properly selected chain can be constructed with a mooring scope ratio ranging between 2.5:1 and 4:1 (length of rode to water depth at extreme high tide). Conversely, conservation moorings with elastic rodes can have a mooring scope ratio as short as 1:1 or 2:1 (McAllister 2018). The ultimate mooring radius must account for the projected length of rode from center at the lowest tide, the pendant, the vessel length, and any allowance for stern tied dinghies. This will generate the mooring swing radius. To avoid vessel contact, the mooring swing radii should not overlap and vessels placed on moorings should be appropriate in scale to the designed mooring load and swing radii.

Conservation moorings have greater rode and pendant elasticity and therefore provide more consistent energy absorption curve than conventional chain tackle. This means that the elastic mooring rode and elastic pendant lines are more efficient at absorbing wave energy by continuously increasing the tension between anchor and the moored vessel. This is especially true when vessels are already pulled tight against moorings such as in strong current or wind and subject to wave impact. This means that vessels on elastic moorings tend to ride more smoothly than those on ground chain tackle and there is less potential for bow cleat pull-out due to static shock energy such as when chains are pulled tight.

Elastic mooring rode and storm pendants can provide a reduction in jarring impacts under severe storm conditions (photo from ecomooringsystems.com)

Relative to conventional tackle, conservation moorings have reduced annual mooring cost due to many factors including less abrasion of mooring components, more robust anchoring devices, and readily swappable components. Finally, from a designed and managed mooring area configuration, use of helical anchoring systems provides a degree of positional permanence that restricts the capacity to readily reposition moorings. This makes it easier to ensure a static layout of moorings.

While there are several positive attributes of conservation moorings, there are also some drawbacks. First, these moorings have a greater capital cost due to specialized equipment needed for setting helical anchors, greater component costs, and limited numbers of suppliers. Second, less mobile moorings, while a positive factor in limiting undesirable repositioning also limit capacity to complete desired reconfiguration of moorings. Finally, conservation moorings are not familiar to many mariners and harbor masters. This means that they suffer from a high degree of skepticism and a lack of installation, maintenance, and user expertise.

There have been a number of well referenced failures of conservation mooring components that are worth noting. However, these have generally not been failures of the basic mooring elements, but rather failures in application design, installation, and component selection. Most notable, helical anchor pullout has occurred with applications in very soft sediments, where limited or poor engineering has been undertaken, and where tension testing has not been undertaken. In general, helical anchors are an extremely effective anchoring system but they require good geotechnical data, installation expertise, and load testing to be effective. In many instances, helical anchors that are not professionally installed are undersized with inadequate length and/or helix diameter, incorrect helix vane numbers, or inadequate load testing. As a result, helical type anchors and other earth anchors such as Manta Ray anchors and are not authorized in the Tomales Bay mooring program (GFNMS 2018). Notwithstanding such application issues, helical anchors are a well-tested and understood anchoring methodology, but are not for amateur installations.

Other failures of conservation moorings have been related to component failures pairing in various installations as well as poor inspection and maintenance schedules. Perhaps the most notable example of issues with conservation moorings relate to Seaflex Mooring Systems installed off Santa Barbara's East Beach. In this application, 12 Seaflex Moorings were installed along with 45 single point conventional catenary moorings. In short-order 9 of the conservation moorings had failed (Hill 2012). Blame for the failure was spread widely but appears to be most likely related to chaffing of components as a result of inappropriate component pairing and inadequate maintenance. As a result of a 75 percent failure rate, Santa Barbara ceased installation of Seaflex moorings, but allowed the existing installed helical anchors to be retrofitted with conventional ground chain moorings.

Mooring Costs

Mooring costs vary significantly based on design, sizing, material costs, labor and equipment required for installation and number of moorings to be installed. In general, conventional moorings are less expensive to install than conservation moorings and garner less synergy of scale associated with installation of multiple moorings concurrently. A single point conventional catenary mooring with a gravity anchor costs approximately $1,000-$2,000 to install, depending much on the nature of the anchor used. Two and three point conventional moorings generally rely on plow anchors rather than gravity anchors and thus are often easier to install, but may include higher material and labor costs. As a result such moorings may run from $1,500-$2,500, depending mostly on the sizing of component parts.

