



Estuary Wetland Assessment

BIGHT '23



Southern California Bight
2023 Regional Monitoring Program
Volume IX

SCCWRP Technical Report 1489

Southern California Bight 2023 Regional Marine Monitoring Program: Volume IX. Estuary Wetland Assessment

Jan Walker¹, Eric D. Stein¹, Adriana Le Compte Santiago¹, Kathryn Beheshti², Xavius Boone³, Jeff Crooks⁴, Natalie De Wet⁵, Karina Johnston⁶, Dane Lazarus⁷, Dan Robinette⁸, Rachel Smith², and Christine Whitcraft⁹

¹*Southern California Coastal Water Research Project, Costa Mesa, CA*

²*University of California, Santa Barbara, Santa Barbara, CA*

³*San Diego State University, San Diego, CA*

⁴*Tijuana River National Estuarine Research Reserve, Imperial Beach, CA*

⁵*University of San Diego, San Diego, CA*

⁶*Heal the Ocean, Santa Barbara, CA*

⁷*University of Southern California Sea Grant, Los Angeles, CA*

⁸*Point Blue Conservation Science, Petaluma, CA*

⁹*California State University, Long Beach, Long Beach, CA*

ACKNOWLEDGEMENTS

Prepared for:

Commission of Southern California Coastal Water Research Project
3535 Harbor Blvd, Suite 110
Costa Mesa, CA 92626

This report should be cited as:

Walker, J.B., E.D. Stein, A. Le Compte Santiago, K. Beheshti, X. Boone, J. Crooks, N. De Wet, K. Johnston, D. Lazarus, D. Robinette, R. Smith, C. Whitcraft. 2026. Southern California Bight 2023 Regional Marine Monitoring Program: Volume IX. Estuary Wetland Assessment. Technical Report 1489. Southern California Coastal Water Research Project. Costa Mesa, CA.

Keywords:

Ecosystem function-based assessment, estuaries, Southern California Bight, ecosystem condition, marsh vascular plant support, sea-level rise amelioration, regional monitoring

Data Availability: All data are publicly available and accessible.

California Estuary Monitoring Program (CalEMP). 2026. California Estuary Monitoring Program Query Tool. Southern California Coastal Water Research Project (SCCWRP), Costa Mesa, CA. <https://calemp.sccwrp.org> (accessed [date]).

Schroeter, S.C., H.M. Page, D.C. Reed, K.M. Beheshti, R.S. Smith, D.Y. Huang, and SONGS Mitigation Monitoring. 2025. UCSB SONGS Mitigation Monitoring. Environmental Data Initiative. <https://marinemitigation.msi.ucsb.edu/data> (accessed [date]).

Tijuana River National Estuarine Research Reserve (TRNERR). 2026. Program-wide monitoring data. <https://tijuanaestuary.org/what-we-do/research/monitoring/> (accessed [date])

BIGHT '23 ESTUARINE WETLAND ASSESSMENT WORKGROUP MEMBERS

Member	Organization
Alys Arenas	California Department of Fish and Wildlife
Ami Latker	City of San Diego
Bradley Nussbaum	Nature Collective
Cameron Young	Orange County Public Works
Celine Gallon	Los Angeles Regional Water Quality Control Board
Chad Loflen	San Diego Regional Water Quality Control Board
Corey Clatterbuck	California Coastal Commission
Ed Almanza	The Laguna Ocean Foundation
Emily Duncan	Los Angeles Regional Water Quality Control Board
Erica Yelensky	US EPA, Region 9
Gabriel Penaflor	California Department of Fish and Wildlife
Hannah Gray	Resource Conservation District of the Santa Monica Mountains
Josh Westfall	LA County Sanitation
Karin Wisenbaker	Aquatic Bioassay
Kate Becker	San Diego Regional Water Quality Control Board
Katherine Beauchamp	City of San Diego
Katie Nichols	State Coastal Conservancy
Kellie Uyeda	UC San Diego
Laurie Koteen	California Marine Sanctuary Foundation
Luke Ginger	Santa Monica Bay Restoration Commission
Maria Rodriguez	Ocean Protection Council
Mark Baker	Physis
Melissa Loebel	California Department of Fish and Wildlife
Melissa Scianni	US EPA, Region 9
Mo Wise	The Laguna Ocean Foundation
Rachel Darling	USC Sea Grant
Rosi Dagit	Resource Conservation District of the Santa Monica Mountains
Sara Worden	California Department of Fish and Wildlife
Stefani Daryanto	Los Angeles Regional Water Quality Control Board
Taruna Schuelke	City of Ventura
Thanhloan Nguyen	Los Angeles Regional Water Quality Control Board
Tom Ford	The Bay Foundation
Valerie Vartanian	Naval Base Ventura County

EXECUTIVE SUMMARY

The overall goal of the Estuary Wetland Assessment component of Bight '23 was to assess the condition of estuaries through the lens of ecosystem function in the Southern California Bight (SCB). Specifically, the Bight '23 Estuary Element strove to:

1. Characterize estuaries within the SCB across key functions and indicators
2. Leverage multiple regional efforts to answer key regional questions
3. Collect baseline data and pilot assessment frameworks for future coordinated efforts

To accomplish these objectives, Bight '23 focused on three primary questions:

1. What is the relative condition of Southern California estuaries based on a function-based assessment?
2. What are the primary factors influencing the relative condition of estuaries within the SCB?
3. What are the predominant stressors and/or factors that are impacting the lower-condition estuaries?

The Bight '23 assessment piloted an ecosystem function-based approach to measure estuarine condition and to provide data that can be easily compared across systems and among monitoring programs within the region. Three priority ecological functions (Support of Marsh Vascular Plant Communities, Sea Level Rise Amelioration and Resiliency, and Bird Habitat Provision) were selected because 1) assessment strategies were already developed and piloted for two of the three functions by the California Estuary Monitoring Program (CalEMP) and 2) the majority of sites had the necessary data available to assess the functions. The functions were evaluated using eight indicators, which in turn were assessed via 15 metrics measured at 19 estuaries across the Bight.

Results of the survey provide a first-ever initial assessment of regional estuary condition using a function-based approach thereby demonstrating the utility and value of this assessment approach. The analysis provides the following preliminary conclusions as a starting point for ongoing evaluations:

1. Sea-level rise (SLR) amelioration is a region-wide vulnerability in the sampled sites. Of the three functions scores, SLR Amelioration showed the lowest and most compressed distribution, with no site reaching the High Function category. This finding suggests that sea-level rise resilience is a systemic challenge across southern California estuaries rather than a problem limited to a subset of sites. The relatively low upland migration potential scores driving this pattern indicate that many estuaries may lack the physical space needed to keep pace with projected sea-level rise, making this a priority concern for regional management.

2. Bird habitat is the strongest performing function of the ones assessed but masks important site-level disparities. Bird Habitat scores were the highest and most variable of the three function indicators, with the majority of sites scoring in the Good to High Function range. Sites that had lower Bird Habitat scores also tended to score poorly on physical condition (high anthropogenic disturbance), suggesting that degraded habitat structure could be a driver of poor bird community performance at these locations. However, the bird assemblage-based indicators in estuaries are strongly influenced not only by underlying habitat condition but also by sampling effort and site accessibility, which can influence detectability and observed species richness.

3. The Marsh Vascular Plant Function was generally in good condition across the southern California estuaries. Marsh Vascular Plant Support scores were notably consistent across the sampled sites, with the majority of sites falling within the Good category. This tight clustering suggests that marsh plant communities across the sampled sites within the region are broadly functional, supporting adequate levels of native vegetation cover, structural complexity, and general habitat condition. The absence of any sites in the Low Function category and the limited number reaching High Function together indicate that catastrophic vegetation loss is not widespread.

4. The three functions assessed, Marsh Vascular Plant Support, Sea Level Rise Amelioration, and Bird Habitat Provision, represent important but incomplete dimensions of estuarine health, and conclusions about overall site condition should be interpreted accordingly. A site that scores well across all three functions may still be significantly degraded with respect to unmeasured functions, as illustrated by the Tijuana River Estuary, which ranked among the highest-functioning sites despite documented impacts from transboundary sewage flows on biological community diversity.

5. Eutrophication and non-native species stressors are predominant at a few sites but were not observed to be a consistent problem among sampled sites. The presence and dominance of non-native or regionally introduced species, such as inland silversides (*Menidia beryllina*) and rainwater killifish (*Lucania parva*) in southern California estuaries are often indicative of altered or degraded environmental conditions. Both species are highly tolerant of wide ranges in salinity, temperature, and dissolved oxygen, and they tend to thrive in systems with simplified habitat structure, reduced tidal exchange, and variable or poor water quality.

6. Anthropogenic disturbance, defined as the extent and intensity of urban infrastructure within the estuary boundary and buffer zone, is the most widespread stressor within the sampled estuaries. Anthropogenic disturbance in southern California estuaries is strongly reflected in the reduction and degradation of buffer zones and the loss of internal physical structure that supports characteristic estuarine flora and fauna. Unlike eutrophication and non-native species,

which were concentrated at a few sites, anthropogenic disturbance scores showed a broadly distributed pattern across the sampled sites in the region, suggesting that physical modification and degraded buffer condition affect nearly all estuaries to varying degrees.

7. Managed sites had generally higher function than less managed sites, while estuary type had less influence on the overall condition. However, bird habitat function was lower in temporarily closed estuaries than in perennially open systems.

The function-based assessment illustrates that overall site condition is not driven by a single factor or function. The three functions assessed during this survey provide a partial view of overall estuary condition. Inclusion of additional functions and assessment over time will improve our understanding of condition and its relationship to stressors and management actions. To support this objective, future surveys should establish a core set of indicators that must be collected at every site. We recommend habitat and elevation mapping, marsh vegetation, water quality, hydrology, the California Rapid Assessment Method (CRAM), fish, invertebrate, and sediment nutrients.

Water quality data is among the most ecologically important indicators yet were unavailable for nearly half of the sites. Future surveys should prioritize deploying continuous water quality loggers to capture, at a minimum, temperature, salinity, and dissolved oxygen at all sites for a minimum deployment period that captures both tidal and diel variation. Summer deployment should be considered as a complement to fall surveys specifically to capture potential hypoxic conditions. Finally, repeated monitoring across multiple seasons and years is essential to distinguish persistent site-level patterns from transient conditions, to detect change over time, and to build the long-term baseline needed to evaluate management effectiveness and track responses to climate change.

TABLE OF CONTENTS

Acknowledgements	i
Bight '23 Estuarine Wetland Assessment Workgroup Members	ii
Executive Summary	iii
Table of Contents.....	vi
Table of Tables	viii
Table of Figures	ix
Introduction	1
Bight '23 Objectives.....	2
Methods	3
Southern California Coastal Wetlands	3
Statewide and Regional Monitoring Programs	5
California Estuary Monitoring Program.....	5
Southern California Wetland Recovery Project Regional Monitoring Program.....	6
Sampling Design	8
Function-Based Assessment Framework.....	11
Indicators	13
Functions	14
Stressors.....	19
Results	22
Indicators.....	22
Functions.....	25
Stressors	34
Discussion.....	37
Core Insights	38
Lessons Learned and Recommendations.....	43
Conclusion	48
References.....	49
Appendix 1. Indicators	54
Abiotic Indicators	54
Water Quality	54
Sediment Quality	61
Mouth Dynamics	63
Trash.....	65

Biotic Indicators	66
Benthic infauna	66
Fish	70
Vegetation.....	77
Birds.....	81
Habitat Indicator	86
California Rapid Assessment Method.....	86
Appendix 2. Site Descriptions	88
Appendix 3. Narrative Synthesis	89

TABLE OF TABLES

Table 1. Site ID and Estuary names for the 19 targeted southern California sites.	9
Table 2. The total number of estuaries sampled during the Bight '23 estuary wetland survey and the total number of estuaries present within the SCB for each archetype.	10
Table 3. Eight indicators and 15 metrics were monitored across the 19 sites.	14
Table 4. Summary table of all five lessons learned with recommended actions and estimated level of effort.	47
Table 5. The data sensors available for each estuary. * marks sensors that are deployed permanently and empty cells indicate no sensor was deployed.	55
Table 6. Rough cost estimates for one logger array at a single estuary site.	57
Table 7. Mouth closure events from January to December 2023 using Planet satellite.	64
Table 8. Species assignments for each infauna feeding group.	68
Table 9. Total survey effort (number of surveys) broken out by survey protocol type for each of the 19 Bight '23 estuaries.	82
Table 10. List of the 20 bird guilds used to develop the bird function indicator. Guilds are categorized as to general habitat in which they reside.	82
Table 11. Available bird data for southern California: number of bird species, number of observed guilds, proportion of observed to expected guilds, number of human subsidized species (5 possible species), and number of invasive/exotic species (14 possible species).....	83
Table 12. Species assignments for each bird guild.	85
Table 13. The most recent CRAM surveys conducted at the Bight sites.	87
Table 14. Grouping Factors.	88
Table 15. Data-informed best professional judgement to qualitatively describe the condition of each site based on these functions. Cells are colored according to four categories: Low Function (dark purple; 0–25 for Marsh Vascular Plant and SLR Amelioration, 0–40 for Bird Habitat), Moderate (teal; 26–50, 41–80), Good (green; 51–75, 81–120), and High Function (yellow; 76–100, 121–160+).....	89

TABLE OF FIGURES

Figure 1.....	5
Figure 2.....	9
Figure 3.....	11
Figure 4.....	13
Figure 5.....	16
Figure 6.....	24
Figure 7.....	25
Figure 8.....	27
Figure 9.....	28
Figure 10.....	29
Figure 11.....	31
Figure 12.....	33
Figure 13.....	36
Figure 14.....	37
Figure 15.....	58
Figure 16.....	59
Figure 17.....	60
Figure 18.....	62
Figure 19.....	63
Figure 20.....	66
Figure 21.....	67
Figure 22.....	68
Figure 23.....	72
Figure 24.....	73
Figure 25.....	74
Figure 26.....	75
Figure 27.....	76
Figure 28.....	76
Figure 29.....	77
Figure 30.....	78
Figure 31.....	79
Figure 32.....	80
Figure 33.....	84

INTRODUCTION

Estuaries sit at the interface of marine, freshwater, and terrestrial realms, making them among the most productive and ecologically significant ecosystems on the planet (Costanza et al. 1997; Barbier et al. 2011). They support exceptional biodiversity and provide critical habitat for resident and migratory species, including invertebrates and fish that use estuaries as nursery habitat and refugia before migrating to the ocean (Beck et al. 2001). Beyond their biological value, estuaries deliver a broad suite of ecosystem services including food provisioning, water purification, sediment transport, carbon storage, coastal protection against storm surge and sea level rise, and recreational and aesthetic values (Costanza et al. 1997; Barbier et al. 2011; McLeod et al. 2011). Despite this importance, estuaries are among the most degraded coastal habitats in southern California (Kennish 2002; Lotze et al. 2006), and previous Southern California Bight Regional Monitoring Program reports have consistently identified estuaries and embayments as the most contaminated habitat stratum in the region.

Estuaries are disproportionately vulnerable to degradation because human populations are concentrated in coastal areas and because estuaries sit at the downstream end of catchments, accumulating stressors from entire watersheds (Kennish 2002). These include altered hydrology, modified sediment dynamics, nutrient loading, and chemical and trash contamination from urban and agricultural land uses (Valiela et al. 1992; Cloern 2001). Estuaries are simultaneously exposed to marine stressors such as fishing pressure, ocean acidification, and climate-driven changes in sea level and storm frequency (Harley et al. 2006). The cumulative effect of these pressures has contributed to substantial habitat loss across the Southern California Bight (SCB): the region has lost an estimated 62% of its historical estuarine area to fill, diking, and development, leaving a fragmented network of remnant systems under continued stress (SCWRP 2018). Protecting and restoring what remains is therefore a regional conservation priority, requiring not only an understanding of individual stressor pathways but a comprehensive view of cumulative condition across the Bight.

The SCB encompasses more than one hundred estuaries spanning a wide range of sizes, configurations, and landscape settings. This diversity complicates regional assessments and makes it difficult to identify dominant stressors or prioritize management actions. Addressing these challenges is increasingly urgent, given that estuarine condition is central to multiple state and regional regulatory programs, including MS4, NPDES, California Wetlands Mitigation policy, and biostimulatory provisions, and California is directing over \$500 million toward coastal resiliency over the next three years. Estuaries are a cornerstone of that investment, and rigorous condition assessments are essential to ensuring resources are allocated effectively.

The Bight Regional Monitoring Program offers a framework to build on existing assessment tools and approaches and address these management priorities. Through an integrated

assessment, this effort advances our understanding of estuarine health, stressor response, and long-term resiliency across the region.

Bight '23 Objectives

The overall goal of the Estuary Wetland Assessment component of Bight '23 was to assess the condition of estuaries through the lens of ecosystem function in the SCB. Focusing an assessment framework on ecological functions allows for the creation of linkages among assessment results, ecosystem services, and designated beneficial uses for each estuary.

Specifically, the Bight '23 Estuary Element strove to:

1. Characterize estuaries within the SCB across key functions and indicators
2. Leverage multiple regional efforts to answer key regional questions
3. Collect baseline data and pilot assessment frameworks for future coordinated efforts

To accomplish these objectives, Bight '23 focused on three primary questions:

1. What is the relative condition of Southern California estuaries based on a function-based assessment?

The central question to Bight '23 was understanding the relative condition of Southern California estuaries at a single time point (Fall 2023). Condition means the status of physical, chemical, and biological indicators of the levels of services and beneficial uses of estuarine wetland systems (SCWRP 2018). Specifically, this question was assessed using a function-based approach, where individual indicators were linked to specific functions to evaluate estuary condition via functional performance. Each estuary was assessed across three functions relative to other estuaries in the SCB. Estuaries were scored relative to all evaluated estuaries using condition descriptors: Low Function, Moderate, Good, and High Function.

2. What are the primary factors influencing the relative condition of estuaries within the SCB?

Specific factors were evaluated relative to estuary condition, such as archetype (i.e., physical structure and setting), estuary mouth status (whether a site is perennially open or temporarily closed), and level of management (federal, state, private, or none).

3. What are the predominant stressors and/or factors that are impacting the lower-condition estuaries?

The condition of estuaries may be impacted by multiple potential stressors, including climatic conditions, sediment contaminants, and nutrients. This question helps us understand the response of estuaries to disturbances and stressors. Given the limited availability of

systematically collected stressor data itself the integrative relationship between stressors and estuarine condition scores was evaluated qualitatively based on best professional judgement of managers and Bight participants.

METHODS

To assess the overall health and condition of estuaries in the Southern California Bight (SCB), we adapted and refined the assessment framework for the California Estuary Monitoring Program (CalEMP; <https://calemp.sccwrp.org/>). The CalEMP program's goals are to monitor California estuaries with a standard, comprehensive function-based assessment framework to determine the health of California's estuaries. Bight '23 focused on southern California coastal estuarine wetlands and leveraged many ongoing monitoring programs to produce a regional condition assessment.

Southern California Coastal Wetlands

Southern California estuarine wetlands are complex, highly variable ecosystems that therefore exist in many shapes and sizes. The physical features, climate, and hydrology of coastal southern California have produced a unique set of physical conditions and a diversity of plants and animals that distinguish the region from any other in North America. Unlike the broad, gradually sloping coastal plains of the Atlantic and Gulf Coasts, southern California has steep coastal mountains that descend sharply to the ocean. Summers are hot and dry in this semi-arid, Mediterranean climate, while winters are cool, with rainfall varying in amount and intensity, from droughts to steady rains to torrential downpours.

Southern California's estuarine wetlands historically supported large areas of vegetated and unvegetated tidal marsh; however, in the last 200 years, more than 62% of these wetlands have been lost to intensive urban development (Stein et al. 2014). Wetlands have been filled, diked, drained, and broken into pieces to allow for agriculture, grazing, transportation, urban development, and flood protection. For many tidal wetlands, the hydrologic connection to the ocean has been modified as tidal inlets have been dredged, filled and drained to maintain open tidal connections, reduce inlet migration, and address inland flooding. These many wetland stressors have reduced large wetland complexes down to small fragmented systems. These modifications within wetlands and their associated watersheds have not only reduced wetland areas, but the composition of wetland habitat has also changed (Stein et al. 2014). Predicted higher sea levels will result in more wetland loss and habitat type conversion, which will threaten our ability to maintain a network of diverse wetlands along the southern California coast into the future (Doughty et al. 2019).

There are 118 individual estuarine wetlands in the SCB, which are categorized into coastal wetland "archetypes", or representations of a group or class of coastal wetlands similar in form

and structure (Figure 1). Grouping wetlands into archetypes provides a general conceptual model that can explain how a specific group of wetlands function and how they may respond to external pressures or drivers (SCWRP 2018). For a detailed list of the 188 sites and designations, see the Southern California Wetlands Recovery Project [Sentinel Site Network](#), Appendix 4 (SCWRP 2024).

- Small Creek – Small inlets with minimal subtidal habitat area, a small area of vegetated marsh at the inlet, and a generally steeper channel slope. These creeks are intermittently open to the ocean throughout the year, creating an estuarine salinity gradient during open periods.
- Large Lagoon – Shallow basins usually created by a beach berm or barrier, which traps the lagoon between the ocean and uplands. Depending on the water level when the inlet closes and the length of closure, areas of ponded water may dry completely to become salt flats.
- Intermediate Estuary – Estuaries that lie between the small creeks and the large river valleys and have significant tidal prism and river flows. When they are closed, water levels within these estuaries can be affected by river flow, runoff from the immediate watershed, waves that overtop the berm, tides which affect groundwater elevations, seepage through the berm from the ocean, evapotranspiration, and overtopping on extreme tides.
- River Valley Estuary – Large, depositional river valleys with a primary channel and many secondary channels with adjacent fringing marsh. This archetype also includes fragmented river valleys, where remnants of the floodplain have been dissected into smaller, spatially distinct units. The habitats within these fragments will not necessarily reflect the diversity or proportions of habitats of the undisturbed wetlands units.
- Open Bay/Harbor – Tidally dominated estuaries with large tidal prisms, small river inputs, large subtidal habitats, relatively little intertidal wetlands and permanently open inlet.

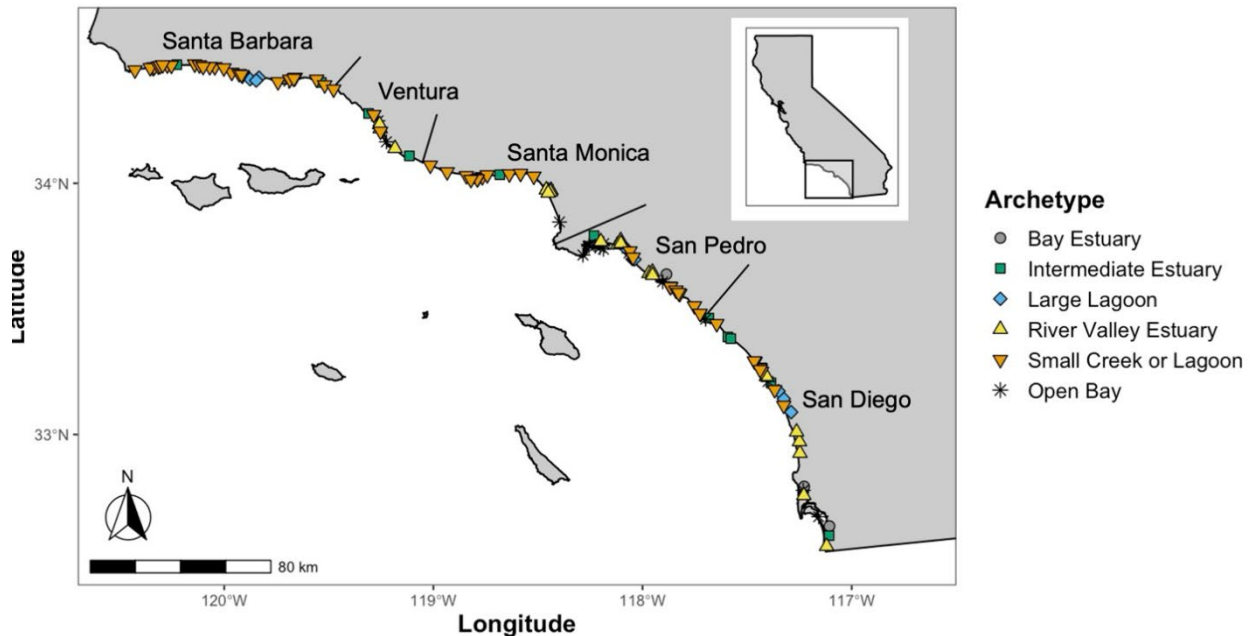


Figure 1. The Southern California Bight showing the location of the 118 coastal wetlands within the five subregions.

The geomorphic diversity, spatial heterogeneity, temporal variability, and varying degrees of anthropogenic modification in southern California make it difficult to monitor without substantial effort and standardized protocol. Traditional assessment approaches often rely on single taxa, assemblages, or habitat-specific metrics, which can limit comparability across estuary types and constrain synthesis at larger spatial scales. Therefore, monitoring strategies, like a function-based approach, that can accommodate the diversity of systems is critical for monitoring the SCB.

Statewide and Regional Monitoring Programs

The Bight '23 Estuary Wetland element builds on ongoing efforts to collect standard and comparable monitoring data throughout the region. These programs can be leveraged to conduct an integrated, regional assessment of estuaries using a function-based approach.

California Estuary Monitoring Program

The California Estuary Monitoring Program (CalEMP) is an ongoing, statewide effort to assess the quality and condition of California estuaries by leveraging regional and local monitoring programs and projects. The program is designed to evaluate estuarine health and condition using a standardized, comprehensive, function-based assessment framework. Program partners have collaboratively developed an assessment framework, standardized monitoring protocols, data structures, and quality control measures to ensure consistency and comparability across projects and sites.

The program began in 2020 with the creation of the California Estuary Marine Protected Area (EMPA) Monitoring Program, which was designed to evaluate estuarine health and the efficacy of Marine Protected Area (MPA) designation. Since its inception, the EMPA assessment framework has been adopted by many regional and local projects and is increasingly being incorporated into agency permits and grant programs. In response to this continued growth, the program provides a [comprehensive landing page](#) that offers programmatic information, documents standardized monitoring protocols, supports data uploads and access, serves program data, and delivers synthesized results to inform management and decision-making.

The Bight '23 program utilized the CalEMP assessment framework, standard operating procedures, and data portal.