Conservation moorings have a longer design life than conventional moorings, but cost more to install. As an example, the Hazelett mooring has a design life of 30 years and reduced maintenance needs compared to traditional moorings. Elastic rode components can be installed as 1 unit or 4 in parallel for heavier loads. As a result of the relevant range of configurations that may be required, the price for a single unit ranges from $1,700-$4,500 without anchors and $1,850-$5,000 with helical anchors for a single system. Installation may cost an additional $500 to $2,000 per unit when installed in multiples. For individual installations, costs may be even higher unless the helical anchor is omitted and a large gravity anchor is substituted instead. This is principally due to the need for specialized equipment to install the helical anchors.

Mooring Carrying Capacity

A goal of the present study was to determine the mooring carrying capacity of Richardson Bay. To do this the mooring suitability model (Figure 16) was used. Areas of potential moorings were distributed within the modeled suitable locations with a consideration of what uses were best suited within the areas. The outermost exposed areas were identified as suited to transient cruiser mooring uses and large vessel moorings. The more protected inner portions of the bay were identified as suitable for primary moorings, including smaller vessels. Finally, an area located within the Marinship Basin was identified as most suited to transitional and storm shelter moorings (Figure 19). This area was considered to be most suited to vessels that have been damaged and under repair, or vessels that are not yet seaworthy in a transition towards some of the outer mooring locations. Notably, the Marinship Basin presently supports eelgrass and it is expected eelgrass will continue to expand in this area as the site shoals to shallower depths. However, it was recognized that any mooring shift in Richardson Bay would require a transition area and storm refuge since many of the vessels are not considered to be presently seaworthy. As previously noted, the mooring areas identified only consider resolution of ecological conflicts and do not consider other factors of land and water uses, political, or social considerations.

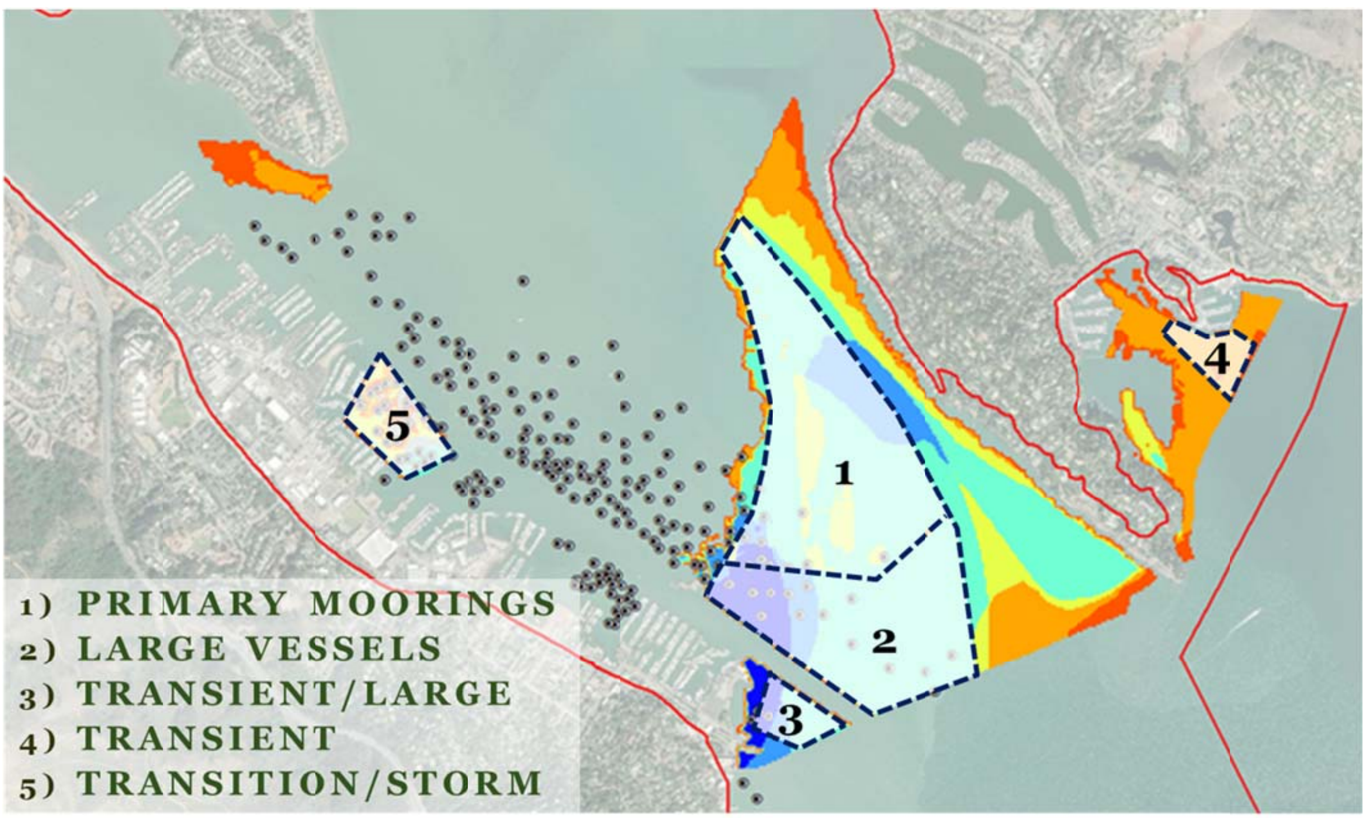
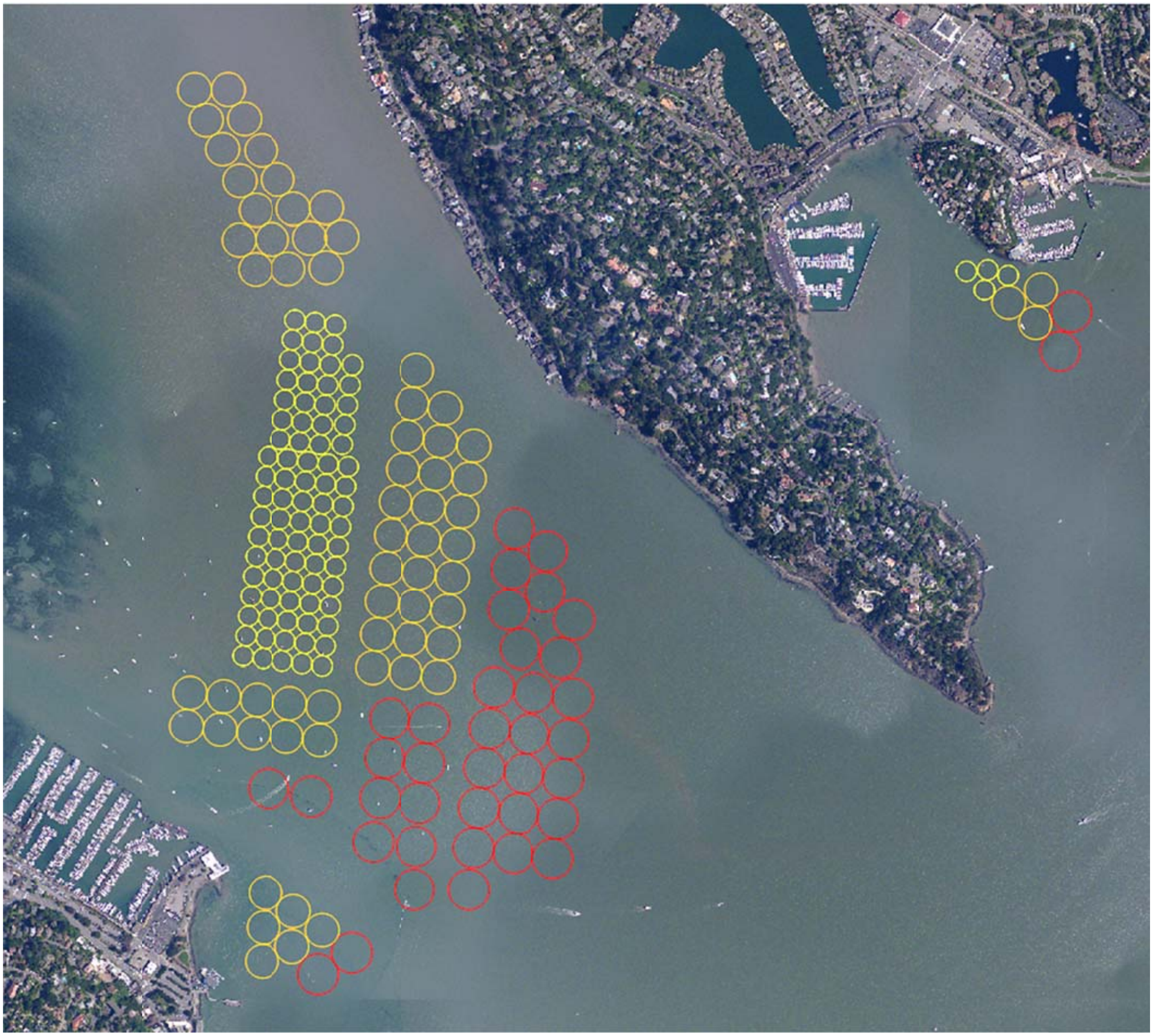