Southern California Wetland Recovery Project Regional Monitoring Program

The [Southern California Wetlands Recovery Project \(WRP\)](#) is a partnership of 18 State and Federal agencies that was formed in 1997 as a regional voice for the valuable yet diminishing coastal wetlands of southern California. These agencies entered into a [Working Agreement](#) that allowed directors and staff to exercise their respective authorities and coordinate to expand, restore and protect wetlands in the WRP region, which stretches across the SCB. The WRP priorities are guided by the [Wetlands on the Edge: Regional Strategy 2018](#), which provides guidance for the WRP and its stakeholders to achieve the WRP's four goals.

The Regional Strategy 2018 included a set of Quantitative Objectives and Management Strategies to provide numeric targets that help quantify progress towards meeting the WRP's Goals. As a part of the multi-year, collaborative planning process to develop this shared vision for wetland recovery, agencies and scientists *identified a critical need to develop a comprehensive, regional wetland monitoring program for coastal wetlands* to evaluate whether the goals and objectives of the Regional Strategy-Goal 1 (Restore Coastal wetlands) are being achieved. This goal prompted the creation and development of the WRP Regional Monitoring Program (WRP RMP) in Fall of 2022. The WRP RMP aims to develop coordinated approaches for coastal wetland monitoring to track progress toward achieving objectives of Goal 1 of the Regional Strategy and to assist interested agencies and implementing organizations in incorporating these approaches into site-specific permit- and funding-required monitoring programs along with general resource management monitoring efforts.

The Bight '23 program was ongoing as the WRP RMP was being developed. Participants from both groups collaborated to help inform the current and future Bight and WRP RMP monitoring cycles.

Santa Monica Bay National Estuary Program

Santa Monica Bay supports 18 estuaries consisting of mostly small creek mouth estuaries (11 out of 18), but also includes large embayments, such as Malibu Lagoon. Together, the 18 estuaries of the Bay form an interconnected set of habitats that support a broad range of wetland dependent plants and animals and provide numerous ecosystem services. Urban sprawl, oil and gas exploration, the development of Marina del Rey, channelization, dredging, filling, and modification of estuary mouth conditions (among other human activities) have reduced wetland acreage and estuary function in the Bay. Although federal and state policies are in place to minimize future loss, and much of the remaining habitat is under public ownership, restoration efforts combined with long-term management are critical to preserving the diversity found in these habitats. Many of these efforts are coordinated through the Santa Monica Bay National Estuary Program (NEP) Comprehensive Management Plan. However, until recently, there has been no comprehensive and consistent monitoring program that tracks the collective health and resiliency of wetlands in the region, how they are responding to stressors brought on by climate change and anthropogenic impacts, or how they are responding to restoration and management actions.

In 2023-2024, partners worked with the Santa Monica Bay Restoration Commission and National Estuary Program to monitor a subset of estuaries within SMB. Monitoring occurred alongside Bight '23 efforts to complement monitoring and assessment and produce the [2026 State of the Bay Coastal Wetlands Chapter](#).

San Onofre Nuclear Generating Station (SONGS) Mitigation Monitoring Program (MMP)

Long-term, independent monitoring and evaluation of the San Onofre Nuclear Generating Station (SONGS) mitigation projects is a condition of the coastal development permit issued by the California Coastal Commission (CCC) for the operation of SONGS Units 2 and 3. The Permit requires Southern California Edison (SCE) as majority owner and operating agent of SONGS to design and build mitigation projects that adequately compensate for the adverse effects of the power plant's once-through seawater cooling system on living marine resources.

University of California, Santa Barbara (UCSB) scientists, working under the direction of the Executive Director of the CCC as part of the SONGS Mitigation Monitoring Program (SONGS MMP), are responsible for designing and implementing monitoring programs that assess the effectiveness of these mitigation projects. The San Dieguito Wetlands Restoration Project was built from 2006-2011 in San Dieguito Lagoon as out-of-kind mitigation for SONGS impacts to nearshore fish populations in the SCB.

Since 2012, the SONGS MMP has annually monitored this estuary, as well as three other reference estuaries within the SCB. UCSB scientists participated in Bight '23 to contribute to the 2023 regional assessment.

Tijuana River National Estuarine Research Reserve

The National Estuarine Research Reserve System is a network of 30 coastal sites designated to protect and study estuarine systems in collaboration with and service to surrounding communities. Established through the Coastal Zone Management Act, this partnership program between NOAA and the coastal states supports ecosystem health and the interconnectedness of people and the environment.

Specifically, the Tijuana River NERR and adjacent project sites participated in Bight '23 to better align water and vegetation monitoring protocols within the region and contribute to the 2023 regional assessment.

Sampling Design

A targeted sampling design was used to assess the study objectives. Sites were specifically chosen by the committee to ensure adequate representation of all estuarine archetypes across the SCB, as well as to incorporate estuaries with varying levels of management. Sites were selected based on committed effort and the ability to assess a representative sample of the SCB (Figure 2, Table 1, Table 2). The survey sampled 19 of the 118 coastal wetlands in the SCB, approximately 16% of estuarine systems by count, representing 4,596 hectares or 34% of the total estuarine area (13,430 hectares). When open bays and harbors are excluded from the total, the sampled sites account for approximately 75% of the estuarine wetland area in the region, indicating that the assessment captures the large majority of biologically complex, vegetated estuarine habitat in the SCB despite the relatively small number of sites. Findings should nonetheless be interpreted with the spatial scope in mind, as the 19 sampled sites do not fully represent the full diversity of smaller and less-managed systems across the region. Additional sites were monitored for a subset of indicators when resources were available.

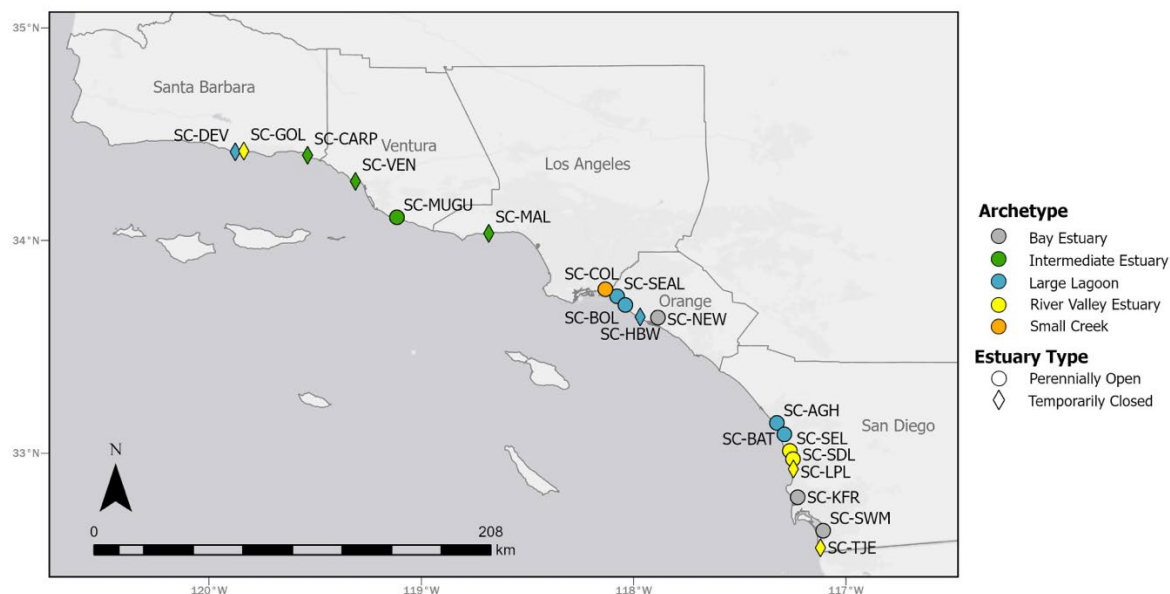


Figure 2. Map of the 19 targeted southern California sites. Site IDs listed in Table 1.

Table 1. Site ID and Estuary names for the 19 targeted southern California sites.

Site ID	Estuary Name
SC-DEV	Devereux Slough
SC-GOL	Goleta Slough
SC-CARP	Carpinteria Salt Marsh Reserve
SC-VEN	Ventura River
SC-MUGU	Point Mugu Lagoon
SC-MAL	Malibu Lagoon
SC-COL	Colorado Lagoon
SC-SEAL	Seal Beach National Wildlife Refuge
SC-BOL	Bolsa Chica Ecological Reserve
SC-HBW	Huntington Beach Wetlands
SC-NEW	Upper Newport Bay Ecological Reserve
SC-AGH	Agua Hedionda
SC-BAT	Batiquitos Lagoon
SC-SEL	San Elijo Lagoon
SC-SDL	San Dieguito Lagoon
SC-LPL	Los Peñasquitos Lagoon
SC-KFR	Kendall-Frost Marsh Reserve
SC-SWM	Sweetwater Marsh, San Diego Bay National Wildlife Refuge
SC-TJE	Tijuana River Estuary

Table 2. The total number of estuaries sampled during the Bight '23 estuary wetland survey and the total number of estuaries present within the SCB for each archetype.

Archetype	Sampled Sites	Total Sites	% archetype sampled
Bay estuary	3	18	17%
Intermediate estuary	4	13	31%
Large lagoon	6	8	75%
River valley estuary	5	22	23%
Small creek	1	57	2%
Total	19	118	16%

To answer all three questions, the bulk of sampling occurred in Fall 2023, with some collections happening in Winter 2023-2024 and additional California Rapid Assessment Method (CRAM) monitoring in 2026. The fall season was chosen for the study because it represents the end of the growing season for most vascular plants, as well as the end of the critical breeding season for protected species.

This study aimed to conduct a holistic assessment of estuarine condition at as many estuaries as possible within the SCB. To accomplish this effort, indicators were assessed at multiple locations within each estuary. To capture seasonal and interannual variation among and within estuaries, users established a number of permanent sampling stations or zones within their sites to concentrate multiple sampling methods (i.e., cluster sampling; Figure 3); giving users the ability to resample the same plots overtime (View the [Interactive Station Map](#)). These stations were selected by sampling teams to capture the heterogeneity across the site. Each site distributed their stations across the estuary with station 1 located at or adjacent to the estuarine mouth. This approach was favored over distributing measures more diffusely across the site, as concentrating multiple measures increased the ability for comparisons across indicators.

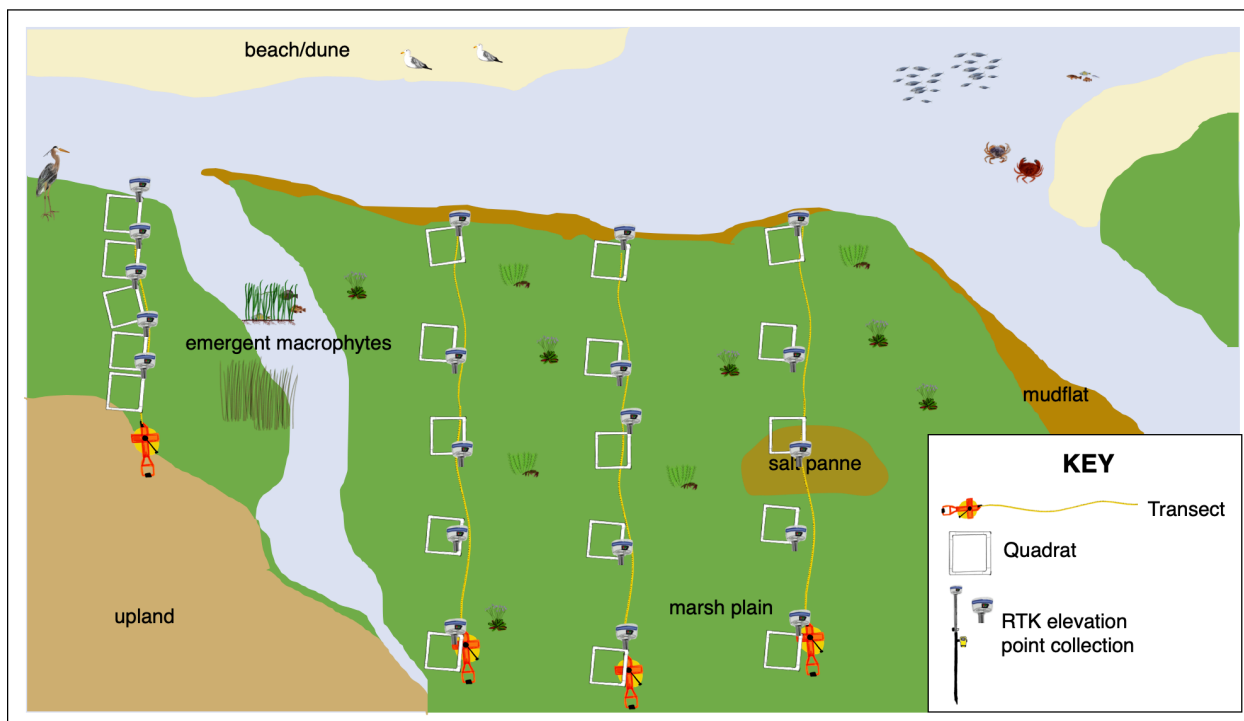


Figure 3. Depiction of the sampling schema for the functions (Marsh Vascular Plant Support, Sea Level Rise Amelioration, Bird Habitat Provisioning) evaluated for Bight 2023. Note: Additional methods were applied (e.g., infauna cores, sediment cores, eDNA, seines, eelgrass surveys) to a subset of sites but were not included in the final function-based assessment that included all sites. (figure by K. Beheshti).

Function-Based Assessment Framework

The Bight '23 assessment piloted an ecosystem-function based approach to measure estuarine condition and to provide data that can be easily compared across systems and among monitoring programs within the region. Focusing an assessment framework on ecological functions supports linkages among assessment results, ecological services, and designated beneficial uses for each estuary. Furthermore, an assessment framework built to evaluate ecological functions has greater application flexibility within a highly heterogeneous region, like southern California. The species of plants and animals that are used as indicators of ecological functions may change between subregions and estuarine types, but the focal estuarine functions should remain constant. Flexibility of the function-based approach ultimately allows for comparative assessment across estuary types, while accounting for regional differences and anthropogenic impacts. This approach will ultimately allow for the assessment of management actions and protected area designations.

In new elements (e.g., this Bight '23 Estuary Element) or infrequently sampled monitoring programs, emphasizing the assessment process, such as standardized methods, indicator

selection, and data interpretation frameworks, is a critical first step to ensure consistency, transparency, and comparability over time. This focus helps establish a robust foundation for future assessments, where limited or single-season results may not yet capture the full range of natural variability needed for confident evaluation. This Bight '23 Element *focused on providing a transparent, repeatable, and clearly documented approach for assessing estuarine condition based on available data.*

The overall approach used a hierarchical framework comprised of five tiers: raw data, metrics, indicators, functions, and an overall condition assessment (Figure 4). At each tier, information from the previous tier was aggregated and synthesized to produce a progressively higher-level characterization of estuary condition. Raw data were collected across 19 southern California estuaries during fall 2023. Field surveys included continuous water quality logger deployments (temperature and dissolved oxygen), intertidal infauna core sampling, fish seine surveys, bird point count surveys, vegetation transect surveys, and Coastal Rapid Assessment Method (CRAM) habitat assessments. Metrics were then derived from field data and represent quantitative measures of specific aspects of biological community structure or habitat condition. Metrics were grouped into eight indicators categories — Water Quality, Sediment Nutrients, Sediment Characteristics, Infauna, Fish, Birds, Vegetation, and CRAM — summarizing site performance across all sites with available data using rank-based percentile binning.

Function scores were calculated for three ecosystem functions: Marsh Vascular Plant Support, SLR Amelioration, and Bird Habitat Provision. Each function score was derived from a subset of relevant indicator metrics using a standardized scoring algorithm, producing a composite score that reflects the capacity of each estuary to support that function. Score ranges and performance categories differed by function to reflect the different scales and maximum possible values of each scoring algorithm, with scores categorized as Low Function, Moderate, Good, or High Function based on equal quartiles of the maximum possible score. Finally, stressor scores were assessed in parallel for four stressor categories (Eutrophication, Anthropogenic Disturbance, Non-native Species, and Trash) and used to contextualize function scores and the overall condition assessment. Rather than being integrated into a composite function score, stressor scores were evaluated independently and used to inform interpretation of where and why functional condition may be elevated or degraded.

The overall assessment synthesizes performance across all three function scores to characterize the condition of each estuary relative to others in the SCB. Function scores and stressor assessments were compared across three site classification factors (estuary type, archetype, and management authority) to evaluate whether broad categorical differences explain variation in functional condition across the region.

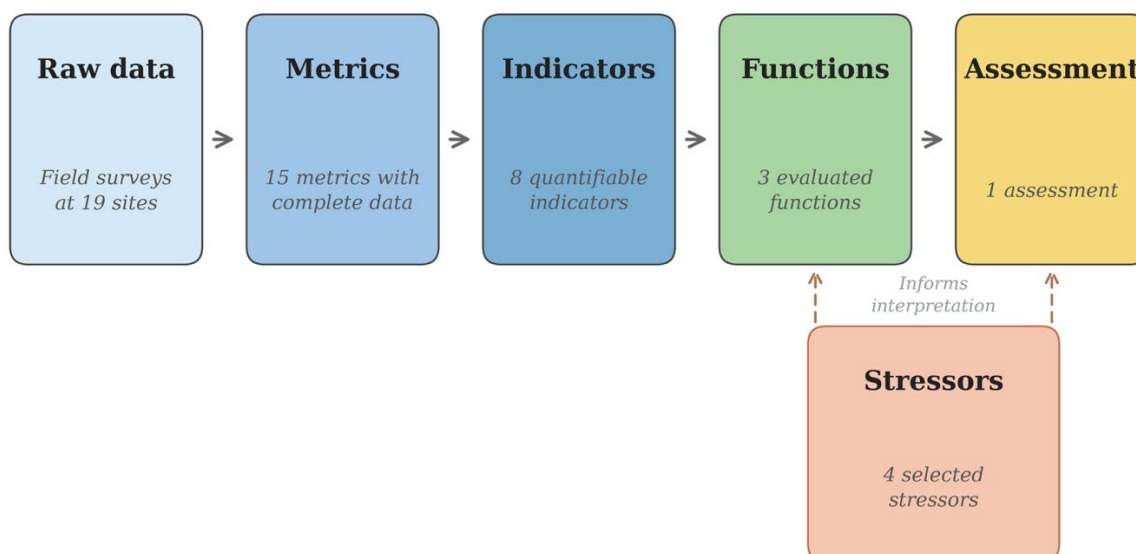


Figure 4. Conceptual framework for the multi-function estuary condition assessment. Raw data collected from field surveys are processed into quantitative metrics, which are grouped into eight indicator categories. Indicator performance is summarized using rank-based percentile bins relative to all evaluated estuaries. Three function scores (Marsh Vascular Plant Support, SLR Amelioration, and Bird Habitat Provision) are derived from relevant indicator metrics and scored against fixed performance categories (Low Function, Moderate, Good, High Function). Stressor scores, assessed independently across four categories (Eutrophication, Anthropogenic Disturbance, Non-native Species, and Trash), inform interpretation of function scores and the overall condition assessment but are not integrated into composite function scores. The overall assessment characterizes estuary condition across 19 southern California estuaries surveyed during fall 2023 as part of the Southern California Bight Regional Monitoring Program.

Indicators

Given the inherent variability and complexity of estuaries, ongoing monitoring of key indicators is essential for improving our understanding of the relationship between abiotic and biotic parameters and for detecting changes that may signal the need for management intervention. Eight indicators were monitored across all 19 sites. Each indicator was assessed using multiple quantitative metrics. For detailed descriptions of each indicator and the associated metrics see the [Bight '23 Estuary Wetland Assessment Workplan](#), [Bight '23 Estuary Wetland Assessment Field Operations Manual](#), and Appendix 1. Indicators.

Biotic metrics included measurements of abundance, diversity, and richness for producers, such as plant communities, and consumers, such as benthic macroinvertebrates and fish. Abiotic metrics included measures of water quality parameters, such as salinity, dissolved oxygen, and temperature, and sediment characteristics.

Table 3. Eight indicators and 15 metrics were monitored across the 19 sites.

Indicator	Metric
Water quality	• Percent time temp < 25C • Percent time DO > 3mg/L
Sediment nutrients	• Average Total Nitrogen • Average Total Organic Carbon
Sediment characteristics	• Percent mud • Percent sand
Benthic infauna	• Species abundance per standardized core • Proportion of expected feeding groups
Fish	• Rarefied species richness given a standardized number of individuals
Bird	• Species richness • Proportion of expected unique guilds
Marshplain vegetation community	• Total absolute cover • Rarefied species richness given a standardized number of quadrats • Range of maximum plant height
General habitat condition	• CRAM index score

Percentile rankings were calculated independently for each indicator metric using a rank-based approach. For each metric, sites with available data were ranked from lowest to highest value, and each site was assigned to one of four percentile bins (0–25th, 25–50th, 50–75th, and 75–100th) based on its rank position relative to all other sites with data for that metric. Because rankings are calculated only among sites with available data, the number of sites contributing to each metric's percentile distribution varies. For metrics with limited data availability, particularly infauna abundance and dissolved oxygen, the small number of sites with measurements means that intermediate percentile bins (25–50th and 50–75th) may be sparsely populated or absent, with sites appearing only in the lowest and highest bins. This reflects the limited sample size for those metrics rather than a biological pattern, and results for data-limited metrics should be interpreted with caution.

Functions

Given the ecological and hydrological complexity of estuaries, there are a vast number of potential indicators one could use to evaluate functions. Therefore, functions were evaluated by one or more indicators providing flexibility to use indicators appropriate for the specific estuary type, while still allowing the standard set of functions to be evaluated. This focus on

function allows the framework to accommodate different estuary types and assimilate data from diverse existing monitoring programs, while maintaining underlying comparability.

Three priority ecological functions (Support of Marsh Vascular Plant Communities, Sea Level Rise Amelioration and Resiliency, and Bird Habitat Provision) were identified by the Bight Data Subcommittee with the underlying principle that all estuaries should provide these ecosystem functions at high levels in the absence of anthropogenic disturbance. These three functions were selected because 1) assessment strategies were already developed and piloted for two of the three functions by the CalEMP program, and 2) the majority of sites had the necessary data available to assess the functions.

The study focused on the following functions:

1. **Support of Marsh Vascular Plant Communities** - Support of a diversity of emergent fresh- and salt-tolerant plant species distributed throughout the system based on the complex geographic and temporal variability in water depth, sediment composition and elevation, salinity gradient, and submergent condition.
2. **Sea Level Rise Amelioration and Resiliency** - Capacity of the estuary to adapt to rising sea levels based on the geomorphology and habitat associated with the marine-freshwater-terrestrial interfaces. Intact estuaries provide resiliency to sea level rise by accreting sediment and providing space for habitat migration.
3. **Bird Habitat Provision** - Provision of physical and biological structure for resident and migratory birds to support predator evasion or nesting and abundant food. *For this report, nesting was not evaluated as part of this function.*

The assessment strategy focused on linking individual indicators to specific functions to evaluate estuary condition via functional performance.

Step 1: The Bight '23 assessment utilized the CalEMP indicator-function relationships to link field-based monitoring to function (Figure 5).

Figure 5. A function-based assessment was used to assess the condition of each estuary, where multiple indicators can be used to assess a given ecological function. Green squares represent the indicators that can be used to evaluate each function. Table provided by CalEMP, O'Connor et al. 2025.

Step 2: To assess each function, a suite of condition statements based on available indicator data were developed by an expert panel. Condition statements help direct data analysis to quantify the function supported by each estuary. The assessment of function was based on the best available monitoring data.

Step 3. To produce a final score for each function, the indicators were aggregated into conceptual scoring algorithms, relating the specific indicators to more integrative “functions” and describing how the indicators interact to support overall function (Figure 5). The Bight Data Subcommittee developed consensus around each scoring rubric for each function.

For monitoring programs in the early stages of implementation (e.g., under 5 years of data collection, like the Bight '23 Estuary Element), each condition statement output (i.e., data interpretation) was scored relative to the total pool of estuaries. A high score was considered better condition, while a low score was considered worse condition. The scores for each condition statement were then averaged for each estuary to give a final function score. By averaging scores, this approach allowed the comparison of estuaries relative to one another. This method does not produce an absolute score for each estuary (i.e., whether or not the estuary is in ‘good’ or ‘bad’ condition). Estuaries were scored relative to all evaluated estuaries using condition descriptors: Low Function, Moderate, Good, and High Function. Categories were split equally into quarters based on the maximum possible score for each scoring algorithm.

As monitoring programs mature (e.g., collect more monitoring data), function-based evaluation should mature to be able to quantify the absolute performance of each estuary (i.e., whether a site is in good condition rather than good condition relative to others). To do this, significant research will need to be conducted to fully understand how estuary type and underlying or historic conditions may impact functional performance and condition. This would allow condition categories to be better defined by thresholds of condition rather than relative category classifications. Additionally, sites are currently scored at the site-level, rather than the station-level. As more data is collected, condition scores may be able to be compared within an estuary in addition to among estuaries.

Below we list the condition statements and scoring algorithms for each function. We list the full set of condition statements as defined by the CalEMP program, however only a subset of statements were evaluated due to data availability. Condition statements that were not evaluated are *italicized*. More details for each scoring algorithm are included in the results.

Marsh Vascular Plant Support

Condition Statements

Condition Indicator 1: Assessments of the marshplain using the California Rapid Assessment Method (CRAM) show high values for the Biotic Attribute score.

Condition Indicator 2: The marshplain vegetation community exhibits high vegetation cover in upper marsh elevation habitats (mid and high marsh).

Condition Indicator 3: The marshplain shows a large range of elevations within the estuary as expressed on available digital elevation models (DEM).

Condition Indicator 4: Water elevations in the estuary are variable across time and inundate multiple topographic surfaces of varying elevation across the marshplain.

Condition Indicator 5: The estuary contains a high number of plant habitat alliances along the vegetation transects.

Scoring Algorithm

Marsh Vascular Plant Support = (CRAM Biotic Attribute + % cover in upper marsh + ruggedness) / 3

- CRAM Index – The Biotic Attribute scores for each station at an individual site are averaged to get a single site index score. The CRAM Index ranges from 25-100.

- % cover in upper marsh – The absolute vegetation cover in the high and mid marsh zones are summed across all quadrats. Cover ranges from 0-100.
- Ruggedness - GIS data of the marshplain are analyzed to quantify the relative amount of marshplain topographic variability (levels of ruggedness using the [Terrain Ruggedness Index Tool](#)). Higher values indicate greater topographic complexity. Scoring is relative to the highest value of “ruggedness” across all sites and is scaled to a score out of 100.

The maximum score an estuary could receive is 100.