Figure 19. Potential mooring locations and uses to remove moorings from areas of ecological conflict.

The largest radii of moorings with conventional single point ground chains presently in use in the Richardson Bay moorings are approximately 150 feet. This mooring radii scale is much larger than required for either the present conventional ground tackle moorings or conservation moorings. When the suitable mooring locations are examined it is clear that dense packing of moorings with 75, 125, and the oversized 150 foot radii, would result in accommodation of a minimum mooring capacity in excess of 100 vessels. At a tight packing of moorings at the smaller 75 foot radii (still larger than necessary with conservation moorings), the number of moorings that could be accommodated are in excess of double the number of moorings presently existing within Richardson Bay.



Example configuration of moorings using extremely large radii of 75 feet (yellow), 125 feet (orange), and 150 feet (red). The tight packing of moorings with these larger than required radii demonstrates that capacity for mooring positioning exceeds need or desirability of any of the stakeholder parties. As such considerable flexibility would exist for scaling and adapting mooring locations to address concerns beyond the scope of the present study.

The adoption of policies to curb influx of new vessels and requirements for vessels in the bay to be sea-worthy means that the overall capacity of the suitable mooring locations is not an important consideration since the capacity is much greater than the vessel count available to make use of the area. However, this observation does point to the fact that opportunities are therefore available to optimize distribution of moorings based on consideration of non-ecologically based factors beyond the scope of this study.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study documents considerable ecological damage, predominantly to eelgrass habitat and presumably to resources associated with eelgrass as a result of existing mooring practices and locations. This impact has expanded in recent years. The study further documents ecological and water quality resources that are not likely to be significantly adversely affected. In the case of bird resources, robust analysis was not possible given the data available and a significant data gap exists.

The study also documented constraining factors influencing potential means of addressing ecological impacts. These included constraints of inadequate management resources both within government and community organization, constraints of existing mooring designs and vessel number and condition, and physical and biological constraints of the bay. Most notably, the majority of areas presently utilized by moored vessels are too shallow for appropriate mooring and vessels ground at low to extreme low tides.

Modeling suggests the opportunity for deconflicting moorings and eelgrass resources through spatial separation is possible. However, it is questionable that most of the existing anchor-out vessels are seaworthy and suited to relocation to more energetic environments identified through modeling.

Opportunities for reducing benthic impacts include changes in mooring technologies. This includes implementation of multi-point conventional moorings with three-point moorings being more desirable than two-point moorings. Conservation moorings are also suited for use within Richardson Bay.

Recommendations

While the study suggests means to resolve ecological conflicts several recommended actions would facilitate success of such an effort. These recommendations are:

- Enforce existing policies on vessel seaworthiness and registration
- Prohibit new vessels from becoming resident vessels by enforcing mooring time limit restrictions
- Remove unoccupied vessels and enforce a one resident, one vessel goal
- Relocate vessels out of eelgrass and into deeper waters to the south
- Install publically owned three-point conventional moorings or conservation moorings in deeper waters
- Eliminate privately owned and maintained moorings or dictate specific designs and locations
- Number all moorings and assign occupants to specific moorings to reduce management complexity
- Commit staffing and vessel resources necessary for effective enforcement
- Schedule, complete, and document regular tackle inspections
- Enlist and support community collaboration in self-reliant management to reduce enforcement needs
- Explore mooring fee-based or other means of funding regular maintenance costs
- Pursue capital funding through grants, and maybe mitigation funds to implement initial actions necessary to remove non-seaworthy vessels and relocate sea-worthy vessels

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