Sea Level Rise Amelioration

Condition Statements

Condition Indicator 1: Assessments of the marshplain using the California Rapid Assessment Method (CRAM) show high values for the Index score.

Condition Indicator 2: The marshplain vegetation community exhibits high vegetation cover in upper marsh elevation habitats (mid and high marsh).

Condition Indicator 3: The estuary has the space and surrounding topography that is necessary for habitat migration to take place in response to sea level rise.

Condition Indicator 4: Accretion rates measured across multiple elevations in the marshplain match or exceed current SLR rate as defined by OPC.

Scoring Algorithm

Sea Level Rise Amelioration = (CRAM Index + % cover in upper marsh + % natural buffer cover + % natural perimeter cover + % perimeter contiguity + % future wetland extent) /6

- CRAM Index – The CRAM index scores for each station at an individual site are averaged to get a single site index score. The CRAM Index ranges from 25-100.
- % cover in upper marsh – The absolute vegetation cover in the high and mid marsh zones are summed across all quadrats. Cover ranges from 0-100.
- % buffer cover - Percent of combined natural and agricultural land cover in a 500m buffer around the site. Percent buffer cover ranges from 0-100.
- % perimeter cover - Percent of combined natural and agricultural cover in a 30m buffer around the site. Percent perimeter cover ranges from 0-100.

- % perimeter contiguity - Percent of *contiguous* combined natural and agricultural land cover along the 30m perimeter. Percent perimeter contiguity ranges from 0-100.
- % future wetland extent - Percent of the existing estuary boundary plus the 500m buffer area (excluding development) that is wetland habitat (low, mid, and high marsh) under 1.2 ft of sea level rise. Percent future wetland extent ranges from 0-100.

The maximum score an estuary could receive is 100.

Bird Habitat Provision

The Bird Habitat Provision function was developed by the Bight Data Subcommittee and led by the Point Blue Conservation Science team. This is the first time this function has been assessed and therefore all indicators are calculated based on the maximum number of identified species and guilds

Condition Statements

Condition Indicator 1: The estuary supports a high number of identified bird species.

Condition Indicator 2: The estuary supports a high proportion of identified guilds.

Scoring Algorithm

Bird Habitat Provision = total species richness x proportion of expected guilds

- Total species richness – The total number of species observed at each estuary utilizing data compiled from three data sources 1) Pacific Flyway Shorebird Survey ([PFSS](#)), 2) San Onofre Nuclear Generating Station ([SONGS](#)), and [eBird](#).
- Proportion of identified guilds – The proportions of observed guilds out of 20 total identified guilds

The maximum score an estuary could receive is dependent on the number of identified species and guilds.

Stressors

Stressors were evaluated to assess how function scores may vary with stress. A similar process as outlined above was used to score specific stressors. Scoring algorithms were adapted from the [Santa Monica Bay National Estuary State of the Bay Coastal Wetland Chapter Report](#).

Estuaries were scored relative to all evaluated estuaries along a gradient of stress. Rather than categorizing sites against fixed thresholds, each site's score was ranked relative to all other sites with available data for that stressor. This relative approach was chosen for stressor scores

because the scoring algorithms for each stressor category have different scales and theoretical maxima, making fixed category thresholds less meaningful for cross-site comparison. Instead, the gradient communicates each site's stressor burden relative to the regional distribution, highlighting which sites stand out as high or low outliers within the SCB.

Eutrophication

Definition The overgrowth of organic material from anthropogenic nutrient subsidy, which alters community dynamics of primary producers, fish, invertebrates, and other wildlife that utilize the estuary water column and/or seafloor.

Scoring Algorithm

Due to data availability, the scoring algorithm was adapted from the ideal algorithm. Sutula et al. (2008) proposes a regression model to obtain eutrophication scores that can be compared across estuaries. However, *italicized parameters* were under able to be calculated for the majority of sites due to limited data.

*Ideal: Eutrophication = % time DO < 3 mg/L + % macroalgae cover + TN + 0.5*TOC*

- *% time DO < 3 mg/L – The percent of time dissolved oxygen is less than 3 mg/L.*
- *% macroalgae cover - The absolute macroalgae cover in the intertidal mudflat are summed across all quadrats.*
- TN – The average Total Nitrogen (mg/g)
- TOC – The average Total Organic Carbon

Actual: Eutrophication = TN + 0.5*TOC

High scores indicate higher levels of relative stress.

Anthropogenic Disturbance and Land Use

Definition The extent and quality of the buffer zone between a wetland and surrounding environment and the level of internal physical structure that provides support to characteristic flora and fauna.

Scoring algorithm

Anthropogenic Disturbance and Land Use = 200 – (CRAM Physical Structure Score + CRAM Buffer and Landscape Context Score)

- CRAM Physical Structure Attribute Score - The CRAM Physical Structure Attribute scores for each station at an individual site are averaged to get a single site index score. The CRAM Index ranges from 25-100.
- CRAM Buffer and Landscape Context Attribute Score - The CRAM Buffer Attribute scores for each station at an individual site are averaged to get a single site index score. The CRAM Index ranges from 25-100.

High CRAM scores indicate better condition. Therefore, scores were subtracted from 200, so that high scores indicate higher levels of relative stress.

Non-Native Species

Definition Pressure of encroachment from terrestrial plant and aquatic fish species that are not native to region. This stressor destabilizes natural plant and animal communities and can indirectly impact both physical and biological attributes of coastal wetland habitat.

Scoring Algorithm

Non-Native Species Indicator = % non-native plants +% non-native fish

- % non-native plants - The percent of non-native plants summed across all quadrats. Score ranges from 0-100.
- % non-native fish - The percent of non-native fish summed across all fish net replicates. Score ranges from 0-100.

High scores indicate higher levels of relative stress.

Trash

Definition The amount and types of anthropogenic debris (i.e., trash) present. Excessive amounts of trash decrease the aesthetic value of the wetland or estuary. Trash also may pose health hazards to humans and negatively impact wildlife (e.g., ingestion, entanglement).

Scoring Algorithm

Trash = total trash

- Total trash – The total trash pieces summed within the estuary across the 10-minute trash survey.

High scores indicate higher levels of relative stress.

RESULTS

Indicators

Six indicator groups (Water Quality, Infauna, Fish, Birds, Vegetation, and CRAM) were compared across all 19 sites for 11 metrics. Two sediment indicators were also compared across 4 metrics. Sites were binned into quartiles using a rank-based approach to make comparisons across sites with high scores and sites with low scores. Percentile rankings across the indicator groups revealed considerable variability among the 19 sites evaluated, with no single site performing consistently in the highest or lowest percentile bin across all metrics (Figure 6, Figure 7). General trends are described below. For more detailed description of results and graphics for each indicator see Appendix 1. Indicators.

When interpreting the results, the following should be considered:

1. Percentiles are relative rankings among sites, not absolute thresholds,
2. Each metric is ranked independently so a site can be in the top percentile for one metric and the bottom for another, and
3. Sparse color patterns in certain metrics are a data availability issue, not an ecological signal.

Water Parameters. Water parameter data were inconsistently collected across the SCB, therefore not all sites had water quality data, nor did sites have the same number of days collected. For example, SC-TJE, SC-LPL, and SC-SEL had almost 150 collection days during the Fall 2023 season, while SC-NEW had 36 days and SC-BOL had 62 days. Therefore, the comparison of metrics should be done with caution. For more details regarding water quality parameters for each site, see Appendix 1. Indicators: Water Quality.

There was little site-to-site variability for percentage of time temperature remained below 25°C, therefore sites could not be broken into distinct percentiles, only grouping into three categories. SC-MAL and SC-LPL had the highest percentage of time where temperatures were greater than 25°C. There was more variability in dissolved oxygen (DO) readings. SC-BOL, SC-AGH, and SC-BAT were in the 75–100th percentile, while SC-VEN and SC-TJE fell in the lowest bin.

Sediment parameters. Sediment characteristics were also compared across sites, specifically sediment grainsize, sediment total organic carbon, and sediment nitrogen (Figure 7). SC-MAL was the sandiest estuary by a considerable margin (nearly 100% sand), while SC-DEV and SC-HBW had the highest mud content, falling in the 75–100th percentile for percent mud. TN and TOC were strongly correlated, with SC-DEV, SC-TJE, SC-NEW, SC-BAT, and SC-SDL all ranking in the upper percentile bins for both metrics, indicating elevated organic matter and nutrient

loading at these sites. Notably, SC-TJE had the highest raw TN value (6.78 mg/g) and the highest TOC (36.05 mg/g) of all sites with data. In contrast, SC-MAL, SC-COL, SC-AGH, SC-LPL, and SC-SWM consistently ranked in the lowest percentile bins for both TN and TOC, suggesting relatively low nutrient enrichment at these locations.

Infauna. Due to the variability in size of benthic sediment cores, infauna abundance was standardized to a core size of 100 cm³. Cores were collected at all 19 sites; however, due to limited resources, only a subset of cores were processed, and infauna metrics should be interpreted with caution. Among sites with available data, SC-NEW, SC-KFR, SC-SWM, and SC-TJE ranked in the 75–100th percentile for infauna abundance, while SC-GOL, SC-BAT, and SC-SDL fell in the 0–25th percentile with lowest abundance. Despite having low abundance, SC-BAT had all five feeding groups present (detritivores, algivores, carnivores, omnivores, and herbivores), while SC-GOL, SC-NEW, and SC-AGH ranked in the lowest percentile with only 1 feeding group. This site discrepancy between total abundance and community composition highlights the importance of considering both abundance and community composition when interpreting biological data.

Fish or Nekton. To compare fish species richness across sites while accounting for differences in total catch between sampling methods (beach seine and block net), we applied individual-based rarefaction following Hurlbert (1971). Rarified fish richness showed strong differentiation among estuaries. SC-BAT, SC-SEL, SC-CARP, SC-SEAL, and SC-BOL ranked in the 75–100th percentile, while SC-DEV, SC-GOL, SC-MUGU, SC-MAL, and SC-KFR fell in the lowest bin. We did not report rarified richness for SC-TJE because it had very low number of fish caught in fall 2023, which prevented analysis.

Bird. Bird data were collected from a variety of sources, therefore the given amount of effort per site varied drastically. Sites with more effort typically corresponded with sites with higher access for birders. For bird species richness, SC-BOL, SC-NEW, SC-BAT, SC-SEL, and SC-TJE ranked in the 75–100th percentile, while SC-GOL, SC-COL, SC-HBW, SC-AGH, and SC-SWM fell in the 0–25th percentile. This indicator was heavily reliant on community bird observations. For more details on sampling effort, see Appendix 1. Indicators: Birds.

Vegetation. We calculated the percent native vegetation cover by summing the total cover across all the vegetation quadrats. SC-GOL, SC-MAL, SC-LPL, and SC-KFR ranked in the 75–100th percentile, indicating diverse, stable community rather than just a result of sampling more individuals, while SC-DEV, SC-VEN, SC-BOL, and SC-SDL fell in the lowest bin. We calculated sample-based rarefaction to account for the unequal number of quadrats among sites. Rarified vegetation richness was highest at SC-DEV, SC-VEN, SC-LPL, and SC-TJE, and lowest at SC-SEAL, SC-HBW, SC-SDL, and SC-KFR. The plant height range was greatest at SC-VEN, SC-MAL, SC-NEW, and SC-BAT, and lowest at SC-DEV, SC-SEAL, SC-AGH, and SC-LPL.

CRAM. CRAM Index scores were highest at SC-DEV, SC-CARP, SC-SEAL, SC-BOL, and SC-KFR, reflecting strong overall habitat condition at these sites. In contrast, SC-GOL, SC-MAL, SC-NEW, SC-BAT, and SC-SEL fell in the 0–25th percentile, indicating comparatively degraded habitat conditions.

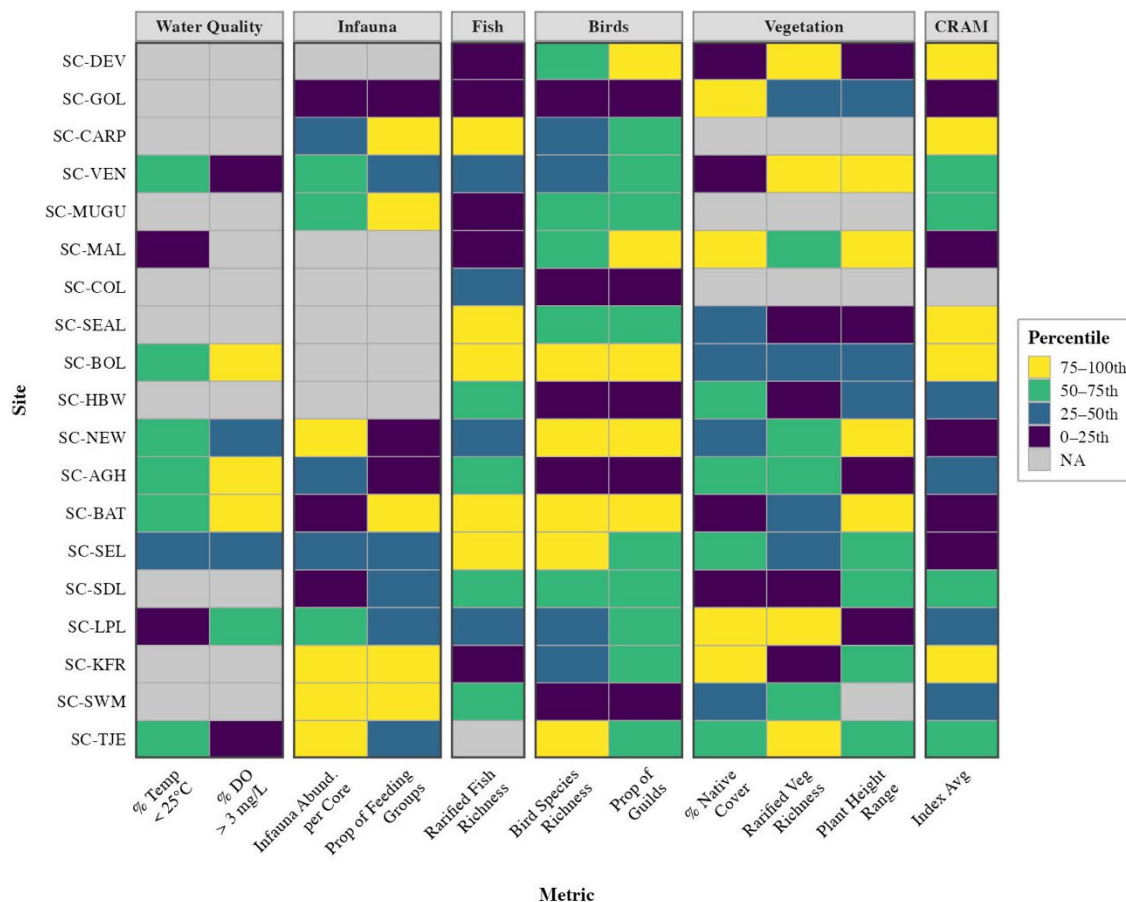


Figure 6. Percentile rankings of six biological and habitat indicators across 19 sites. Indicators are grouped into six categories: Water Quality (percentage of time temperature < 25°C and dissolved oxygen > 3 mg/L), Infauna (standard abundance per core and proportion of feeding group), Fish (rarified species richness), Birds (species richness and proportion of guilds), Vegetation (percent native cover, rarified species richness, and plant height range), and CRAM (index average). Each cell reflects the rank-based percentile bin of the raw metric value relative to all sites: 0–25th (dark purple), 25–50th (teal), 50–75th (green), and 75–100th (yellow). Grey cells indicate sites where data were not available or too rare to be analyzed.

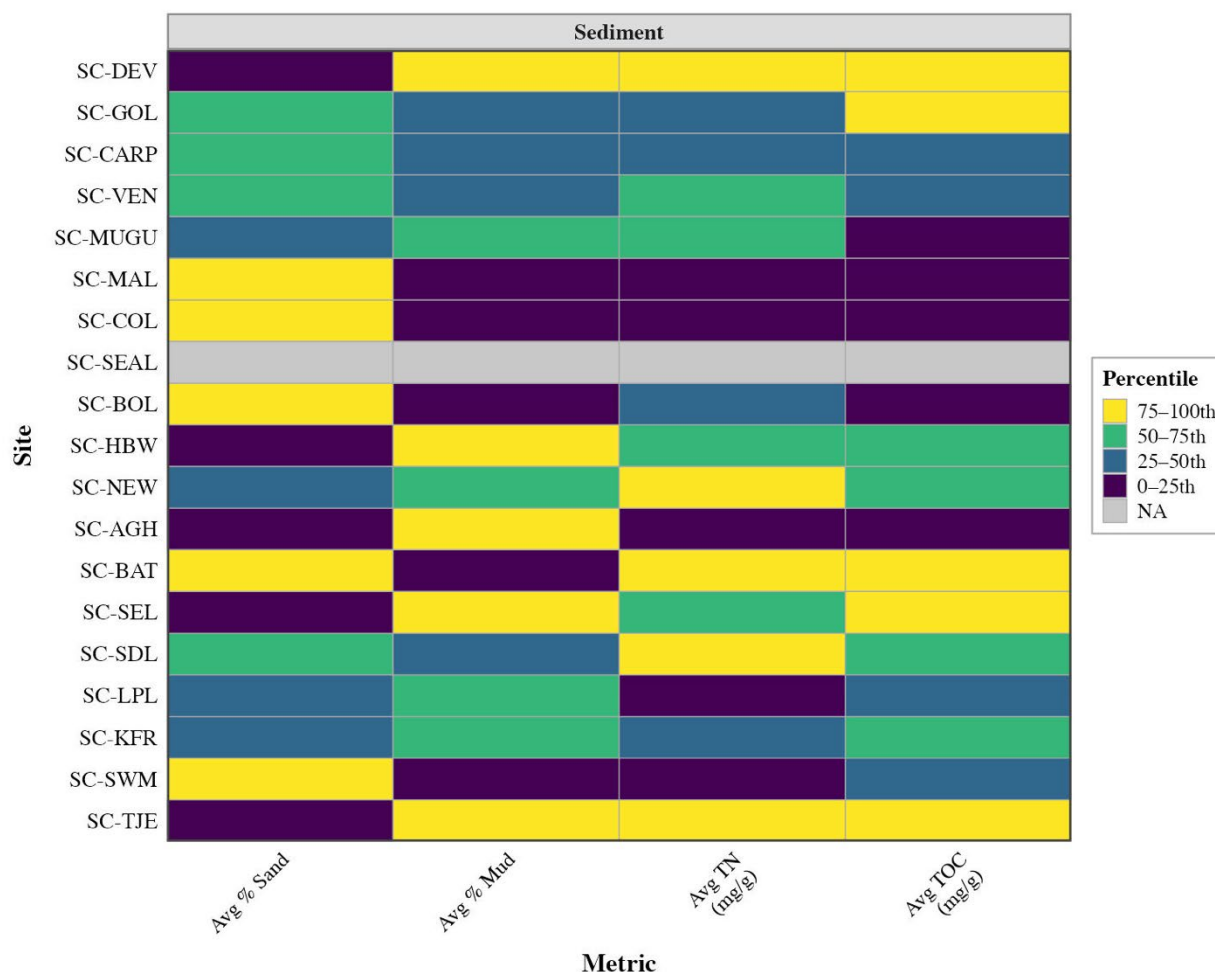


Figure 7. Percentile rankings of sediment quality indicators across 19 sites. Metrics include average percent sand, average percent mud, average total nitrogen (TN; mg/g), and average total organic carbon (TOC; mg/g). Each cell reflects the rank-based percentile bin of the raw metric value relative to all sites: 0–25th (dark purple), 25–50th (teal), 50–75th (green), and 75–100th (yellow). Grey cells indicate sites where data were not available.

Functions

Scores

The assessment strategy focused on linking individual indicators to specific functions. Three ecosystem functions were assessed for all 19 sites. Estuaries were binned into the following categories based on their relative function scores: Low Function, Moderate, Good, and High Function. Categories were split equally into quarters based on the maximum possible score for each scoring algorithm. We report the individual indicator scores and the final scores for Marsh Vascular plant support (Figure 8), sea level rise amelioration (Figure 9), and bird habitat (Figure 10).

The Marsh Vascular Plant Support function scored from 0-100. SC-TJE had the Highest Function score of 75.97 and SC-VEN had the Lowest Function score of 51.58. Most sites within the region scored Good between 51 and 75. The Sea Level Rise Amelioration function scored from 0-100. The sites in the region either scored a Good (51-75) or Moderate (26-50). Five sites scored Good - SC-TJE, SC-LPL, SC-SEL, SC-BOL, and SC-DEV. The Bird Habitat function scored from 0-160+. Sites were classified into all four categories. SC-TJE, SC-BAT, SC-NEW, and SC-BOL were the Highest Function sites, while SC-AGH, SC-HBW, and SC-COL were the Lowest Function sites.

Estuary	General Habitat Condition	Marsh vegetation distribution	Marsh plain elevation	
	<i>CRAM Biotic Index</i>	<i>Vegetation cover</i>	<i>Varied marsh plain elevation (high ruggedness)</i>	Final Score
SC-DEV	83.33	69.60	27.45	60.13
SC-GOL	74.07	90.00	60.78	74.95
SC-CARP	89.81	NA	29.41	NA
SC-VEN	80.56	42.80	31.37	51.58
SC-MUGU	66.67	NA	41.18	NA
SC-MAL	66.67	86.10	17.65	56.80
SC-COL	NA	NA	11.76	NA
SC-SEAL	77.77	47.20	100.00	74.99
SC-BOL	87.06	78.00	39.22	68.09
SC-HBW	90.78	82.90	25.49	66.39
SC-NEW	52.78	79.80	82.35	71.64
SC-AGH	53.00	82.70	47.06	60.92
SC-BAT	63.89	63.70	43.14	56.91
SC-SEL	59.08	89.60	27.45	58.71
SC-SDL	81.48	33.60	37.25	50.78
SC-LPL	75.69	86.50	33.33	65.18
SC-KFR	89.80	88.80	33.33	70.64
SC-SWM	58.33	72.70	47.06	59.36
SC-TJE	68.06	87.30	72.55	75.97

Final Score:

Low Function (0-25)	Moderate (26-50)	Good (51-75)	High Function (76-100)	No data
------------------------	---------------------	-----------------	---------------------------	---------

Figure 8. Marsh Vascular Plant Support function scores. Summary of marsh plant indicator scores for 19 sites. Columns represent three component metrics: General Habitat Condition (CRAM Biotic Index), Marsh Vegetation Distribution (vegetation cover in the upper marsh), and Marsh Plain Elevation (high ruggedness). The Final Score represents the mean of available component metrics for each estuary. Cell colors reflect Final Score bin categories: Low Function (0–25), Moderate (26–50), Good (51–75), and High Function (76–100). Grey cells indicate sites or metrics where data were not available.

Estuary	General Habitat Condition	Marsh vegetation cover	Sufficient upland migration potential			Composition of future areas	Sediment accretion rates	Final Score
	CRAM Index	Vegetation cover	Buffer land cover	Perimeter land cover	Perimeter contiguity	Future Wetland Extent (1.2 ft SLR)	Sediment supply	
SC-DEV	86.00	69.60	38.00	33.00	51.30	23.00	NA	50.15
SC-GOL	62.00	90.00	23.00	22.00	21.30	46.00	NA	44.05
SC-CARP	85.00	NA	4.00	18.00	21.30	29.00	NA	NA
SC-VEN	71.00	42.80	28.00	28.00	52.00	42.00	NA	43.97
SC-MUGU	74.00	NA	48.00	31.00	20.30	72.00	NA	NA
SC-MAL	65.00	86.10	13.00	26.00	61.50	29.00	NA	46.77
SC-COL	NA	NA	2.00	8.00	80.00	7.00	NA	NA
SC-SEAL	77.00	47.20	29.00	18.00	10.90	73.00	NA	42.52
SC-BOL	76.00	78.00	38.00	51.00	45.00	28.00	NA	52.67
SC-HBW	67.00	82.90	5.00	1.00	28.60	36.00	NA	36.75
SC-NEW	58.00	79.80	4.00	12.00	14.60	53.00	NA	36.90
SC-AGH	67.00	82.70	22.00	35.00	30.40	17.00	NA	42.35
SC-BAT	65.00	63.70	16.00	9.00	50.00	31.00	NA	39.12
SC-SEL	64.00	89.60	27.00	47.00	35.10	50.00	NA	52.12
SC-SDL	75.00	33.60	17.00	19.00	39.00	54.00	NA	39.60
SC-LPL	69.00	86.50	36.00	47.00	40.90	60.00	NA	56.57
SC-KFR	75.00	88.80	5.00	20.00	23.60	37.00	NA	41.57
SC-SWM	67.00	72.70	10.00	22.00	23.90	73.00	NA	44.77
SC-TJE	72.00	87.30	52.00	75.00	22.00	53.00	NA	60.22
Final Score:								
Low Function (0-25)		Moderate (26-50)		Good (51-75)		High Function (76-100)		No data

Figure 9. Sea Level Rise Amelioration function scores. Summary of sea-level rise (SLR) resilience indicator scores for 19 sites. Columns represent component metrics across five indicator categories: General Habitat Condition (CRAM Index), Marsh Vegetation Cover (vegetation cover in the upper marsh), Sufficient Upland Migration Potential (buffer land cover, perimeter land cover, and perimeter contiguity), Composition of Future Areas (future wetland extent under 1.2 ft SLR scenario), and Sediment Accretion Rates (sediment supply). The Final Score represents the mean of available component metrics for each estuary. Cell colors reflect Final Score bin categories: Low Function (0–25), Moderate (26–50), Good (51–75), and High Function (76–100). Grey cells indicate sites or metrics where data were not available.

Estuary	Bird Species	Bird Guilds	
	# of species	Prop. of identified guilds	Final Score
SC-DEV	116.00	0.95	110.20
SC-GOL	37.00	0.85	31.45
SC-CARP	90.00	0.90	81.00
SC-VEN	93.00	0.90	83.70
SC-MUGU	122.00	0.90	109.80
SC-MAL	119.00	0.95	113.05
SC-COL	85.00	0.85	72.25
SC-SEAL	124.00	0.90	111.60
SC-BOL	153.00	0.95	145.35
SC-HBW	46.00	0.70	32.20
SC-NEW	139.00	1.00	139.00
SC-AGH	45.00	0.85	38.25
SC-BAT	139.00	0.95	132.05
SC-SEL	128.00	0.90	115.20
SC-SDL	119.00	0.90	107.10
SC-LPL	87.00	0.90	78.30
SC-KFR	107.00	0.90	96.30
SC-SWM	71.00	0.85	60.35
SC-TJE	134.00	0.90	120.60

Final Score:

Low Function (0–40)	Moderate (41–80)	Good (81–120)	High Function (121–160+)	No data
------------------------	---------------------	------------------	-----------------------------	---------

Figure 10. Bird habitat function scores. Summary of bird indicator scores for 19 sites. Columns show the two component metrics used to calculate the Final Score: bird species richness (# of species) and the proportion of identified bird guilds. The Final Score is calculated as the product of species richness and guild ratio. Cell colors reflect Final Score bin categories: Low Function (0–40), Moderate (40–80), Good (80–120), and High Function (120–160+). Grey cells indicate sites where data were not available.

Distribution

Overall, the distribution of final scores across the three functions revealed that the Marsh Vascular Plant Support function was generally good across southern California estuaries, while SLR Amelioration function was moderate (Figure 11). No clear patterns were observed for the Bird Habitat function

Marsh Vascular Plant Support scores (n = 15) were tightly clustered in the Good bin (51–75), with a mean score of 63.9 and a median of 63.1. This tight clustering suggests that while most estuaries support a moderate level of Marsh Vascular plant function, there is limited regional variation and few sites achieving high functional performance.

SLR Amelioration scores (n = 16) showed the lowest overall performance of the three indicators, with all sites falling in either the Moderate (n = 12) or Good (n = 4) bins and no sites reaching the High Function category. Scores ranged from 33.9 to 60.2, with a mean of 45.0 and a median of 44.0. The distribution was right-skewed, with most sites clustered in the lower portion of the Moderate range, suggesting that sea-level rise resilience is a widespread vulnerability across the region.

Bird Habitat scores (n = 19) showed the widest range and most even distribution of the three indicators, spanning from 31.5 to 145.4 with a mean of 93.6 and a median of 107.1. Three sites fell in the Low Function bin (0–40), three in the Moderate bin (41–80), nine in the Good bin (81–120), and four in the High Function bin (121–160+). This result indicates that there is high regional variation in bird habitat provisioning across the region, with multiple areas supporting high quality bird habitat.

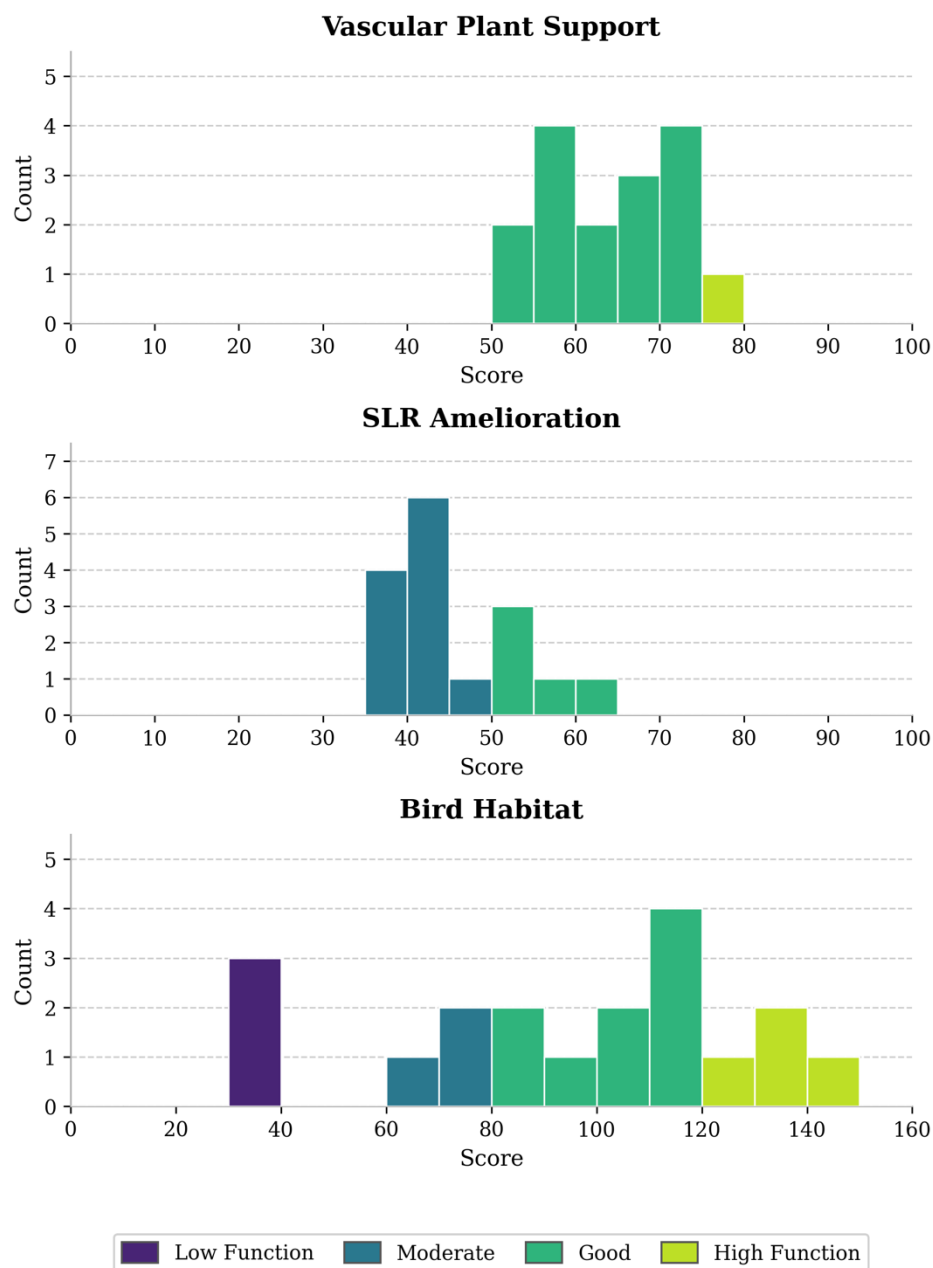


Figure 11. Distribution of final scores for three functions across the southern California estuaries: Marsh Vascular Plant Support (n = 15), SLR Amelioration (n = 16), and Bird Habitat (n = 19). Bar heights represent the number of estuaries falling within each score interval. Bars are colored according to four categories: Low Function (dark purple; 0–25 for Marsh Vascular Plant and SLR Amelioration, 0–40 for Bird Habitat), Moderate (teal; 26–50, 41–80), Good (green; 51–75, 81–120), and High Function (yellow; 76–100, 121–160+).

Factors

Boxplot comparisons of Marsh Vascular Plant Support, SLR Amelioration, and Bird Habitat scores across estuary type, archetype, and management authority revealed generally modest differences between groups, though some notable patterns emerged (Figure 12). Managed sites had generally higher function scores than less managed sites, while estuary type had less influence.

Estuary Type

For Marsh Vascular Plant Support, perennially open and temporarily closed estuaries performed similarly, with overlapping score distributions and comparable medians (perennially open mean = 62.1; temporarily closed mean = 63.1), suggesting estuary type has little influence on this function. SLR Amelioration scores were also broadly similar between the two groups (perennially open mean = 42.7; temporarily closed mean = 48.0), with considerable spread within both categories. Bird Habitat scores showed the clearest difference between estuary types, with perennially open estuaries achieving a higher mean (102.5) than temporarily closed estuaries (81.3), though this difference was largely driven by SC-GOL and SC-HBW as low outliers within the temporarily closed group, and within-group variability was considerable high in both cases.

Archetype

River Valley Estuaries showed the highest median SLR Amelioration scores (52.8) among archetypes with sufficient sample sizes, likely reflecting greater upland migration potential. Bay Estuaries and Intermediate Estuaries showed moderate and relatively consistent performance across all three functions, with limited spread within groups. Large Lagoons showed the greatest within-group variability for Bird Habitat, spanning from 32.2 to 145.4, suggesting that habitat quality within this archetype is highly site-specific. Small lagoon archetype was represented by only a single site (SC-COL).

Management

Federally managed sites achieved the highest mean scores across all three functions: Marsh Vascular Plant Support (mean = 69.9), SLR Amelioration (mean = 48.9), and Bird Habitat (mean = 100.6) though sample sizes were small ($n = 3-4$). State-managed sites, which comprised the largest group ($n = 9-11$), showed the widest range of scores and the lowest medians for Marsh Vascular Plant Support and SLR Amelioration, reflecting the diversity of conditions across this management category. UC Nature Reserve sites performed consistently in the moderate-to-good range across all three functions. City-managed sites had the smallest sample size ($n = 1-2$) and the lowest Bird Habitat scores, though the limited data preclude strong conclusions.

Based on the current available data, the relatively modest differences between groups across all three factors suggest that site-level conditions — including local stressors, habitat extent, and hydrological connectivity — likely exert a stronger influence on function scores than estuary type, archetype, or management authority alone.

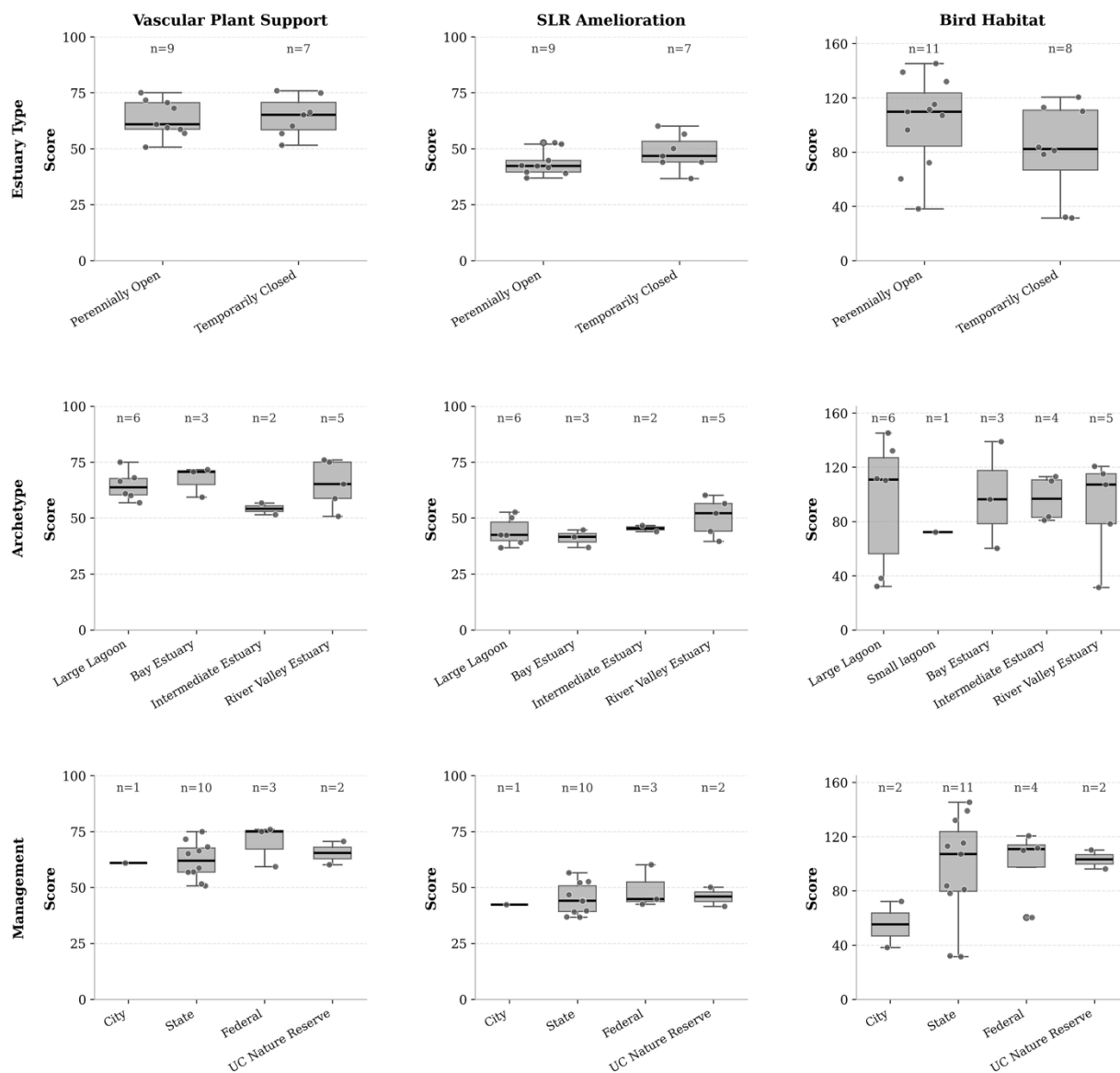


Figure 12. Boxplots comparing final scores for three functions — Marsh Vascular Plant Support, SLR Amelioration, and Bird Habitat — across estuary type (top row), archetype (middle row), and management authority (bottom row) for southern California sites. Boxes represent the interquartile range (IQR), with the horizontal line indicating the median. Whiskers extend to 1.5× the IQR, and individual data points are shown as jittered dots. Sample sizes (n) are shown above each box.

Stressors

Four stressor categories (Eutrophication, Anthropogenic Disturbance, Non-native Species, and Trash) were assessed across southern California estuaries using composite scores derived from component metrics (Figure 13, Figure 14). Data availability varied considerably across stressor categories, with Trash having the most limited coverage (n = 10) and Eutrophication the most complete (n = 18).

Eutrophication

Eutrophication scores ranged widely from 1.0 to 24.8, with a mean of 7.5 and a median of 5.3, indicating a right-skewed distribution where a small number of sites had substantially high values. SC-TJE (24.8) and SC-DEV (21.2) were clear outliers, with TN values exceeding 5 mg/g and TOC exceeding 30 mg/g, far above the regional median. In contrast, SC-MAL, SC-AGH, SC-COL, and SC-BOL all had scores below 3, reflecting less eutrophied conditions. The density curve confirms this pattern, with the distribution heavily concentrated at the lower end of the score range and a long tail extending toward higher stressor values.

Anthropogenic Disturbance

Anthropogenic Disturbance scores ranged from 6.48 to 82.21, with a mean of 53.45 and a median of 55.13. Lower transformed scores reflect better physical and buffer condition. SC-CARP (6.5), SC-DEV (23.4), and SC-MUGU (37.5) had the lowest transformed scores, indicating the strongest physical structure and buffer condition in the region. In contrast, SC-HBW (82.21), SC-GOL (77.7), and SC-MAL (74.3) had the highest transformed scores, indicating the greatest degree of anthropogenic modification. The distribution was relatively symmetric and spread across the full range, suggesting genuine variation in physical and buffer condition across the region.

Non-native Species

Non-native Species scores showed the most skewed distribution of all stressor categories, ranging from 0 to 62.5 with a mean of 15.3 and a median of only 5.1. The dominant driver of elevated scores was percent non-native fish rather than percent non-native plant cover, which was generally low across all sites. SC-HBW (62.5) and SC-VEN (48.7) had the highest scores, driven by non-native fish proportions of 62% and 46% respectively, considerably above the regional median. SC-BOL also scored highly (44.2) due to a substantial non-native fish

component. Most sites scored below 10, with SC-KFR and SC-BAT having negligible non-native species presence.

Trash

Trash scores were the most variable and had the most missing data of all stressor categories (n = 9), limiting regional interpretation. Among sites with data, scores ranged from 27 (SC-VEN) to 148 (SC-BOL), with a mean of 89.9 and a median of 115.0. The distribution was notably bimodal, with a cluster of sites scoring low (SC-VEN, SC-DEV, SC-GOL) and a larger cluster scoring high (SC-BOL, SC-MAL, SC-SEAL, SC-NEW, SC-BAT, SC-HBW). Plastic was the most abundant type of trash across all sites comprising 52-100% of the trash items found.



Figure 13. Summary of stressor indicator scores for 19 sites across four stressor categories: Eutrophication (total nitrogen, TN; total organic carbon, TOC), Anthropogenic Disturbance (CRAM Physical and Buffer attribute sub-indices), Non-native Species (percent non-native plants, percent non-native fish), and Trash (total trash count). Score columns reflect the composite score for each stressor category. C For Anthropogenic Disturbance, the raw score was transformed as 200 – raw score, so that all four stressor categories follow the same direction, where lower scores indicate lower stressor burden. Cell colors are scaled using a continuous gradient based on each site's rank relative to all sites, where yellow indicates the lowest observed stressor and dark purple indicates the highest. Grey cells indicate sites where insufficient data were available to calculate a score.

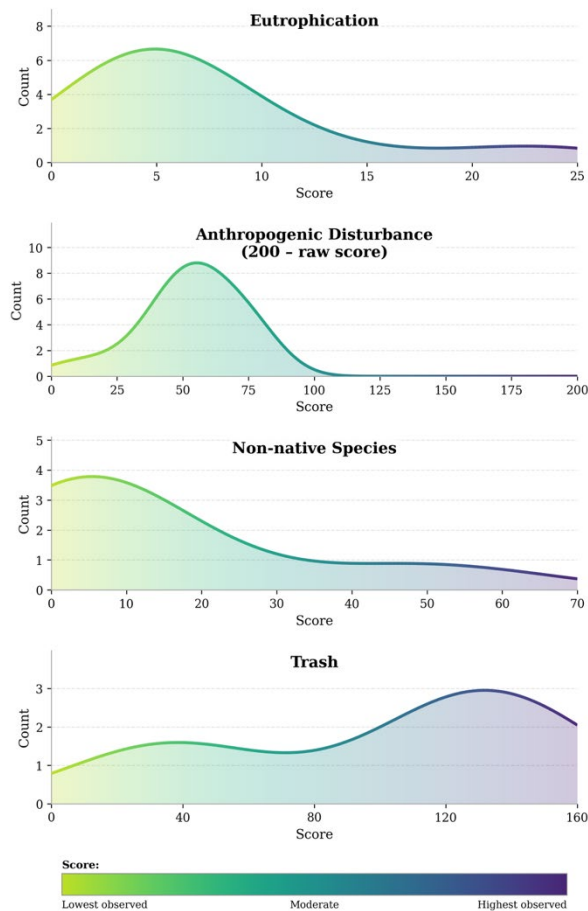


Figure 14. Kernel density estimates of stressor scores for four indicator categories: Eutrophication (n = 18), Anthropogenic Disturbance (n = 17), Non-native Species (n = 16), and Trash (n = 9). Curve height reflects the estimated density of sites at each score value, scaled to count. The Anthropogenic Disturbance score was transformed as 200 – raw score so that all categories follow the same direction. Curve and fill colors reflect the relative stressor burden using a continuous gradient, where yellow indicates the lowest observed stressor condition and dark purple indicates the highest. Sites with insufficient data to calculate a score were excluded.

DISCUSSION

Southern California estuaries show considerable variability in biological function and stressors, with no single site excelling or failing across all metrics. The survey sampled 19 of the 118 coastal wetlands in the SCB, approximately 16% of estuarine systems by count, representing 34% of the total estuarine area and approximately 75% of the estuarine wetland area in the region when open bays and harbors are excluded. Among the sampled sites, the SLR amelioration function represents the most consistent regional vulnerability, while eutrophication and non-native species stressor scores were high at a small number of sites, indicating site-specific vulnerabilities. However, stressor benchmarks have yet to be determined; therefore, further research needs to be conducted to determine if these scores

indicate true stress. Anthropogenic disturbance is the most broadly distributed stressor and likely represents the greatest structural barrier to improving estuary function across the region. For sites with consistently low scores in one or more functions, targeted interventions could improve that site as well as generate the greatest regional gains. Future monitoring efforts should prioritize consistent and comprehensive monitoring across multiple sites to better fill data gaps.

Core Insights

1. SLR amelioration is a region-wide vulnerability in the sampled sites.

Of the three function scores, SLR Amelioration showed the lowest and most compressed distribution, with all sampled sites scoring below 65 and the majority clustering in the Moderate bin (26–50). No site reached the High Function category. This finding suggests that sea-level rise resilience may be a systemic challenge across southern California estuaries. The relatively low upland migration potential scores driving this pattern indicate that many estuaries may lack the physical space needed to keep pace with projected sea-level rise, making this a priority concern for regional management.

However, conclusions about relative SLR resilience across estuary types, particularly between intermittently or temporarily closed and perennially open systems, should be interpreted with caution, as sediment accretion data were not collected as part of this assessment. Sediment accretion rates are a critical component of SLR resilience, and there is evidence that temporarily closed estuaries may accrete sediment at higher rates than open systems, potentially conferring greater resilience to sea-level rise than the current scores reflect (Thorne et al. 2021). Incorporating sediment accretion monitoring into future Bight estuary surveys is essential to resolving these differences and drawing more confident conclusions about SLR vulnerability across estuary types.

2. Bird habitat is the strongest performing function but masks important site-level disparities.

Bird Habitat scores were the highest and most variable of the three function indicators, with the majority of sites scoring in the Good to High Function range. However, a small cluster of sites (SC-GOL, SC-HBW, and SC-SWM) consistently ranked in the lowest percentile bins for both bird species richness and proportion of guilds. These sites also tended to score poorly on physical condition (high anthropogenic disturbance) and had lower CRAM scores, suggesting that degraded habitat structure could be a driver of poor bird community performance at these locations.

However, bird assemblage-based indicators in estuaries were strongly influenced not only by underlying habitat condition but also by sampling effort and site accessibility, which can

influence detectability and observed species richness. Numerous studies have shown that increased survey effort is positively associated with higher detection probabilities and species counts, particularly for mobile taxa such as birds, while limited access can bias observations toward more detectable or common species (MacKenzie et al. 2002; Kéry and Schmidt 2008). In estuarine and coastal systems, accessibility constraints (e.g., tidal inundation, private lands, or difficult terrain) can further influence where and when surveys occur, thereby affecting interpretations of habitat use and ecological function (Ralph et al. 1995; Conway 2011). As a result, while efforts were made to control for variation in survey effort, it does influence the results and could have introduced a site bias.

3. The marsh plant communities across sampled sites in the region were generally in good condition.

Marsh Vascular Plant Support scores were notably consistent across sampled southern California estuaries, with the majority of sites (14 of 16 with available data) falling within the Good category and scores ranging narrowly from 50.8 to 76.0. This tight clustering suggests that marsh plant communities across the region may be broadly functional, supporting adequate levels of native vegetation cover, structural complexity, and general habitat condition. The absence of any sites in the Low Function category and the limited number reaching High Function together indicate that while vegetation loss may not be widespread, few estuaries were found to achieve the highest levels of plant support. SC-TJE was the only site to reach the High Function category, driven by high native vegetation cover and strong CRAM Biotic scores, while SC-SDL was the only site scoring in the Moderate category, reflecting lower vegetation cover and reduced structural complexity relative to other sites. The consistency of scores across estuary types, archetypes, and management authorities further suggests that Marsh Vascular Plant Support is not strongly shaped by these broad categorical factors, and that site-level conditions such as hydrology, salinity regime, and disturbance history likely play a more deterministic role. However, the narrow score range also means that the assessment may have limited sensitivity to detect early-stage degradation or subtle differences in plant community composition that could signal emerging threats, particularly given that data were collected in a single season and year, and that only a small portion of some archetypes were sampled.

4. The three function scores provide a partial view of overall estuary condition.

The analyses presented here assess estuary condition through three functions, Marsh Vascular Plant Support, SLR Amelioration, and Bird Habitat, which represent important but incomplete dimensions of an estuary's health and condition. Southern California estuaries support additional ecological functions, including nutrient cycling, carbon sequestration, nursery habitat, primary production, and many more (Figure 5). None of these are directly captured by the current scoring framework. A site that scores well across the three assessed functions may

still be significantly degraded with respect to other ecological functions, and conversely, a site with low scores may still provide critical functions not measured here. This possibility is particularly relevant for indicators such as infauna abundance, fish richness, and sediment quality, which are included in the overarching monitoring but currently not formally integrated into the composite function scores. Strong performance in one estuarine function does not necessarily indicate overall ecosystem condition, as deficits in other functions may offset or constrain system performance. For example, SC-TJE had some of the highest scores for the three functions, however in 2023, impacts from transboundary sewage flows had known negative impacts on certain ecosystem functions not assessed in this report (e.g., biological community diversity and abundance) and positive impacts on others (e.g., marsh vascular plant support).

Evaluating multiple functions is therefore essential to capture trade-offs and provide a more balanced assessment of ecological integrity. Future iterations of this assessment framework should consider expanding the range of functions evaluated to provide a more comprehensive picture of estuary condition. Conclusions about overall site condition should be interpreted with the understanding that the current scores represent a snapshot of selected functions rather than a holistic assessment.

5. Site condition is not uniformly driven by a single factor.

No single estuary type, archetype, or management authority consistently predicted high or low performance across all function scores and stressor categories. This finding suggests that site-level processes, such as local land use, hydrological connectivity, and management history, may exert a stronger influence on estuary condition than broad categorical classifications. This result could have important implications for prioritization and management frameworks, which may be better based on site-specific assessments rather than categorical assumptions.

6. Scores reflect a single season and year and should be interpreted with caution.

All function scores and stressor assessments presented are derived from data collected during a single sampling period (Fall 2023) and therefore represent a snapshot of estuary condition rather than a characterization of long-term or baseline status. Estuaries are dynamic systems subject to considerable seasonal and interannual variability driven by rainfall, freshwater and sediment inflow, temperature, and climatic events such as drought, flood, and El Niño cycles. Biological communities, water quality conditions, and stressor levels can fluctuate substantially across seasons and years, meaning that scores obtained in a single fall sampling event may not be representative of conditions at other times of the year or in years with different climatic conditions. For example, dissolved oxygen impairment is often most severe in summer months when temperatures are highest and biological oxygen demand peaks, meaning the current

water quality scores (measured in fall) may underestimate the frequency or severity of hypoxic conditions that biological communities experience. Similarly, bird communities can vary seasonally with migratory patterns. Repeated monitoring across multiple seasons and years is therefore essential to distinguish persistent site-level patterns from transient conditions, to detect change over time, and to build the long-term baseline needed to evaluate management effectiveness and track responses to climate change.

7. Eutrophication and non-native species stressors are predominant at a few sites.

Both eutrophication and non-native species scores showed strongly right-skewed distributions. SC-TJE and SC-DEV consistently had the highest eutrophication scores, driven by elevated TN and TOC, while SC-HBW and SC-VEN were clear outliers for non-native fish. The presence and dominance of non-native or regionally introduced species, such as inland silversides (*Menidia beryllina*) and rainwater killifish (*Lucania parva*) (present at SC-HBW and SC-VEN) in southern California estuaries are often indicative of altered or degraded environmental conditions. Both species are highly tolerant of wide ranges in salinity, temperature, and dissolved oxygen, and they tend to thrive in systems with simplified habitat structure, reduced tidal exchange, and variable or poor water quality. Their success is frequently associated with anthropogenic influences such as hydrologic modification, nutrient enrichment, and the loss of native vegetated habitats, which can disadvantage more specialized native estuarine fishes. As a result, their presence, particularly when coupled with reduced native diversity or dominance in assemblages as in these cases, can signal decreased condition and increased stressors. However, because these species are also capable of exploiting naturally variable estuarine environments, their occurrence should be interpreted in context with emphasis on relative abundance and community composition rather than presence alone. The concentration of these stressors at specific sites suggests that targeted management interventions at a handful of locations could meaningfully reduce the regional stressor burden rather than requiring broad-scale action.

8. Anthropogenic disturbance is the most widespread stressor.

Anthropogenic disturbance in southern California estuaries is strongly reflected in the reduction and degradation of buffer zones and the loss of internal physical structure that supports characteristic estuarine flora and fauna. Unlike eutrophication and non-native species, which were concentrated at a few sites, anthropogenic disturbance scores showed a broadly distributed pattern across the sampled region, suggesting that physical modification and degraded buffer condition affect nearly all the sampled estuaries to varying degrees. SC-HBW and SC-GOL had the highest scores (most disturbed), while SC-DEV and SC-CARP had the lowest scores (best condition).

Even in the best scoring sites, extensive urbanization has constrained estuarine wetlands through coastal development, armoring, and infrastructure, resulting in diminished upland transition zones and impaired hydrologic connectivity (Zedler 1996; Callaway et al. 2012). These changes are often accompanied by simplified channel morphology, reduced habitat complexity, and loss of vegetated marsh and transitional habitats, which collectively limit biodiversity and ecosystem function (Lotze et al. 2006; Bromberg Gedan et al. 2009). Across the region, such disturbances are consistently identified as dominant stressors, with estuaries embedded in highly developed watersheds exhibiting greater nutrient loading, altered sediment dynamics, and reduced resilience compared to less modified systems. The widespread nature of this stressor suggests that improving physical structure and buffer condition, likely through habitat restoration and land use management in adjacent watersheds, would have the broadest regional benefit.

9. Temporarily closed estuaries show lower bird habitat scores but similar plant and SLR performance.

Temporarily closed estuaries had notably lower median Bird Habitat scores than perennially open estuaries, which may reflect reduced habitat extent and altered inundation regimes associated with intermittent closure. However, the two estuary types performed similarly for Marsh Vascular Plant Support and SLR Amelioration, which may suggest that hydrological regime affects bird communities more acutely than vegetation or physical resilience metrics. This distinction warrants further investigation, particularly as climate change is expected to alter the frequency and duration of estuary closures.

Bird habitat provision in estuaries is strongly influenced by system size, as larger wetlands generally support greater habitat heterogeneity, resource availability, and spatial capacity for foraging, nesting, and refuge. Species–area relationships are well-documented for birds, with larger estuarine and wetland systems typically supporting higher species richness and more diverse functional guilds due to increased niche availability and reduced edge effects. In southern California, estuary size is linked with estuary type, with the temporarily closed systems being smaller than the permanently open. In coastal environments, larger estuaries also tend to provide a broader range of microhabitats, such as mudflats, marsh plains, and open water areas, that support different feeding strategies and life-history stages (Colwell and Taft 2000). As a result, bird-related ecosystem functions, including habitat provisioning and trophic support, are often scaled with estuary size, although smaller systems may still provide critical, high-value habitat under certain conditions, particularly in fragmented landscapes. Additionally, if any of the temporarily closed estuaries were closed during the fall sampling period of 2023 (Appendix 1. Indicators: Mouth Dynamics), much of the edge habitat could be inundated leading to lower habitat heterogeneity and the associated impacts outlined above.

10. Data gaps limit regional interpretation for several key indicators

Substantial data gaps limited regional interpretation for a variety of indicators and therefore limited the scoring of functions. In particular, the absence of collected infauna data for more than a third of sites and trash data for over half of sites means that conclusions about these stressors should be treated with caution. Expanding monitoring coverage for these indicators would substantially improve the ability to detect regional patterns and track change over time.

Lessons Learned and Recommendations

1. A multi-indicator framework is essential, but only effective when core data are collected consistently across all sites.

The most important methodological insight from this assessment is that no single indicator tells the full story of estuarine condition: sites that performed well on one function underperformed on others, and stressors did not map cleanly onto functional condition. Yet the ability to make those multi-indicator comparisons depended entirely on having comparable data across sites, and the most significant practical constraint in the survey was the uneven availability of data. Infauna, trash, and non-native species data were absent for a substantial proportion of sites, and water quality monitoring was limited to fewer than half of the estuaries surveyed. These absences were due to the limited number of resources to collect those indicators across all 19 sampled sites.

These gaps meant that the richness of the multi-indicator framework could not be fully realized at the sampled regional scale. SC-TJE illustrates this well, where known impacts from transboundary sewage flows, including hypoxia and suppressed biological diversity, could not be captured within the assessment framework despite the site scoring among the highest across the three assessed functions. A multi-indicator approach only reveals complexity when all the indicators are collected.

Recommendation: Future surveys should establish a minimum data standard: a core set of indicators collected at every site before resources are directed toward additional metrics at a subset of locations. We recommend adopting the WRP RMP core indicator set: habitat and elevation mapping, marsh vegetation, water quality, hydrology, CRAM, fish, invertebrates, and sediment nutrients. Water quality loggers (measuring temperature and dissolved oxygen at a minimum) should be deployed at all sites for a minimum period capturing both tidal and diel variation, with summer deployment prioritized to capture hypoxic conditions. Where resources allow, the number of formally scored functions should be expanded and targeted intensive studies conducted at select sites to build the mechanistic understanding needed to interpret regional patterns.

2. Single-season sampling cannot distinguish persistent degradation from natural variability; paired surveys and long-term cycles are needed.

Reliance on fall 2023 data alone means that the scores presented here reflect a seasonal snapshot that may not be representative of the full annual cycle. This limitation is particularly consequential for water quality, where summer hypoxia is likely underestimated, and for biological communities (fish, birds, and invertebrates) that are strongly seasonal in their composition and abundance. A single survey cannot distinguish persistent site-level degradation from transient conditions driven by episodic events such as storms, drought, or unusual freshwater inputs, all of which are common in southern California's highly variable Mediterranean climate.

Confidence in condition assessments and trajectory diagnoses typically requires multiple monitoring cycles before patterns can be interpreted with reliability. Monitoring programs conducted on a recurring five-year cycle, such as the Bight program, provide a valuable framework for identifying broad regional patterns, but only when the estuary element is embedded as a permanent, recurring component rather than a one-time pilot.

Recommendation: Paired fall and spring surveys within each monitoring cycle are recommended to capture the contrast between post-dry and post-wet season conditions, which are likely to differ substantially for water quality and fish assemblage metrics. The estuary element should be embedded as a permanent Bight component, enabling repeated, consistent sampling over decadal timescales so managers can more confidently separate natural variability from directional change and evaluate the long-term effectiveness of restoration and protection efforts.

The Bight '23 Estuary Assessment served as an important test case for the emerging WRP RMP. This assessment piloted the same function-based assessment framework and core indicators that form the foundation of the WRP RMP's monitoring strategy, and demonstrated both the utility and the limitations of deploying this framework across a diverse set of estuarine archetypes in a single coordinated effort. Many of the lessons learned from Bight '23, including the critical need for standardized methods, consistent water quality logger deployment, and a minimum core indicator set collected at every site, are directly reflected in the WRP RMP's recommendations. Looking ahead, the WRP RMP's sentinel site network of 37 coastal wetlands offers a transformative opportunity for future Bight estuary elements. The sentinel sites were deliberately selected to represent the full range of estuarine archetypes, management contexts, and restoration trajectories across the SCB, ensuring reference sites that reflect least-disturbed conditions, active restoration sites that can be tracked through their ecological progression, and other sites of management interest. By anchoring future Bight estuary surveys to this sentinel site network, monitoring efforts gain both consistency and interpretive power.

The same sites, assessed with the same methods on a five-year cycle, can yield the trend data needed to distinguish persistent site-level patterns from transient conditions, evaluate whether restoration investments are producing measurable gains in ecological function, and track regional responses to climate change and SLR over time. Rather than selecting a new set of 19 sites each Bight cycle, embedding the sentinel network into the Bight program would ensure that each successive survey builds directly on the last, transforming what is currently a series of regional snapshots into a true long-term monitoring program capable of informing adaptive management decisions at both the site and regional scale.

3. Inconsistent methods across programs limit regional synthesis; standardization and crosswalks must be prioritized.

Bight '23 drew on a wide range of ongoing regional monitoring efforts to maximize site coverage, but the diversity of established methods (particularly for fish) created real challenges for data synthesis. When methods do not align, it becomes difficult to distinguish true ecological patterns from methodological artifacts, limiting the ability to make valid regional comparisons and track trends over time. This was especially apparent for fish assemblage data, where differences in gear type, sampling effort, and replication across programs precluded direct abundance comparisons among sites.

Recommendation: Where full standardization is not feasible due to long-term permit or grant commitments, deliberate investment in method crosswalks is essential. Calibration studies and conversion relationships among methods can help harmonize datasets and preserve their utility for regional assessment. Where programs are establishing new monitoring, adoption of the CalEMP standard operating procedures should be the default to ensure comparability with the broader statewide monitoring network. Where full standardization is not feasible, transparent documentation and the use of comparable indicators or normalized metrics enable integration of disparate data sources, supporting more robust synthesis and long-term monitoring efforts. These efforts can build off previous efforts to build data crosswalks across disparate methods (Johnston et al. 2021).

4. Multi-stressor and poor performance sites are identifiable even from a single cycle and should be designated as priorities for intensive monitoring and management.

Because this was the first application of the function-based approach within the Bight program, the dataset does not yet provide the multi-cycle evidence base needed to confidently identify sites with the most persistent convergence of poor functional condition and high stressor burden. However, even from this initial survey, sites emerged that showed consistently low function scores alongside elevated anthropogenic disturbance, eutrophication, or non-native

species pressure - patterns that warrant closer attention. These sites represent the locations where targeted intervention is most likely to produce measurable regional gains.

Recommendation: Future surveys should treat sites showing convergent multi-stressor and low performance signals as priority candidates for intensive monitoring between Bight cycles, targeted stressor reduction, and habitat restoration evaluation. Designating these sites within the WRP RMP sentinel site network (where possible) would enable more timely detection of change and provide the before-after data needed to evaluate the effectiveness of management interventions.

5. The first Bight estuary cycle revealed important gaps in scope; future assessments should expand functions, indicators, species linkages, and program partnerships.

The first application of the function-based approach identified a range of directions that would strengthen future assessment cycles. Workgroup participants flagged several additional indicators, including sedimentation rates and soil carbon stock, and functions, particularly nekton habitat provision, that were not formally assessed in this cycle but are ecologically important and methodologically feasible to incorporate. Questions around management effectiveness also warrant deeper investigation, including why federally managed sites outperformed others and how marsh age influences functional trajectory.

Additionally, expanding geographic scope and partnerships to include other estuaries within the Northern section of the SCB (e.g., Regional Water Board 3, Central Coast) would improve the regional context for southern California findings. Improved digital elevation models would strengthen SLR amelioration scoring, and integrating sensitive species data, including site-specific scorecards for listed species such as Ridgway rails, Belding's savannah sparrows, least terns, and snowy plovers, would connect the functional assessment framework to regulatory and recovery program priorities. Finally, linking the estuary element results to findings from other Bight survey components, particularly sediment quality and water quality, would help complete the picture of how contamination burdens interact with ecological function.

Recommendation: Future Bight estuary surveys should develop a roadmap for phased expansion of the assessment framework, prioritizing nekton habitat as the next function to be formally scored, developing species-specific analyses for listed species, and establishing formal linkages with the Bight sediment quality and water quality elements. The program should also explore protocols for event-based monitoring, including El Niño years and post-storm surveys, to capture the episodic dynamics that five-year cycle snapshots inherently miss.

Table 4. Summary table of all five lessons learned with recommended actions and estimated level of effort.

Lesson learned & recommendation	Recommended action	Level of effort
A multi-indicator framework is essential, but only effective when core data are collected consistently across all sites.	1. Adopt the WRP RMP core indicator set at every site.	Medium
	2. Deploy water quality loggers continuously.	High
	3. Expand functions scored and supplement with intensive site studies as resources allow.	Medium
Single-season sampling cannot distinguish persistent degradation from natural variability; paired surveys and long-term cycles are needed.	1. Add paired spring and fall surveys each cycle.	High
	2. Embed the estuary element permanently in Bight and the WRP RMP to build multi-year trend data over decadal timescales.	Medium
Inconsistent methods across programs limit regional synthesis; standardization and crosswalks must be prioritized.	1. Adopt CalEMP SOPs as the default for new monitoring.	Low
	2. Invest in crosswalk development where standardization is not feasible. Document method differences transparently in all syntheses.	Low
Multi-stressor and poor performance sites are identifiable even from a single cycle and should be designated as priorities for intensive monitoring and management.	1. Designate low performance sites as priority candidates for intensive monitoring between Bight cycles, aligned with the WRP RMP sentinel site network.	High
The first Bight estuary cycle revealed important gaps in scope; future assessments should expand functions, indicators, species linkages, and program partnerships.	1. Develop a roadmap to add the nekton habitat function, listed species scorecards, linkages to other Bight elements, and event-based monitoring protocols.	High

CONCLUSION

The Bight '23 Estuary Wetland Assessment represents the first regional evaluation of estuarine condition that ties indicators to functions across the Southern California Bight, establishing a critical baseline for ongoing monitoring and management. This work takes on particular urgency given what the broader Bight program has consistently documented: estuaries and embayments are the most contaminated habitat stratum in the region. Against this backdrop, the Bight '23 estuary element provides the ecological dimension that sediment chemistry alone cannot, assessing whether these systems still support critical ecosystem functions despite their contamination burden.

Assessed across 19 estuaries using three ecological functions (Marsh Vascular Plant Support, Sea Level Rise Amelioration, and Bird Habitat Provision) the sampled region's estuaries showed generally moderate to good condition. Despite documented contamination burdens, the sampled southern California estuaries are still broadly supporting vascular plant communities, providing bird habitat, and maintaining at least partial resilience to sea-level rise, suggesting that ecological function can persist even in chemically stressed systems. However, the three functions assessed here represent only a partial view of overall estuarine condition. Functions more strongly affected by chemical contamination, including primary production, nutrient cycling, nursery habitat provision, nekton habitat provision, and secondary production, were not formally evaluated in this cycle (although individual metrics were assessed), and it remains unknown whether the contamination levels documented in Bight '23 are suppressing these other functions in ways the current assessment framework cannot yet assess due to data gaps. The findings and outcomes of Bight '23 identified critical next steps for future regional surveys, with sediment chemistry, toxicity, and a broader suite of ecological functions, particularly nekton habitat provision, emerging as priority additions for Bight '28 and beyond.

REFERENCES

- Allen, L.G. (1982). Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. *Fishery Bulletin*, 80, 769–790.
- Allen, D.M., Service, S.K., & Ogburn-Matthews, M.V. (1992). Factors influencing the collection efficiency of estuarine fishes. *Transactions of the American Fisheries Society*, 121, 234–244.
- Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., & Silliman, B.R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, 81(2), 169–193.
- Beck, M.W., Heck, K.L., Able, K.W., Childers, D.L., Eggleston, D.B., Gillanders, B.M., Halpern, B., Hays, C.G., Hoshino, K., Minello, T.J., Orth, R.J., Sheridan, P.F., & Weinstein, M.P. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience*, 51(8), 633–641.
- Bromberg Gedan, K., Silliman, B.R., & Bertness, M.D. (2009). Centuries of human-driven change in salt marsh ecosystems. *Annual Review of Marine Science*, 1, 117–141.
- Burkholder, J.M., Mason, K.M., & Glasgow, H.B. (1992). Water-column nitrate enrichment promotes decline of eelgrass *Zostera marina*: Evidence from seasonal mesocosm experiments. *Marine Ecology Progress Series*, 81, 163–178.
- Callaway, J.C., Borgnis, E.L., Turner, R.E., & Milan, C.S. (2012). Carbon sequestration and sediment accretion in San Francisco Bay tidal wetlands. *Estuaries and Coasts*, 35(5), 1163–1181.
- Chao, A., & Jost, L. (2012). Coverage-based rarefaction and extrapolation: Standardizing samples by completeness rather than size. *Ecology*, 93(12), 2533–2547.
- Cloern, J.E. (2001). Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series*, 210, 223–253.
- Colwell, M.A., & Taft, O.W. (2000). Waterbird communities in managed wetlands of varying water depth. *Waterbirds*, 23(1), 45–55.
- Conway, C.J. (2011). Standardized North American marsh bird monitoring protocols. *Waterbirds*, 34(3), 319–346.
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387, 253–260.

- DeGraaf, R.M., Tilghman, N.G., & Anderson, S.H. (1985). Foraging guilds of North American birds. *Environmental Management*, 9(6), 493–536.
- De Wet, N.T. (2025). *Characterizing fish communities using traditional and emerging monitoring approaches in San Diego County estuaries*. Master's Thesis, University of San Diego.
- Doughty, C.L., Cavanaugh, K.C., Hall, C.R., Ambrose, R.F., & Bell, T.W. (2019). Evaluating regional resiliency of coastal wetlands to sea level rise through geometric quantification and habitat connectivity. *Estuaries and Coasts*, 42(7), 1576–1591.
- Glasgow, H.B., & Burkholder, J.M. (2000). Water quality trends and management implications from a five-year study of a eutrophic estuary. *Ecological Applications*, 10(4), 1024–1046.
- Gold, Z., Koch, M.Q., Schooler, N.K., Emery, K.A., Dugan, J.E., Miller, R.J., Page, H.M., Schroeder, D.M., Hubbard, D.M., Madden, J.R., Whitaker, S.G., & Barber, P.H. (2023). A comparison of biomonitoring methodologies for surf zone fish communities. *PLoS One*, 18, e0260903.
- Harley, C.D.G., Hughes, A.R., Hultgren, K.M., Menge, B.A., Minchella, C.W., Stachowicz, J.J., & Williams, S.L. (2006). The impacts of climate change in coastal marine systems. *Ecology Letters*, 9(2), 228–241.
- Hurlbert, S.H. (1971). The nonconcept of species diversity: A critique and alternative parameters. *Ecology*, 52(4), 577–586.
- Johnston, K., I. Medel, C. Whitcraft, J. Crooks, M. Grubbs, S. Anderson, K. Uyeda, E. Stein, and C. Enyart. 2021. California Estuarine Wetland Monitoring Manual (Level 3) V2. Prepared by The Bay Foundation and partners for the United States Environmental Protection Agency. https://cms.santamonicabay.org/wp-content/uploads/2021/06/L3-Estuarine-Wetland-Manual-V.2_FINAL-webversion.pdf
- Kamer, K., & Stein, E.D. (2003). Reach-scale nitrogen cycling in an effluent-dominated southern California river. *Freshwater Biology*, 48(9), 1735–1748.
- Kennish, M.J. (2002). Environmental threats and environmental future of estuaries. *Environmental Conservation*, 29(1), 78–107.
- Kelly, R.P., Port, J.A., Yamahara, K.M., Martone, R.G., Lowell, N., Thomsen, P.F., Mach, M.E., Bennett, M., Prahler, E., Caldwell, M.R., & Crowder, L.B. (2014). Harnessing DNA to improve environmental management. *Science*, 344, 1455–1456.
- Kéry, M., & Schmidt, B.R. (2008). Imperfect detection and its consequences for monitoring for conservation. *Community Ecology*, 9(2), 207–216.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., ... & Jackson, J.B.C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science*, 312(5781), 1806–1809.

Macdonald, T.A., Burd, B.J., Macdonald, V.I., & van Roodselaar, A. (2010). Taxonomic and feeding guild classification for the marine benthic macroinvertebrates of the Strait of Georgia, British Columbia. Canadian Technical Report of Fisheries and Aquatic Sciences, 2874.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Royle, J.A., & Langtimm, C.A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83(8), 2248–2255.

McGlathery, K.J. (2001). Macroalgal blooms contribute to the decline of seagrass in nutrient-enriched coastal waters. *Journal of Phycology*, 37(4), 453–456.

McLaughlin, K., Sutula, M., Busse, L., Anderson, S., Crooks, J., Dagit, R., Gibson, D., Johnston, K., Nezlin, N., & Stratton, L. (2012). *Southern California Bight 2008 regional monitoring program VIII: Estuarine eutrophication assessment*. Southern California Coastal Water Research Project, Costa Mesa, CA.

McLeod, E., Chmura, G.L., Bouillon, S., Salm, R., Björk, M., Duarte, C.M., Lovelock, C.E., Schlesinger, W.H., & Silliman, B.R. (2011). A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO₂. *Frontiers in Ecology and the Environment*, 9(10), 552–560.

Nordström, M.C., Demopoulos, A.W.J., Whitcraft, C.R., Rismondo, A., McMillan, P., Mercer, J.L., & Levin, L.A. (2014). Food web heterogeneity and succession in created saltmarsh communities. *Journal of Applied Ecology*, 52(3), 1176–1187.

O'Connor, K., Fulkerson, B., Walker, J., Stein, E.D., Whitcraft, C., & Huckeba, J.S. (2025). *Estuary marine protected area fall 2023 data analysis report*. Report prepared for the California Ocean Protection Council and the California Department of Fish and Wildlife, OPC Grant #C0302111. 60 pp.

https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1430_EMPADDataAnalysisReport.pdf

Port, J.A., O'Donnell, J.L., Romero-Maraccini, O.C., Leary, P.R., Litvin, S.Y., Nickols, K.J., Yamahara, K.M., & Kelly, R.P. (2016). Assessing vertebrate biodiversity in a kelp forest ecosystem using environmental DNA. *Molecular Ecology*, 25, 527–541.

Ralph, C.J., Geupel, G.R., Pyle, P., Martin, T.E., DeSante, D.F., & Milá, B. (1995). Manual of field methods for monitoring landbirds. USDA Forest Service General Technical Report PSW-GTR-159.

SCWRP. (2018). Wetlands on the Edge: The Future of Southern California's Wetlands: Regional Strategy 2018. California State Coastal Conservancy, Oakland, CA. <https://scwrp.org/regional-strategy-report/>

SCWRP. (2024). Assessing Wetland Recovery: Building capacity for assessing recovery efforts in supporting regional wetland health and resiliency - Development of a coastal wetland sentinel site network. Prepared by the Wetland Recovery Project Scientific Advisory Panel. https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1393A_SentinelSiteNetwork.pdf

Steele, M.A., Schroeter, S.C., & Page, H.M. (2006a). Sampling characteristics and biases of enclosure traps for sampling fishes in estuaries. *Estuaries and Coasts*, 29(4), 630–638.

Steele, M.A., Schroeter, S.C., & Page, H.M. (2006b). Experimental evaluation of biases associated with sampling estuarine fishes with seines. *Estuaries and Coasts*, 29(6B), 1172–1184.

Stein, E.D., Cayce, K., Salomon, M., Bram, D.L., De Mello, D., Grossinger, R., & Dark, S. (2014). *Wetlands of the southern California coast: Historical extent and change over time*. SCCWRP Technical Report 826 / SFEI Report 720. Southern California Coastal Water Research Project, Costa Mesa, CA. https://www.sfei.org/sites/default/files/biblio_files/826_Coastal_Wetlands_and_change_over_time_Aug_2014.pdf

Thorne, K.M., Buffington, K.J., Jones, S.F., & Largier, J.L. (2021). Wetlands in intermittently closed estuaries can build elevations to keep pace with sea-level rise. *Estuarine, Coastal and Shelf Science*, 257, 107386. <https://doi.org/10.1016/j.ecss.2021.107386>

Trainer, V.L., Adams, N.G., Bill, B.D., Stehr, C.M., Wekell, J.C., Moeller, P., Busman, M., & Woodruff, D. (2002). Domoic acid production near California coastal upwelling zones, June 1998. *Limnology and Oceanography*, 45(8), 1818–1833.

Twilley, R.R. (1985). The exchange of organic carbon in basin mangrove forests in a southwest Florida estuary. *Estuarine, Coastal and Shelf Science*, 20(5), 543–557.

U.S. Environmental Protection Agency. (2001). National Coastal Condition Report. EPA-620/R-01/005. Washington, DC.

Valiela, I., Foreman, K., LaMontagne, M., Hersh, D., Costa, J., Peckol, P., DeMeo-Anderson, B., D'Avanzo, C., Babione, M., Sham, C.H., Brawley, J., & Lajtha, K. (1992). Couplings of watersheds and coastal waters: Sources and consequences of nutrient enrichment in Waquoit Bay, Massachusetts. *Estuaries*, 15(4), 443–457.

Whitcraft, C.R., & Levin, L.A. (2007). Regulation of benthic algal and animal communities by salt marsh plants: Impact of shading. *Ecology*, 88(4), 904–917.

Zedler, J.B. (1996). Coastal mitigation in southern California: The need for a regional restoration strategy. *Ecological Applications*, 6(1), 84–93.

APPENDIX 1. INDICATORS

The Bight Estuary Element differed from other Bight surveys in that it allowed existing monitoring protocols and data to be incorporated into the data collection. The majority of sites collected data following the CalEMP protocols; however, some sites modified the SOPs to retain consistency with long-term datasets. For a detailed explanation of indicators and methods, see the [Bight '23 Estuary Wetland Assessment Field Operations Manual](#).

Below we summarize each indicator with key graphics. We include sites beyond the summarized 19 sites above, as a variety of other sites participated in some indicator monitoring.

Abiotic Indicators

Water Quality

Water quality is among the most ecologically important dimensions of estuarine condition and is fundamental to understanding the biological, chemical, and physical dynamics that drive ecosystem function. In southern California, estuaries are subject to a range of water quality stressors, including hypoxia, elevated nutrient loading, salinity fluctuation, and temperature extremes, that are directly linked to regulatory programs, beneficial use designations, and the ecological functions assessed in this report. Despite this importance, water quality data were unavailable for nearly half of the sites assessed in Bight '23, representing one of the most consequential data gaps in this assessment cycle. Where data were available, they provided critical context for interpreting biological community composition, eutrophication indicators, and functional condition scores that could not be obtained from any other source.

A series of loggers were deployed to identify the general water quality conditions. The archetype and mouth state of the estuary can influence abiotic conditions within the estuary; therefore, a multi-array of instruments was used to capture conductivity (salinity), temperature, and dissolved oxygen. The number of sensors deployed within each estuary depended on the size, the vertical gradient (stratification) of the estuary, and the amount of resources that were available to a given estuary.

The level of effort available to deploy and maintain water quality loggers differed among estuaries. Some estuaries (e.g., Tijuana River NERR) have long-term, in situ water loggers deployed all year long. These loggers undergo continual maintenance and calibration. While other estuaries have intermittent loggers deployed, the ability to deploy them more consistently is limited due to resource availability, theft, and winter storm surge (e.g., Ventura River and Goleta Slough). Table 3. lists the available water quality data in the SCB.

Table 5. The data sensors available for each estuary. * marks sensors that are deployed permanently and empty cells indicate no sensor was deployed.

Sites	Deployment Length	Data Access
Tijuana River Estuary*	Continuous	NERR Website; SONGS Portal
San Diego Bay: South Salt Ponds*	Continuous	Jeff Crooks
Sweetwater Marsh		
Mission Bay: Kendall-Frost Reserve		
Los Peñasquitos Lagoon*	Continuous	Jeff Crooks; SONGS Portal (beginning 2025)
San Dieguito Lagoon*	Continuous	SONGS Portal
San Elijo Lagoon*	Continuous	Nature Collective
Batiquitos Lagoon	Continuous	CalEMP
Agua Hedionda	Sporadic	Nature Collective
Newport Bay	Spring, Fall	CalEMP
Huntington Beach Wetlands		
Bolsa Chica	Continuous	CalEMP
Seal Beach		
Malibu Lagoon	Spring, Fall	CalEMP
Point Mugu*	Continuous	SONGS Portal
Ventura River	Spring, Fall	CalEMP
Carpinteria Estuary*	Continuous	SONGS Portal
Goleta Slough	Spring, Fall	CalEMP
Devereux Slough	Continuous	Water level data only; UCSB

Due to these inconsistencies in data collection, we report a subset of the water quality data in this report to illustrate how SCB estuaries are extremely dynamic with varying water quality conditions. At this time, we cannot provide statistical summaries or provide management guidance about these systems. To fully understand the status and trends within and among estuaries, significant effort is needed to improve data collection and storage and to continue over several years (>5 years).

For each parameter (temperature, salinity, dissolved oxygen), we compared a subset of metrics across sites. As data are not necessarily concurrent, we used all the available data from August – December 2023. We illustrate the data as a series of stacked bar plots that display the percent of days the water quality parameter was below specific thresholds (Figure 15, Figure 16, Figure 17).

Continuous water quality monitoring using deployed data sondes or loggers offers the most robust approach to capturing the temporal dynamics of these systems, including tidal cycles, diel dissolved oxygen fluctuations, and episodic hypoxic events that discrete sampling cannot reliably detect. However, logger-based monitoring carries important practical limitations that must be acknowledged. Deployment location is critical; a single logger placed in the main channel may not represent conditions across the full extent of a lagoon, particularly in larger or more complex systems where spatial gradients in salinity, temperature, and dissolved oxygen can be substantial. Loggers also have limited ability to detect vertical stratification (unless deployed together), which can be ecologically significant in deeper channels and embayments where bottom-water hypoxia may develop independently of surface conditions. Finally, the cost of procurement, deployment, maintenance, and data management, including monthly intercalibration and download, represents a meaningful investment that must be planned for explicitly in program budgets. These limitations do not diminish the value of continuous monitoring; rather, they underscore the need for standardized deployment protocols tailored to estuary type and size, so that data collected across programs are comparable and ecologically interpretable.

Looking ahead to Bight '28, expanding water quality monitoring capacity across all WRP RMP sentinel sites should be treated as a funding priority. At a minimum, continuous loggers capturing temperature, salinity, and dissolved oxygen should be deployed at all sites for a period that encompasses both tidal and diel variation, with summer deployment prioritized to capture hypoxic conditions that fall surveys systematically miss. For sites where watershed inputs are a known stressor, including estuaries receiving urban runoff or transboundary flows, autosamplers deployed at estuary inflows offer a complementary approach that has already been implemented at select southern California sites and could be scaled regionally with targeted funding. Passive samplers represent another cost-effective option for characterizing contaminant exposure and time-integrated water quality conditions at sites where continuous logger deployment is not feasible. Establishing a standardized water quality monitoring framework, specifying logger placement, deployment duration, minimum parameters, and quality control protocols by estuary archetype, would ensure that data collected through core monitoring, permit and grant programs, and special studies can be meaningfully integrated and compared across the region. Overall, the Data Subcommittee recommends the continued investment in collecting water quality parameters throughout the region. We compiled rough cost estimates for logger deployment (Table 6).

Table 6. Rough cost estimates for one logger array at a single estuary site.

Item	Cost	Description
Data Logger		One-time costs for the data logger
Telemetry	\$7,000	Telemetry setup includes data logger enclosure, battery, cellular modem, antennae, cables
EXO3 Sonde	\$7,000	Sonde, batteries, software
DO sensor	\$2,200	Dissolved oxygen sensor
Conductivity/Temperature sensor	\$2,000	Conductivity and temperature sensor
Wiper	\$1,400	Wiper port for conductivity
Lead cable	\$700	Sonde adapter cable
Anti-fouling guard	\$1,000	Sensor guard for anti-fouling with copper alloy
Total	\$21,000	
Routine and Maintenance		Annual costs to maintain the loggers
Cellular communication	\$600	2-way cellular communication, 12 months
Maintenance and Calibrations	\$50,000	6-week calibration and maintenance; labor and material costs, 12 months
Total	\$50,600	

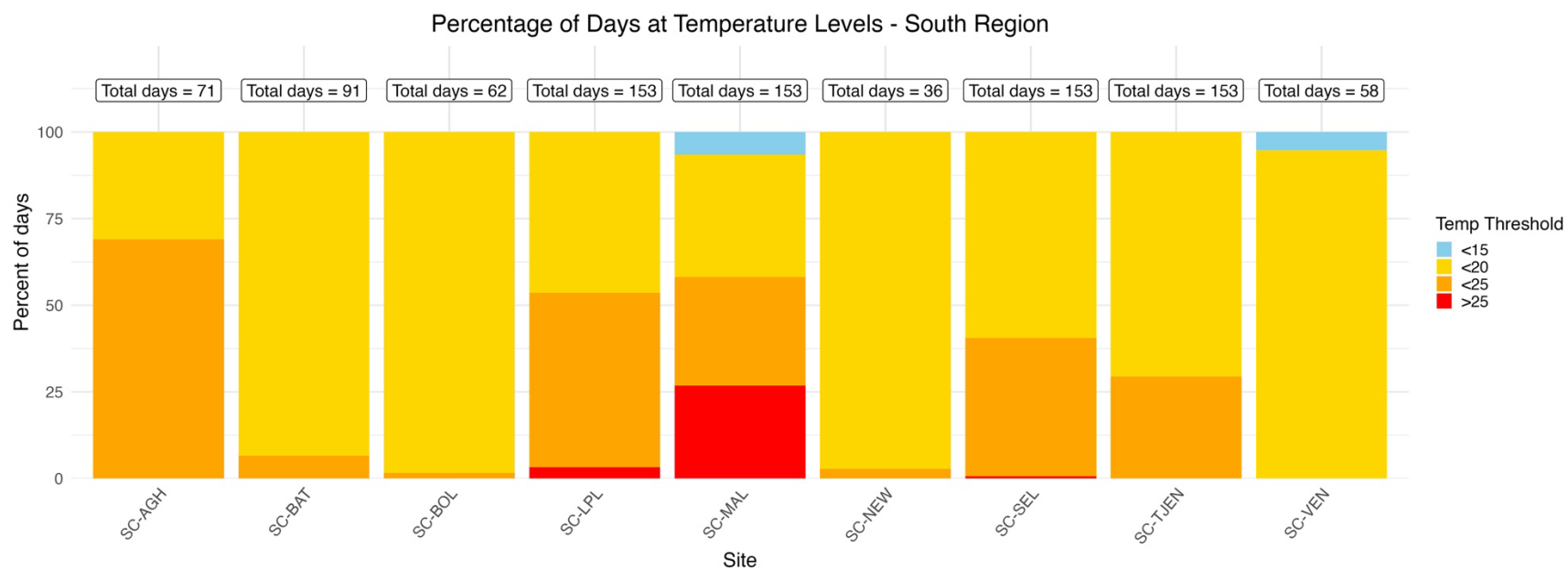


Figure 15. Percent of days the daily average temperature was less than 15 °C (blue), 20 °C (yellow), 25 °C (orange), or greater than 25 °C (red). The total number of available days with temperature data for each site is listed above each bar from August 1, 2023-December 31, 2023.

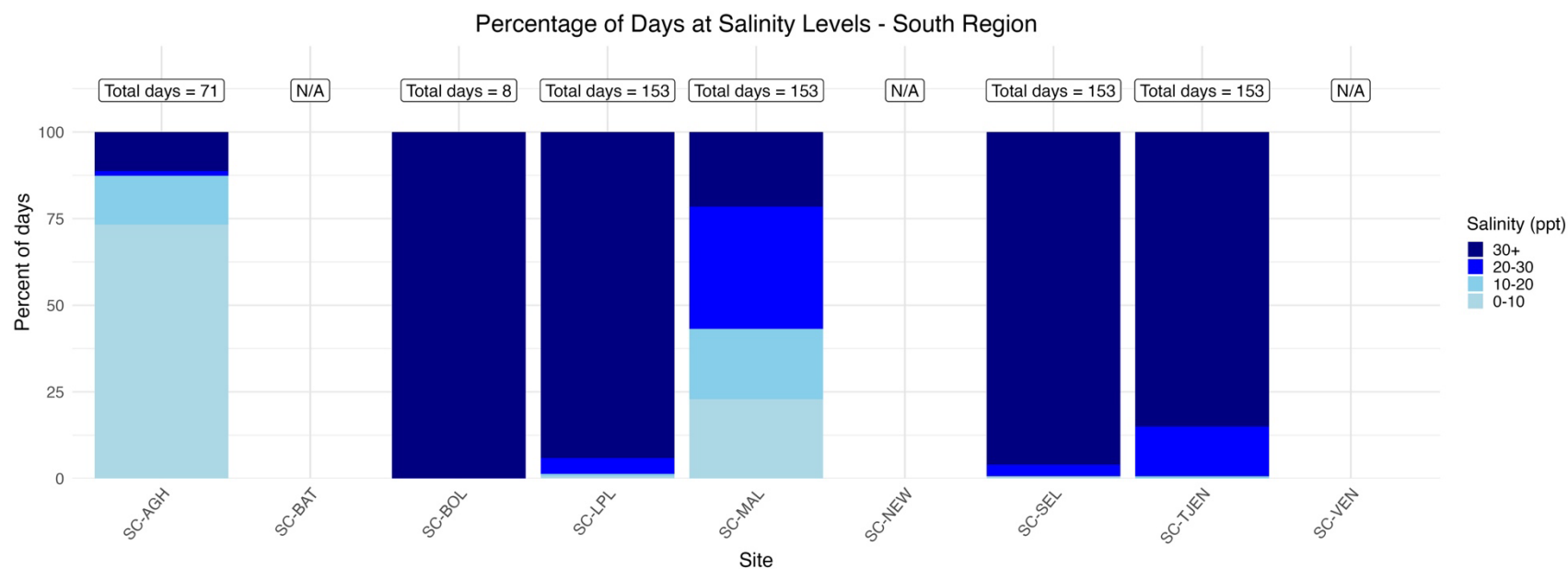


Figure 16. Percent of days the daily average salinity was between 0-10 ppt (light blue), 10-20 ppt (sky blue), 20-30 ppt (dark blue), or greater than 30 ppt (black). The total number of available days with salinity data for each site is listed above each bar from August 1, 2023-December 31, 2023.

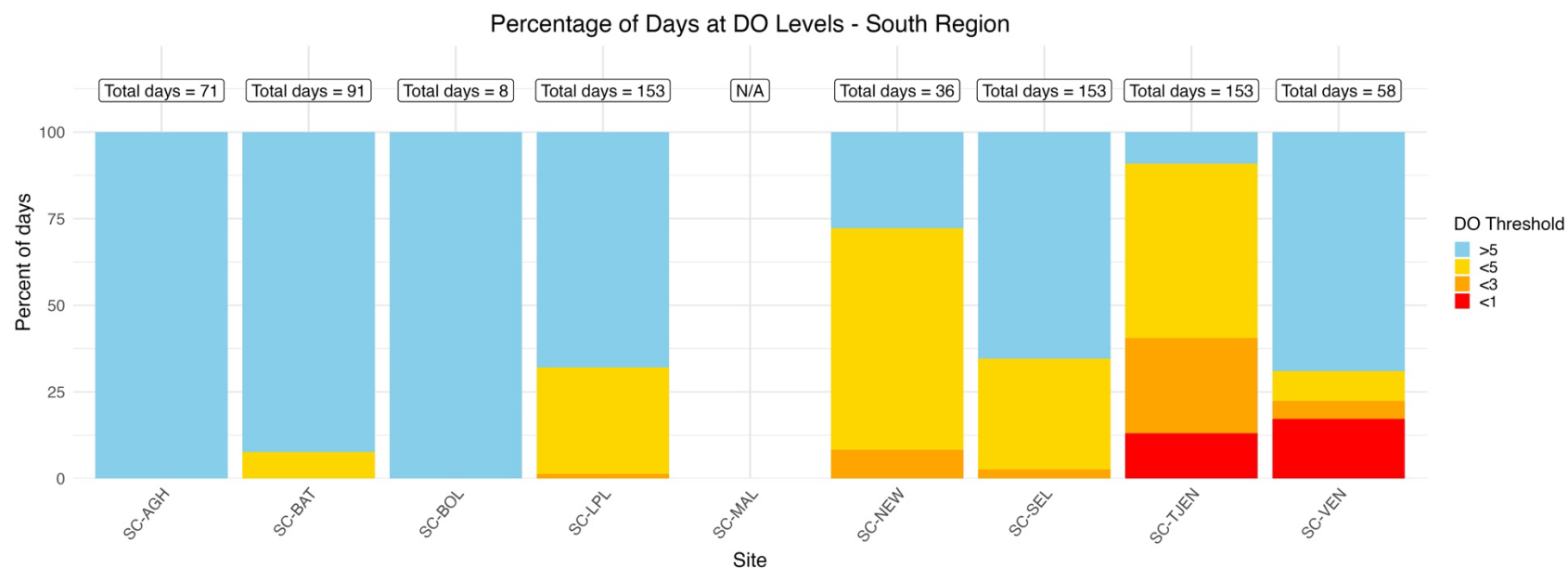


Figure 17. Percent of days the daily average dissolved oxygen (DO) was between less than 1 mg/L (red), 3 mg/L (orange), 5 mg/L (yellow), or greater than 5 mg/L (blue). The total number of available days with DO data for each site is listed above each bar from August 1, 2023-December 31, 2023.

Sediment Quality

Eutrophication is one of the top three leading causes of impairment of the nation's waters (US EPA 2001) and a well-documented global issue in estuarine and coastal systems, with demonstrated links between anthropogenic nutrient loading, harmful algal blooms, hypoxia, and cascading impacts on aquatic food webs (Valiela et al. 1992, Kamer and Stein 2003). In southern California estuaries, these impacts can include fish kills, loss of seagrass beds, smothering of benthic invertebrates, nuisance odors, and risks to human and marine mammal health, all carrying significant ecological, economic, and social costs (Glasgow and Burkholder 2000, Twilley 1985, Burkholder et al. 1992, McGlathery 2001, Trainer et al. 2002).

Total organic carbon (TOC) and total nitrogen (TN) are the primary sediment-based indicators used to assess eutrophication in estuarine environments. TOC reflects the abundance of organic matter in sediments from both natural sources (decaying plant material, phytoplankton) and anthropogenic inputs such as agricultural runoff and sewage discharge. Elevated TOC often signals increased nutrient loading and conditions conducive to excessive algal growth and oxygen depletion. TN captures the total nitrogen pool in sediments, where elevated concentrations similarly point to nutrient pollution from urban runoff, wastewater, and agricultural practices. Together, TOC and TN provide a cost-effective means of tracking nutrient dynamics, identifying pollution hotspots, and evaluating the effectiveness of management actions aimed at reducing nutrient inputs to estuarine systems.

Looking ahead to Bight '28, the sediment nutrient monitoring framework should be expanded in several directions. Increasing spatial replication within sites (sampling across channel, marsh plain, and tributary zones rather than relying on a single station) would improve the ability to detect within-estuary gradients and identify localized pollution sources. Expanding the suite of contaminants measured to include emerging concerns, particularly microplastics and contaminants such as PFAS, would strengthen linkages between the estuary element and the broader Bight sediment chemistry program and provide a more complete picture of the cumulative stressor burden facing southern California estuaries. Incorporating macroalgae surveys alongside sediment nutrient sampling would add a direct biological indicator of eutrophication that sediment chemistry alone cannot capture. Finally, coordinating sediment nutrient sampling with water quality monitoring, particularly at sites where hypoxia or algal blooms have been documented, would allow for more mechanistic interpretation of eutrophication dynamics and support more targeted management responses.

Grab samples were collected at all 19 sites for TOC, TN, and sediment grainsize. An additional 3 sites were also opportunistically sampled – SC-BSC (Big Sycamore Canyon), SC-ASE (Arroyo Sequit), and SC-TOP (Topanga Canyon Lagoon).

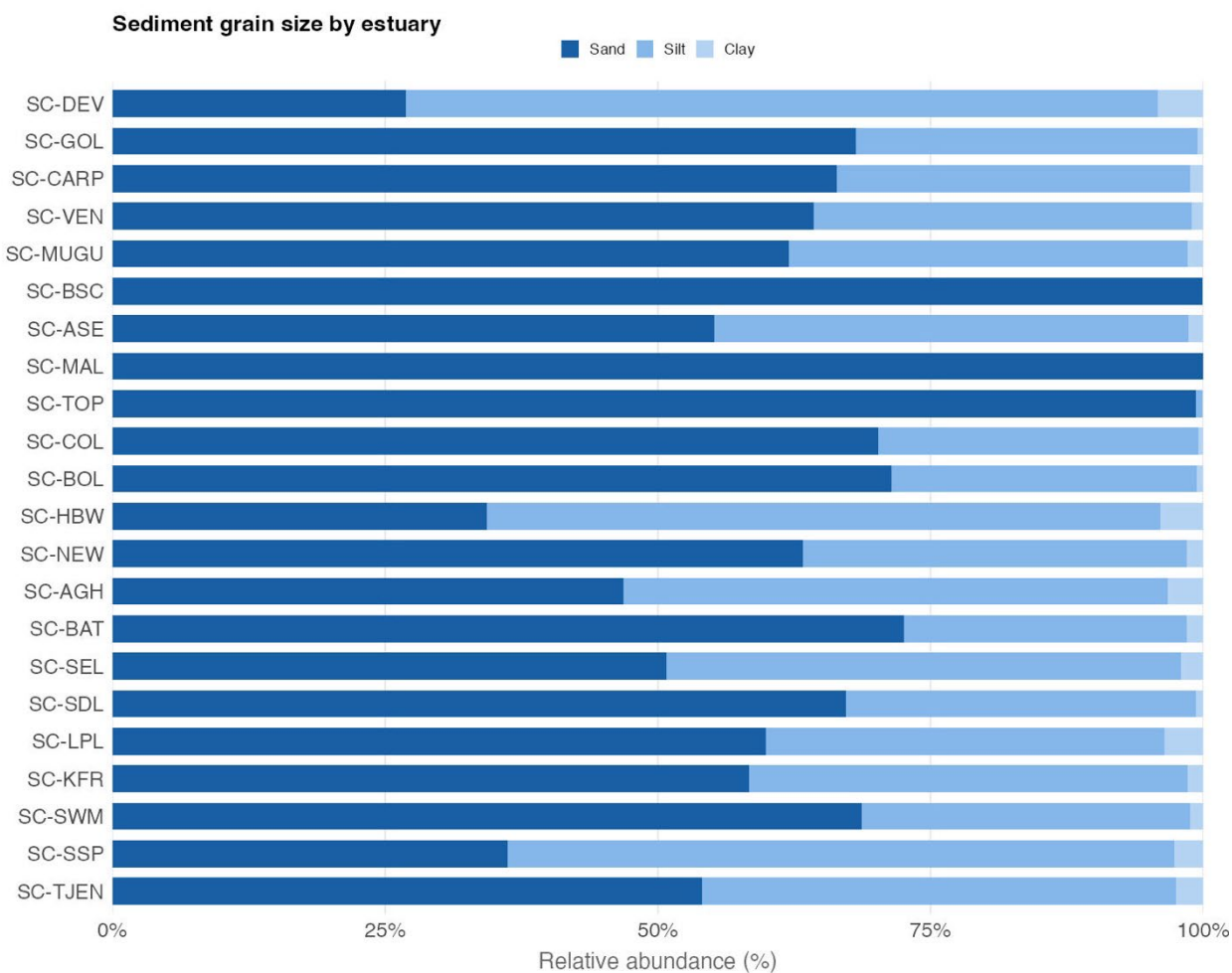


Figure 18. Relative grain size composition of sediment samples. Bars represent the mean proportion of sand, silt, and clay fractions across stations within each estuary, normalized to 100%.

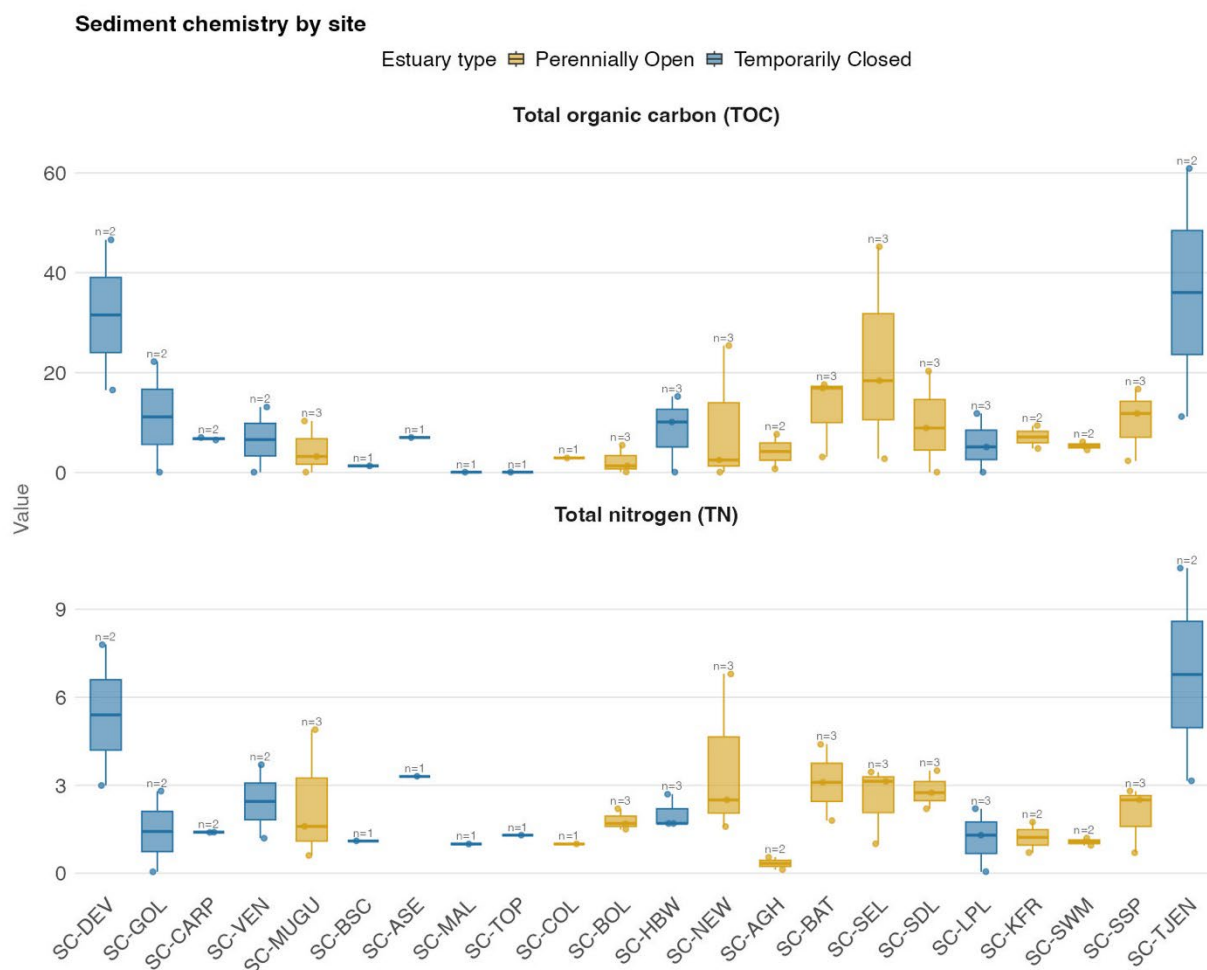


Figure 19. Boxplots of total organic carbon (TOC) and total nitrogen (TN) concentrations measured in sediment samples collected from southern California estuaries during Fall 2023. Each box represents the distribution of station-level values within an estuary, with the interquartile range (IQR) shown by the box, the median by the horizontal line, and whiskers extending to 1.5× the IQR. Individual station values are overlaid as jittered points. Sample sizes (n) reflect the number of stations sampled per estuary. Estuaries are colored by hydrologic connectivity, with perennially open estuaries shown in gold and temporarily closed estuaries in blue.

Mouth Dynamics

Estuary types are typically defined by the duration and frequency of mouth condition (whether or not the estuary mouth is open to the ocean). The dynamic nature of an estuary's mouth can influence water quality, sediment transport, trophic interactions, nutrient cycling, and fish assemblages. The dynamic nature of the mouth should be evaluated across large temporal and spatial scales. To effectively document mouth closure events, we utilized satellite imagery to calculate the percent of time the mouth was open throughout the entire year of 2023.

For each estuary, available Planet imagery was visually analyzed to determine mouth state. Any discernable hydraulic connection between the estuary and ocean was considered “Open”. The first date of visible state change (from open to closed or closed to open) was documented and used to bound open and closed periods from which the percentage of the year was calculated. The date range included was Jan 1 – Dec 31. While Planet imagery provides daily overpass, cloud cover obscuring the mouth was a limitation on the precision of the analysis.

Table 7. Mouth closure events from January to December 2023 using Planet satellite.

Site ID	Estuary Type	Date of Opening	Date of Closing	Days Opened	Day Closed	% Open
SC-TJE	Temporarily Closed	6-Jan		365	0	100%
SC-MAL	Temporarily Closed	1-Jan	5-Jul	301	64	82%
		8-Jul	13-Aug			
		26-Aug	2-Oct			
		19-Nov				
SC-DEV	Temporarily Closed	3-Jan	13-Feb	85	280	23%
		20-Feb	23-Feb			
		25-Feb	5-Apr			
SC-VEN	Temporarily Closed	6-Jan	19-Feb	356	9	98%
		28-Feb				
SC-TOP	Temporarily Closed	1-Jan	3-Aug	275	11	75%
		4-Aug	5-Aug			
		6-Aug	13-Aug			
		22-Aug	26-Sep			
		5-Oct	11-Oct			
		30-Oct	2-Nov			
		4-Nov	11-Nov			
		22-Dec	24-Dec			
SC-LPL	Temporarily Closed	6-Jan	17-Feb	341	24	93%
		26-Feb	21-Apr			
		6-May	31-Dec			
SC-HBW	Temporarily Closed	6-Jan		365	0	100%
SC-CARP	Temporarily Closed	1-Jan	25-Jun	351	14	96%
		9-Jul				
SC-BSC	Temporarily Closed	18-Mar	2-Apr	200	165	55%
		15-Apr	31-May			
		18-Aug	26-Aug			
		4-Sep	8-Sep			
		26-Oct	8-Nov			
		9-Nov	5-Dec			

Site ID	Estuary Type	Date of Opening	Date of Closing	Days Opened	Day Closed	% Open
		14-Dec	22-Dec			
		28-Dec				
SC-ASE	Temporarily Closed		1-Jan	57	308	16%
		19-Jan	4-Feb			
		28-Feb	1-Apr			
		1-May	10-May			
SC-GOL	Temporarily Closed	3-Jan	21-Oct	314	51	86%
		29-Oct	31-Oct			
		14-Nov	19-Nov			
		25-Nov	30-Nov			
		23-Dec				

Trash

Trash assessment methods were piloted in estuaries and wetlands by adapting methods used in streams within the Stormwater Monitoring Coalition. Briefly, trash assessments were performed by conducting a timed search of trash within each station sampling area for ten minutes. Each trash item was counted and categorized by material type (e.g., plastic, metal, glass). In cases where the number of items was too great to reasonably count, a qualitative score was assigned. Detailed methods are described in the [Bight '23 Trash and Microplastics Workplan](#).

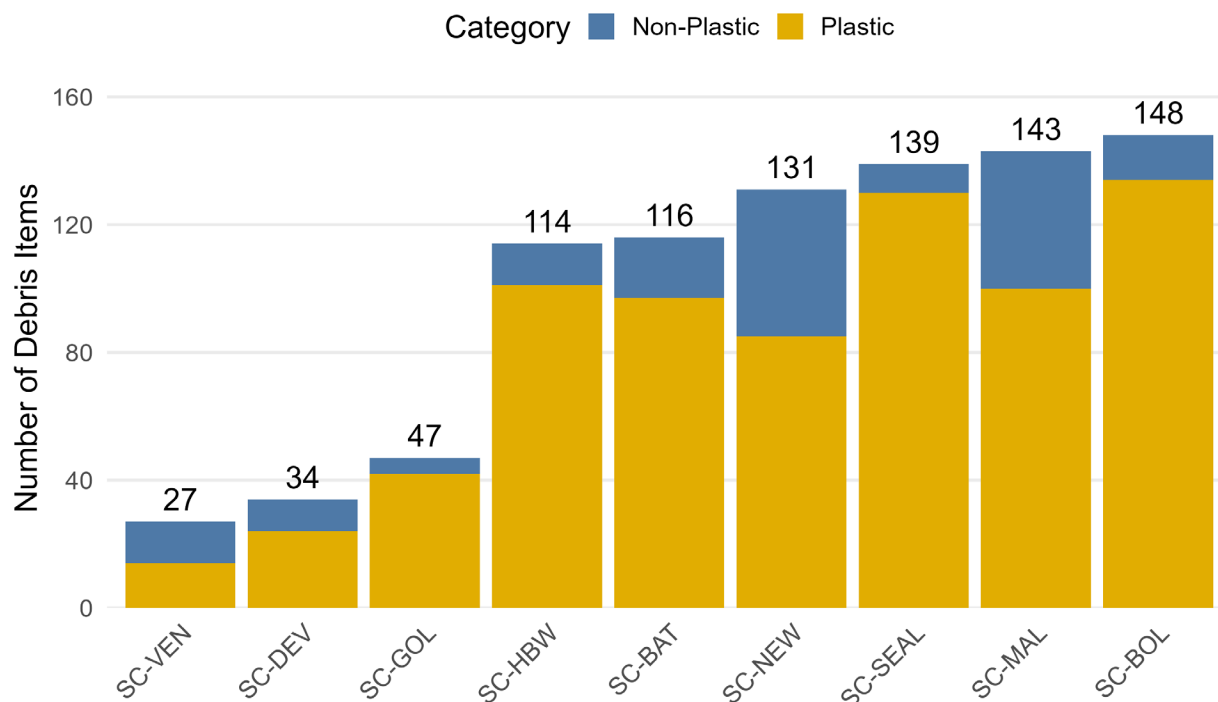


Figure 20. Number of trash debris items at the 9 sites that conducted time search surveys. Gold bars are the plastic debris items and blue bars are the non-plastic debris items. The numbers above the bars are the total number of debris items.

Biotic Indicators

Benthic infauna

Benthic infauna (animals that live in the sediment) are an important part of the ocean food web. Because infauna generally reside in one location for most of their lives and can be chronically exposed to sediment contaminants, they are an excellent indicator of environmental quality.

Samples for small benthic infaunal were collected following similar methods as the Bight '23 Sediment Quality Workplan. The Bight '23 Sediment Quality group collected a subset of subtidal samples in estuaries, while the Estuary Element added additional samples in the intertidal zone.

Benthic infauna data was available at 13 of the 19 sites. Core sizes differed among sites, therefore abundance was scaled by volume per core, where a standard volume = 100 cm³. Invertebrates were grouped into five major feeding groups: detritivores, algivores/microalgivores, omnivores, herbivores, and carnivores. Consumer groupings were based on literature reviews of numerous papers, including Nordström et al., 2014; Macdonald et al., 2010, Whitcraft and Levin 2007.

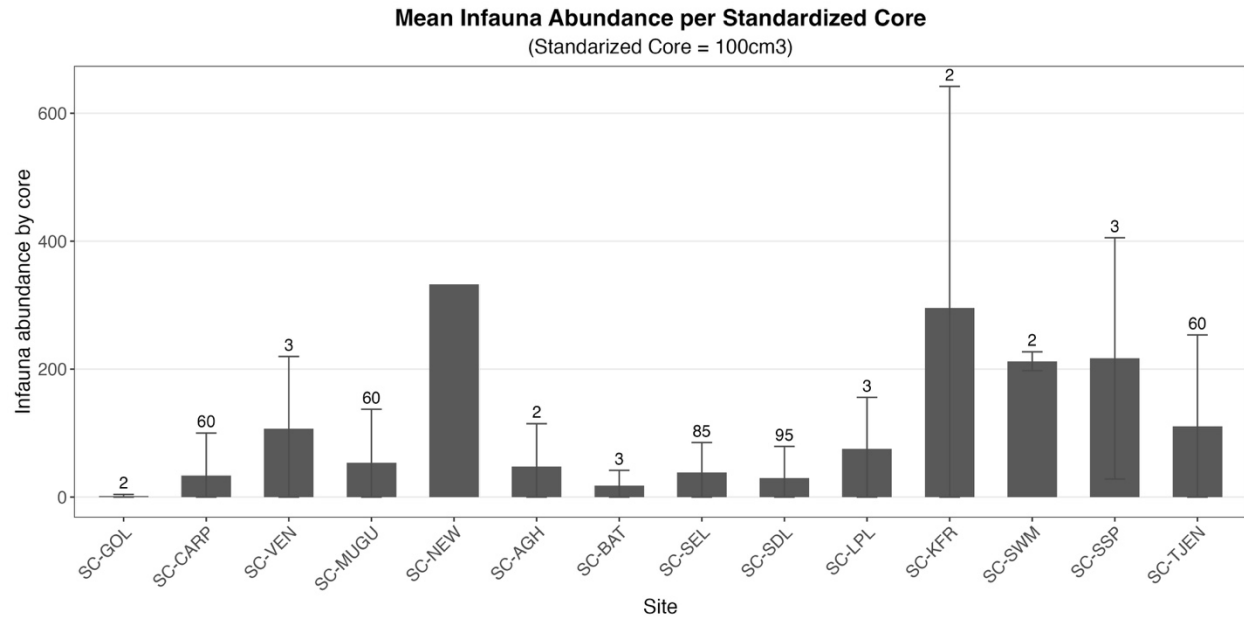


Figure 21. Mean infauna abundance per standardized core (100 cm³) across 14 southern California sites in the intertidal. Bar height represents the mean number of infaunal individuals per core, with error bars indicating standard deviation. Numbers above each bar denote sample size (n).

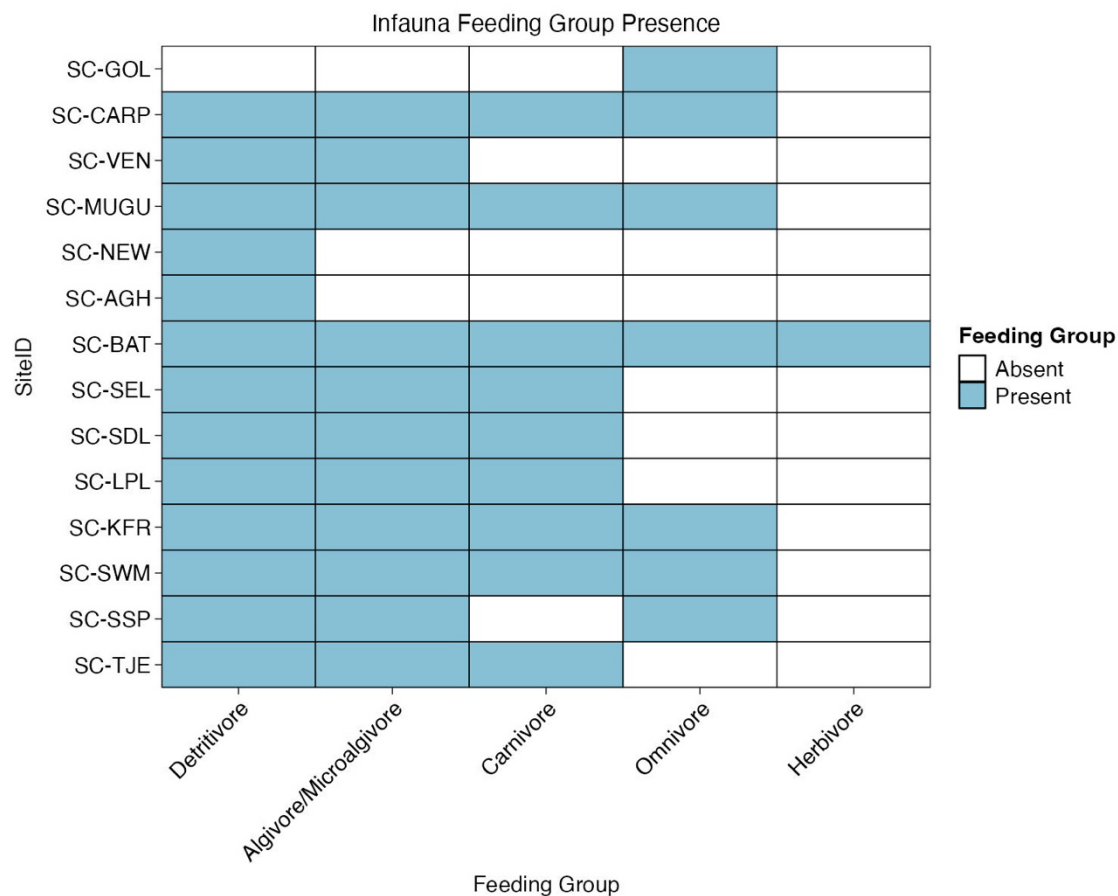


Figure 22. Infauna feeding group presence across the 13 southern California estuarine sites with available infauna data. Species were grouped into 5 feeding groups: detritivores, microalgivores and algivores, carnivores, omnivores, and herbivores.

Table 8. Species assignments for each infauna feeding group.

Detritivore	Carnivore	Algivore/ microalgivore	Omnivore	Herbivore
<i>n</i> = 48	<i>n</i> = 16	<i>n</i> = 15	<i>n</i> = 9	<i>n</i> = 1
Alloniscus perconvexus	Actiniaria	Acteocina inculta	Amphipholis squamata	Aphididae
Armandia brevis	Cnidaria	Acteocina sp	Ctenodrilus serratus	
Boccardia proboscidea	Dolichopodidae	Alderia willowi	Heteroceridae	
Boccardiella hamata	Eulalia sp	Assiminea californica	Hydrophilidae	
Capitella capitata Cmplx	Excirolana chiltoni	Barleeia subtenuis	Macoma sp	
Capitella sp	Excirolana linguifrons	Bivalvia	Melyridae	
Capitellidae	Excirolana sp	Ceratopogonidae	Ophryotrocha sp	
Carazziella sp	Hemipodia simplex	Cerithidea californica	Sphaeromatidae	
Caulerliella pacifica	Lineidae	Chironomidae	Sphaeromatidae	
Chondrochelia dubia Cmplx	Nemertea	Gastropoda		

Detritivore	Carnivore	Algivore/ microalgivore	Omnivore	Herbivore
Cirratulidae	Nereididae	Musculista senhousia		
Cirriformia sp	Nudibranchia	Mytilus sp		
Collembola	Parviplana hymani	Pododesmus macrochisma		
Eteone californica	Pontomalota	Protohyale frequens		
Exogone lourei	Sciomyzidae	Zeuxo normani Cmplx		
Exogone sp	Sphaerosyllis sp			
Fabriciidae				
Gammaridea sp				
Grandidierella japonica				
Leitoscoloplos pugettensis				
Maldanidae				
Mediomastus sp				
Monocorophium acherusicum				
Monocorophium insidiosum				
Monocorophium sp				
Monocorophium uenoi				
Neanthes acuminata Cmplx				
Neanuridae				
Notomastus sp				
Notomastus tenuis				
Oligochaeta				
PHORONIDA				
Paranoides platybranchia				
Phoronis sp				
Podocopida				
Polydora nuchalis				
Polydora sp				
Polyopthalmus pictus				
Prionospio lighti				
Pseudofabriciella californica				
Pseudopolydora paucibranchiata				
Sabellidae				
Scolecopsis (Parascolecopsis) texana				
Scoloplos acmeceps				
Sipuncula				
Spionidae				
Streblospio benedicti				
Tubificidae				

Fish

Fish Seines

The community assemblage of fish is a key indicator of ecological condition in estuaries. Understanding estuarine fish communities relies on quantification of density and/or species richness of fish. Seines are one of the most widely used gear types for sampling estuarine fishes (e.g., Allen 1982; Allen et al. 1992) because they capture a wide variety of species and are relatively easy to use. However, seines themselves are biased towards smaller, mid-water and sometimes slower fish than other methods such as beam trawls or hook and line fishing. As explored thoroughly in Steele et al. 2006a and 2006b, various factors about seines including mesh size, length, skill of fishers, and block netting can influence the density and species richness estimates. Two types of fishing methods were utilized – block netting and beach seining. Block nets measured the total number of fish in an enclosed area by pulling the net 7 times, where 1 seining event = 7 net pulls. Beach seines measured the total number of fish by pulling the net along the beach for 25m, where 1 seining event = 1 net.

Due to the diversity of fishing methods commonly used across southern California, the main parameter of focus and goal of this survey was to generate a species list. Due to different seine type, method, and replication, data **should be used with caution** to compare species abundance or diversity of fish. We used a variety of methods to try and extrapolate fish species richness and abundance.

To compare fish species richness across sites, while accounting for differences in total catch between sampling methods, we applied individual-based rarefaction following Hurlbert (1971). Confidence intervals were estimated using the analytical variance estimator of Chao and Jost (2012).

For each site, the expected number of species at a given number of individuals, $E[S(n)]$, was calculated analytically as:

$$E[S(n)] = \sum_i \{ 1 - C(N - N_i, n) / C(N, n) \}$$

where N is the total number of individuals caught at the site,

N_i is the total count of species i ,

n is the rarefied sample size, and

C denotes the binomial coefficient.

Data was aggregated prior to analysis, making the following decisions.

- 1) Removed all seine nets that only recorded presence or absence of species.
- 2) Removed all fish that were denoted as “juvenile” or “unknown”.
- 3) Aggregated jack silverside and topsmelt silversides.
- 4) Aggregated pipefish.
- 5) Aggregated blennies.

Sampling units in which all records had abundance coded as –88 (presence/absence surveys with no individuals recorded) were excluded prior to analysis. One site, Tijuana River Estuary North, was excluded from the multi-site comparison because its total individual count ($n = 63$) fell below the common rarefaction depth. Rarefaction curves for the remaining 18 sites were truncated to a common depth of $n = 93$ individuals, corresponding to the lowest observed total catch (Colorado Lagoon), to allow direct comparison of rarefied richness across sites and gear types. SC-BAT had the highest species richness with 9.5 species, while SC-DEV had the lowest species richness with 2 species.

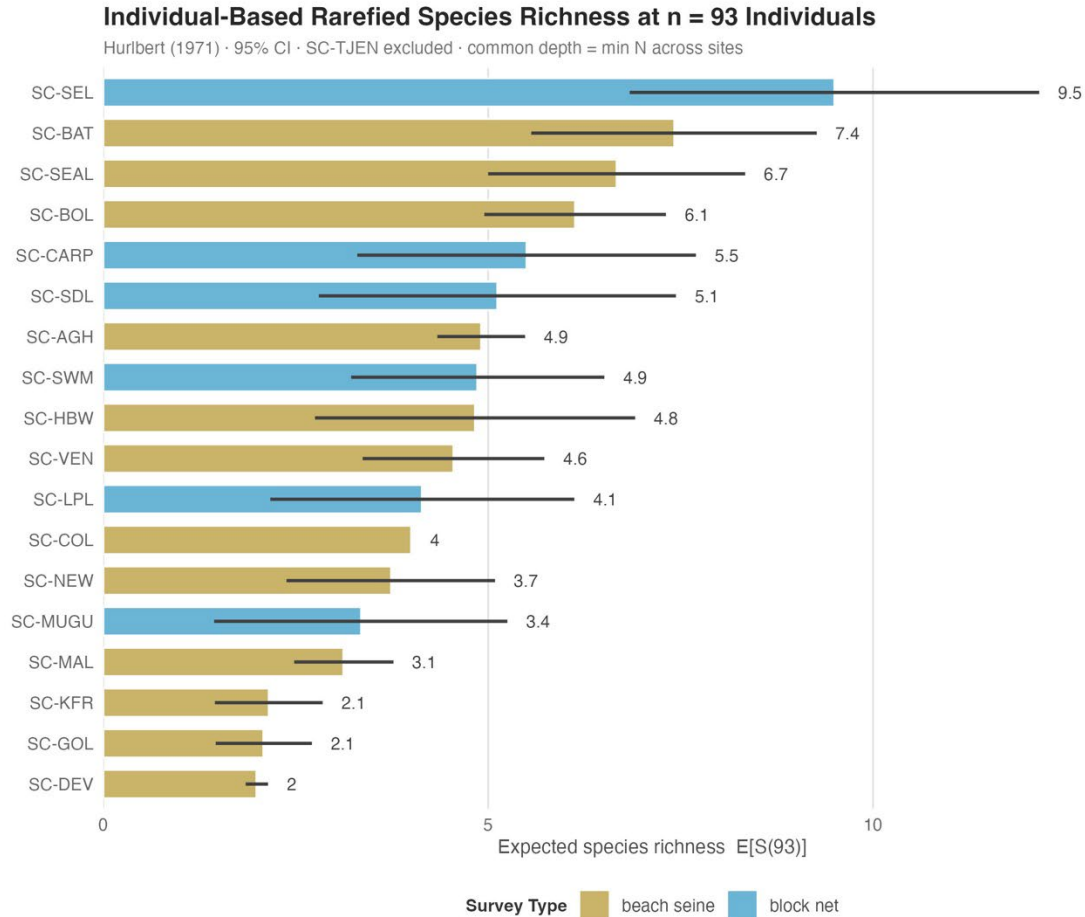


Figure 23. Individual-based rarefaction curves for fish species richness at 18 southern California estuarine sites. Expected species richness $E[S(n)]$ was estimated as a function of the number of individuals sampled using the Hurlbert (1971) estimator. The bar chart shows $E[S(93)] \pm 95\%$ confidence intervals derived from the analytical variance estimator of Chao and Jost (2012). Tijuana River Estuary was excluded from the comparison as its sample size fell below the common rarefaction depth. Sites sampled by beach seine ($n = 12$) and block net ($n = 6$) are shown in gold and blue, respectively.

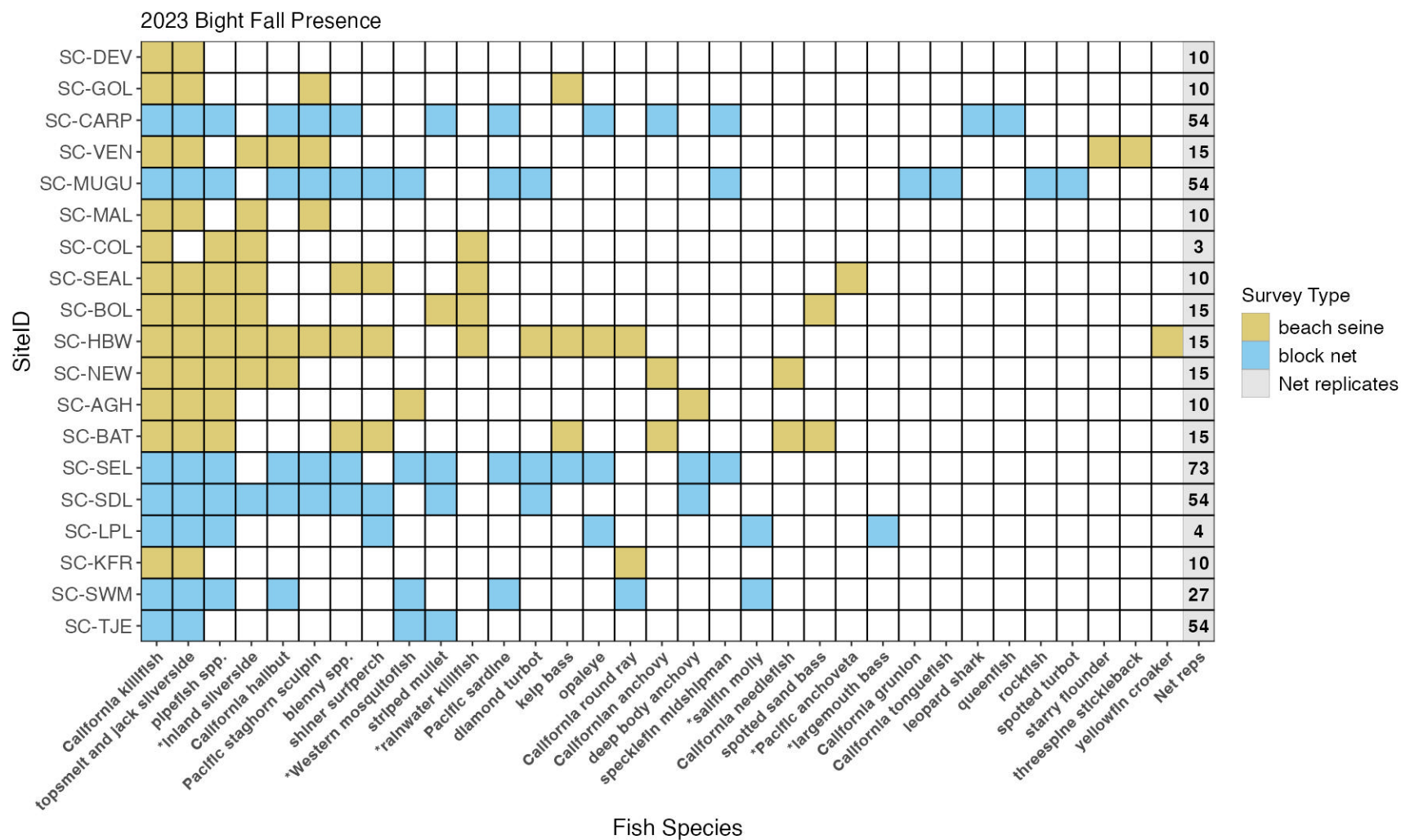


Figure 24. Fish presence across all seine nets at 19 southern California estuarine sites (excluding gobies). Fish presence is indicated by color squares, where beach seine sites are in gold and block net sites are in blue. The total number of net replicates are indicated in the right column. Species with asterisks denote invasive species.

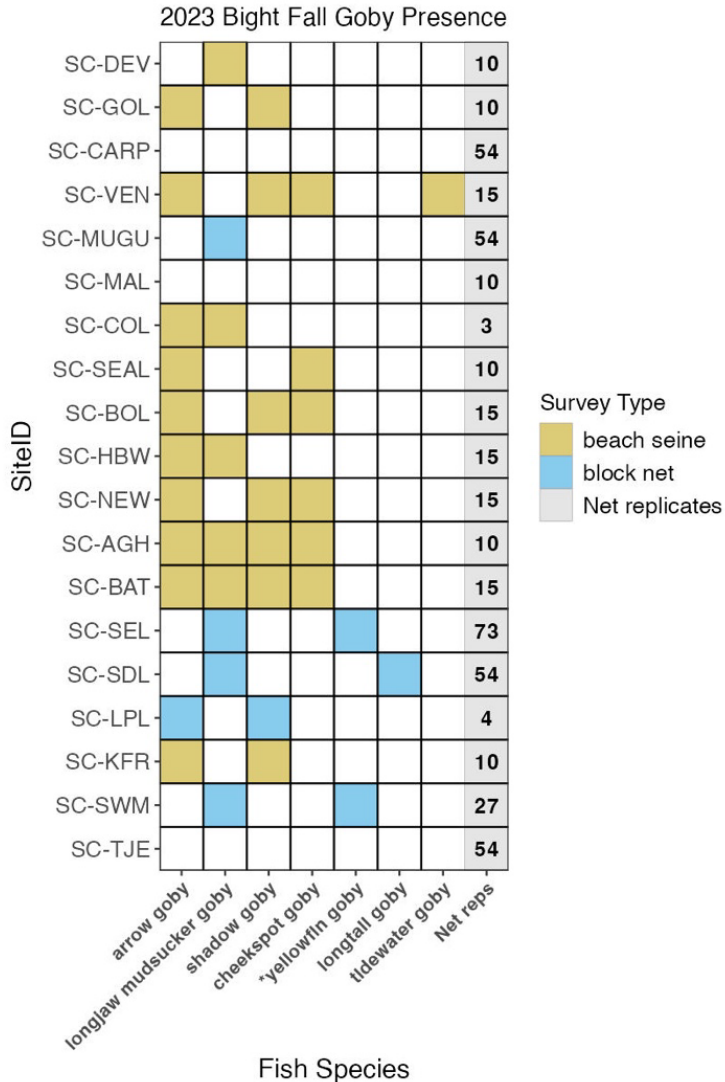


Figure 25. Goby presence across all seine nets at 19 southern California estuarine sites. Some sites only recorded goby presence occasionally, therefore data should be reviewed with caution (SC-CARP, SC-MUGU, SC-SDL, SC-TJE). Fish presence is indicated by color squares, where beach seine sites are in gold and block net sites are in blue. The total number of net replicates are indicated in the right column. Species with asterisks denote invasive species.

eDNA

Molecular methods are becoming increasingly popular in environmental monitoring and bioassessment applications. Environmental DNA (eDNA) metabarcoding can be used to monitor community composition and estimate species richness. eDNA was collected alongside traditional fish seining data to complement estimates of fish community composition. Due to limitations in funding, only a portion of samples were processed as part of Natalie De Wet's Master's Thesis at the University of San Diego. A brief summary is provided here.

De Wet demonstrated how multiple methods, including traditional block net seining and enclosure traps, community science via iNaturalist, and eDNA, can be optimized to improve our ability to detect fish species and related changes in community composition to changes in dissolved oxygen and other water quality parameters. The combined methods were evaluated in 2023 across five San Diego estuaries sampled (Figure 26). Figure 27 illustrates the relationship between the various sampling methods evaluated and Figure 28 shows some of the species detected through the methods compared. Consistent with findings from previous studies (Gold et al., 2023; Kelly et al., 2014; Port et al., 2016), our results suggest that these methods are best used in combination.

While eDNA and iNaturalist expand the breadth of species detection, traditional sampling provides critical information on fish abundance, size classes, and life stages that are not captured by the other methods.

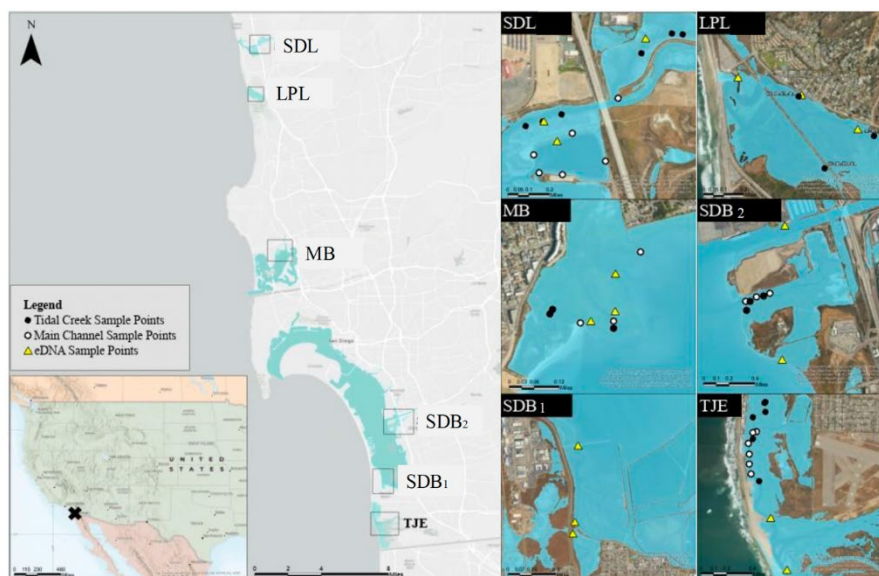


Figure 26. Study area comprising five estuaries within San Diego County: San Dieguito Lagoon (SDL), Los Peñasquitos Lagoon (LPL), Kendall-Frost Reserve in Mission Bay (MB), San Diego Bay (grouped here as SDB, with South Bay Salt Ponds shown as SDB1 and Sweetwater Marsh as SDB2), and Tijuana River Estuary (TJE). From De Wet 2025.

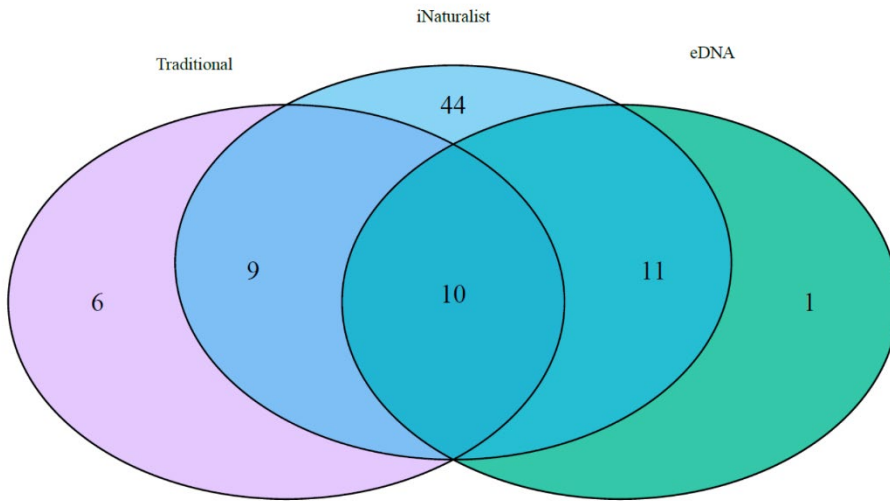


Figure 27. Venn diagram of fish species detected across all sites using traditional sampling (block net seining and enclosure traps), iNaturalist and environmental DNA (eDNA). From De Wet 2025, Master's Thesis.

Common Name	TJE	SDB	MB	LPL	SDL	Common Name	TJE	SDB	MB	LPL	SDL	Common Name	TJE	SDB	MB	LPL	SDL
Pacific sardine						Slender clingfish						Diamond turbot					
Topsmelt silverside						Kelp Clingfish						Spotted turbot					
Jacksnelt Silverside						Yellowfin goby *						Western mosquitofish *					
Inland silverside *						Arrow goby						Sailfin molly *					
Specklefin midshipman						Longtail Goby						Blacksmith chromis					
California Needlefish						Longjaw mudsucker						Garibaldi					
Bay blenny						Cheekspot goby						Shovelnose guitarfish					
Notchbrow blenny						Shadow goby						White seabass					
Mussel blenny						Chameleon goby						Black croaker					
Californian jack mackerel						California butterfly ray						Shortfin corvina					
Largemouth bass *						Xantic sargo						California corbina					
Spotted kelpfish						California salema						Spotfin croaker					
Giant kelpfish						Horn shark						Yellowfin croaker					
Coralline sculpin						Cabezon						Pacific bonito					
Woolly sculpin						Opaleye						Pacific mackerel					
Pacific staghorn sculpin						Zebra perch						California scorpionfish					
Diamond stringray						California sheephead						Kelp bass					
Shiner perch						Rock Wrasse						Spotted sand bass					
Black surfperch						Wrasse						Barred sand bass					
Walleye surfperch						Largemouth blenny						Barred pipefish					
Dwarf perch						Reef finspot						Kelp pipefish					
White seaperch						Flathead grey mullet						Bay pipefish					
Pile perch						California moray						California lizardfish					
Deepbody Anchovy						Bat ray						Pacific electric ray					
Californian anchovy						Speckled sanddab						Gray smooth-hound					
California killifish						California halibut						Leopard shark					
California clingfish						Thornback guitarfish						Haller's round ray					

Figure 28. A heatmap of species detected in 2023 in coastal wetlands throughout San Diego using traditional approaches (block net seining and enclosure traps) and iNaturalist. Blue indicates the detection of fish species at a site by iNaturalist, purple by traditional approaches, green by both iNaturalist and traditional approaches, and diagonal shading indicates species detected using eDNA. Non-native species are indicated by a *. Sites are listed geographically, with the southernmost site on the left and the northernmost site on the right. Fish species are sorted alphabetically by order of family and then by species name. From De Wet 2025, Master's Thesis.

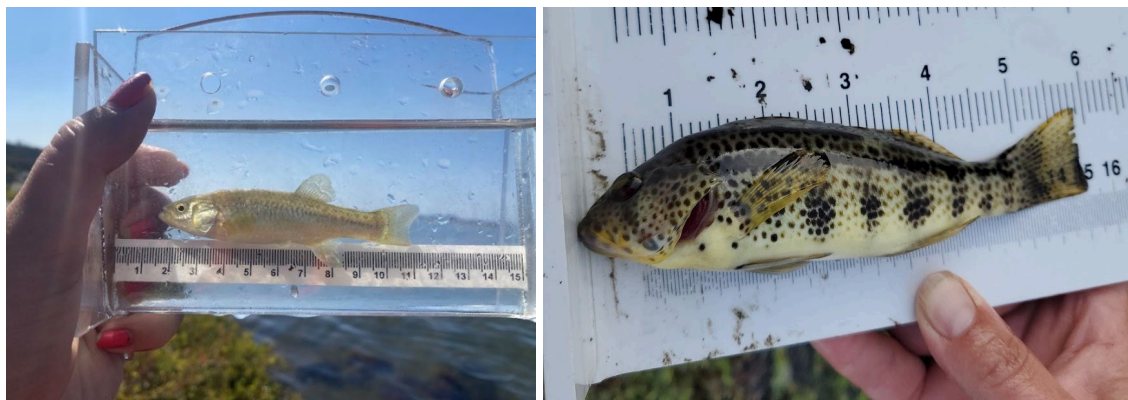


Figure 29. (Left) California killifish (*Fundulus parvipinnis*) detected by all three methods. (Right) Spotted sand bass (*Paralabrax maculatofasciatus*) detected by eDNA and iNaturalist.

Vegetation

A key component to estuary health is the support of Marsh Vascular plant communities. Vegetation surveys were conducted using a standard approach to evaluate three important plant community parameters in tidal marshes: 1) plant species richness, 2) plant cover and the invasion of non-native species, and 3) plant height. The surveys focused on estuarine wetland habitats including the backshore (i.e., upland transition zone), marsh plains, channel margins, tidal pannes and ponds, and foreshore (i.e., channel-ward transition zones from the marsh plain to open tidal mud flats). Transect surveys quantified percent cover and plant height within 1m² quadrats.

Plant Species Richness

To compare vegetation species richness across sites, while accounting for differences in varying effort (unequal number of quadrats among sites), we applied sample-based rarefaction following Hurlbert (1971). Each 1 m² quadrat was treated as a sampling unit, and only live Marsh Vascular vegetation records were included in the analysis.

For each site, the expected number of species at a given number of quadrats, $E[S(n)]$, was calculated analytically as:

$$E[S(n)] = \sum_i \{ 1 - C(N - N_i, n) / C(N, n) \}$$

where N is the total number of quadrats surveyed at the site,

N_i is the number of quadrats containing species i ,

n is the rarefied sample size, and

C denotes the binomial coefficient.

Rarefied richness was compared across 16 sites at a common depth of $n = 28$ quadrats, corresponding to the site with the lowest observed quadrat count (Malibu Lagoon).

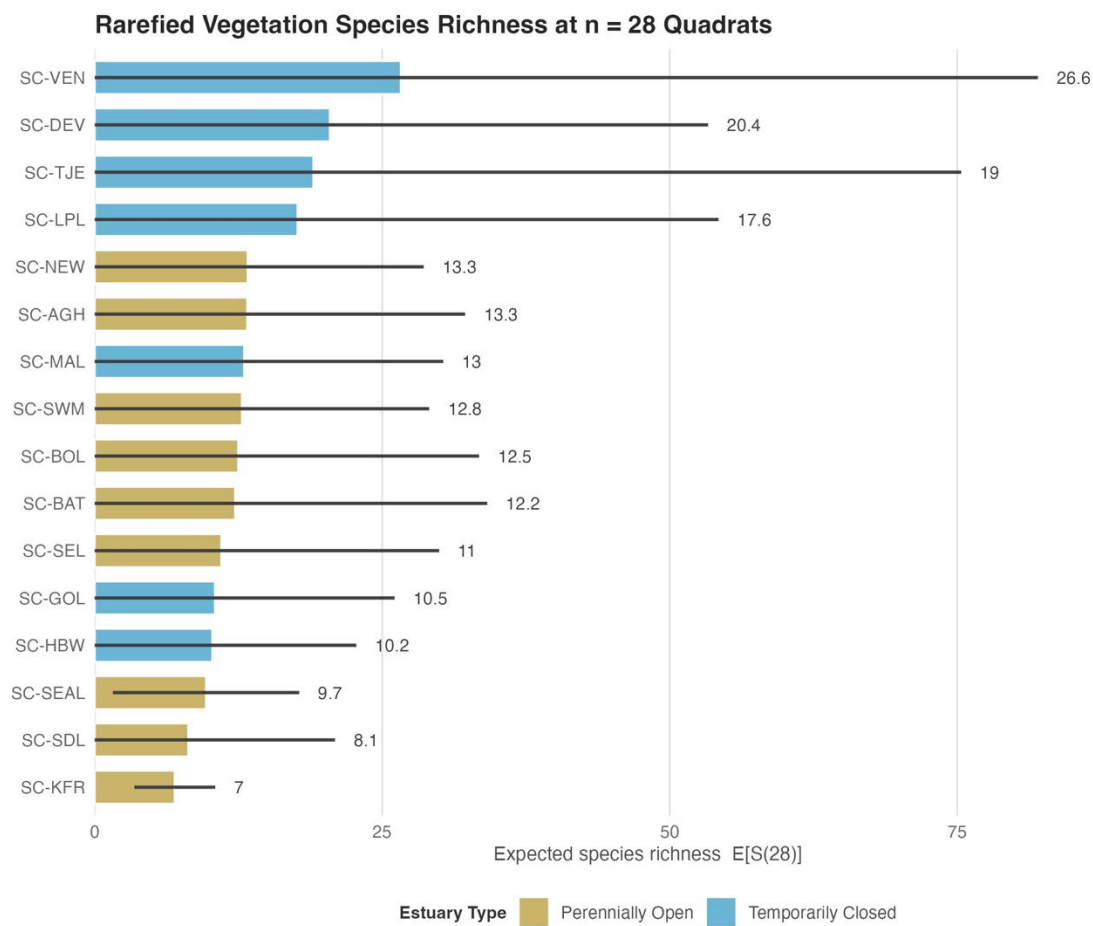


Figure 30. Rarefied plant species richness at 16 southern California estuarine sites. Expected species richness $[E[S(28)]]$ was estimated at a common rarefaction depth of $n = 28$ quadrats using the Hurlbert (1971) sample-based rarefaction estimator, corresponding to the minimum number of quadrats surveyed across all sites (Malibu Lagoon). Error bars represent 95% confidence intervals derived from the analytical variance estimator of Chao and Jost (2012). Only live vascular vegetation recorded in 1 m² quadrats was included. Sites are colored by estuary type: gold = perennially open, blue = temporarily closed.

Plant Cover

Robust vegetation cover within the marshplain directly enhances the estuary's function for Marsh Vascular plant support by promoting ecological stability and habitat complexity. Well-established vegetation provides critical ecosystem services such as sediment stabilization,

organic matter accumulation, and hydrologic regulation, all of which sustain the physical and chemical conditions necessary for plant diversity and recruitment.

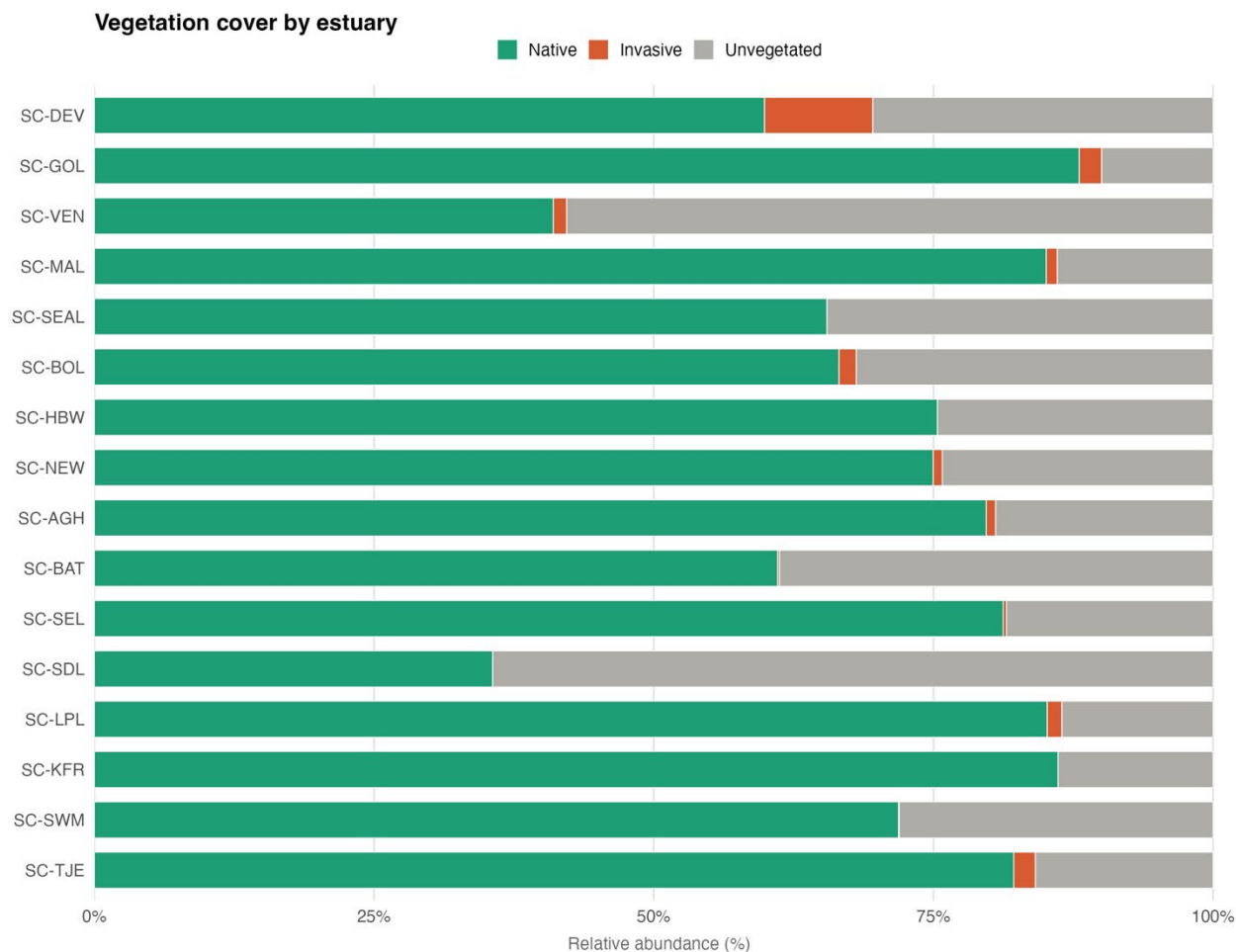


Figure 31. Relative vegetation cover by estuary for southern California sites. Bars represent the proportion of total cover comprised of native vegetation (green), invasive vegetation (orange), and unvegetated substrate (gray). The native and invasive proportions were calculated by summing estimated cover for all live vegetation species (excluding unknowns and unrecorded taxa) across the entire site, then dividing by total vegetated cover.

Plant Height

Plant height in salt marshes is a useful indicator of vegetation condition and productivity. Taller, denser vegetation generally reflects healthier growing conditions, while reductions in height can signal stress from factors like nutrient limitation, grazing, hydrologic alteration, or invasion by competing species. Critically, a range of heights across a marsh is as important as absolute height values — structural heterogeneity in vegetation creates a diversity of microhabitats that support different species and life-history stages. Low-stature vegetation provides foraging and

nesting opportunities for ground-dwelling birds and invertebrates, while tall dense stands offer refuge, nesting cover, and perching structure for marsh-obligate species. This vertical complexity also influences light availability, temperature gradients, and moisture retention at the marsh surface, further diversifying the ecological niches available. Tracking height through time allows you to detect seasonal growth patterns, assess recovery trajectories following disturbance or restoration, and evaluate whether management interventions are producing measurable improvements in marsh structure and heterogeneity. Since vegetation architecture directly influences habitat quality for marsh-dependent birds and invertebrates, height data, and particularly the range of heights present, connects plant community condition to broader ecological function.

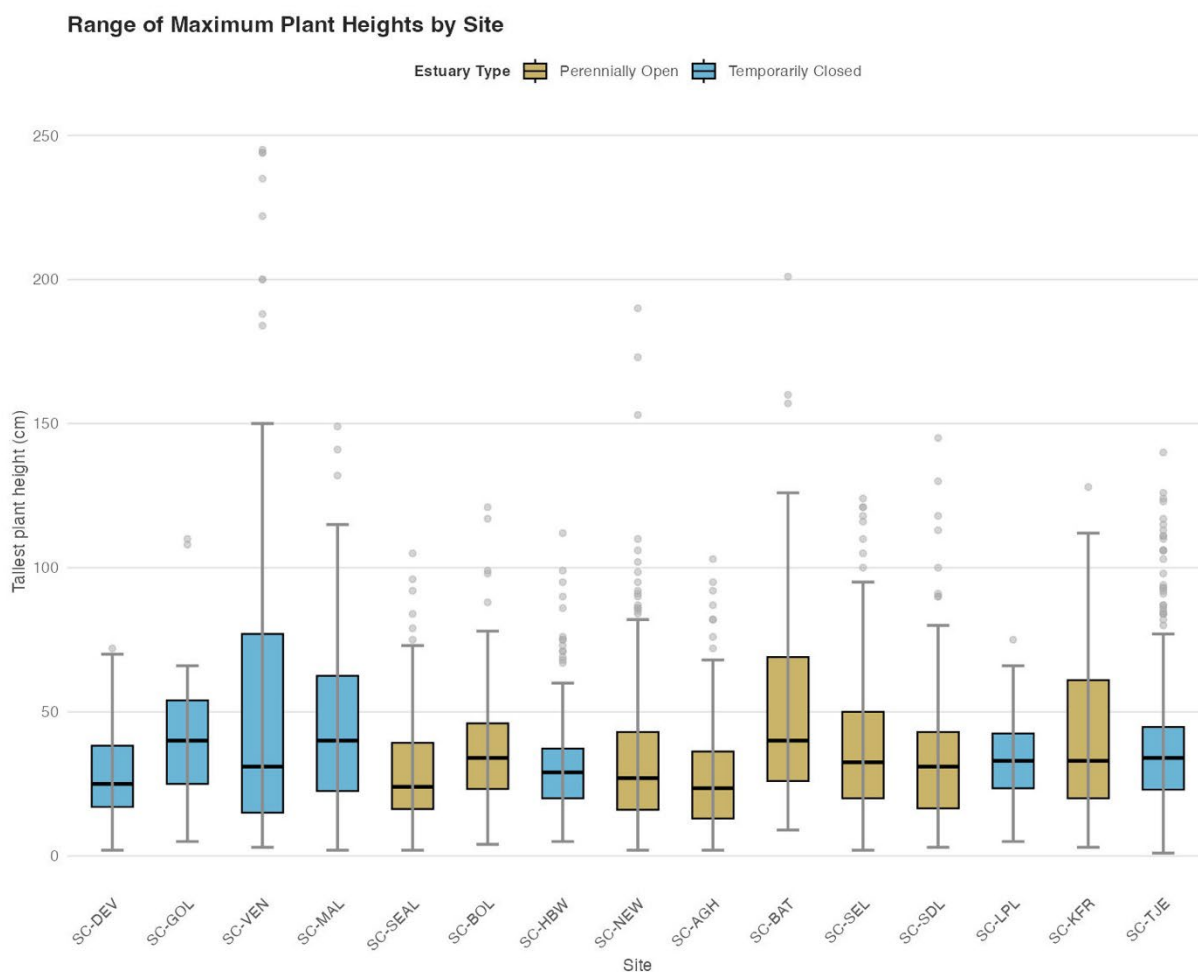


Figure 32. Range of maximum plant heights (cm) across 15 southern sites, grouped by estuary type. Boxplots show the median (center line), interquartile range (box), 1.5× IQR (whiskers), and outliers (grey points) for perennially open (gold) and temporarily closed (blue) estuary types.

Birds

An estuary in good condition should provide physical and biological structure for both resident and migratory birds to support predator evasion or nesting (via their associated wetlands) and abundant food (via high secondary and tertiary (nekton) productivity). To quantify the bird community, southern California bird data was aggregated from three sources: 1) Pacific Flyway Shorebird Survey (PFSS; <https://migratoryshorebirdproject.org/about/pfss/>), 2) San Onofre Nuclear Generating Station (SONGS; <https://msi.ucsb.edu/research/collaborative-programs/songs>), and eBird (<https://ebird.org/>). Both PFSS and SONGS use standardized area search protocols and thus data are comparable across respective sites. Unfortunately, these surveys were not conducted across all 19 Bight '23 estuaries. PFSS surveys were conducted at 9 estuaries and SONGS surveys were conducted at 4 estuaries (Table 6). We therefore complimented the PFSS and SONGS data with data from eBird, a community science program, that was available for all 19 estuaries with varying effort across sites. It is important to note that volunteers contributing data to eBird are bird hobbyists who decide when and where to conduct surveys and tend to visit. They are most likely to choose areas known to have high bird richness and this is reflected in the varying eBird effort across estuaries (Table 6).

We used data from surveys conducted between October 1 and December 31, 2023 to provide the best overlap with the sampling timeframe for other Bight '23 indicators. PFSS surveys were conducted once at each of the 9 estuaries during this window with the number of plots per site varying from 1 to 10. SONGS surveys were conducted 6 times at each of the 4 estuaries with each estuary having 20 established plots, though not all plots were surveyed during each session. PFSS surveys document shorebird and raptor species observed while SONGS surveys document all bird species observed. We used both 'traveling' and 'stationary' surveys from eBird. The traveling protocol involves a volunteer collecting data as they travel along a route of their choosing. They record their starting location, the distance they traveled (minus any backtracking), and the duration of the survey. The stationary protocol involves a volunteer collecting data within 30m of a fixed location and recording the duration of their survey. Both protocols document all bird species observed.

We established a list of 20 possible bird guilds based on the full list of species observed for all estuaries combined. We established the guilds primarily based on foraging habits but also included 3 guilds of unique generalists (corvid, gull, and upland game). The guilds follow, but do not adhere to, those outlined in DeGraaf et al. (1985). We further categorized the list of guilds into guilds that would be found in terrestrial habitat and guilds that would be found within aquatic habitat or at the edge of the aquatic habitat (e.g., intertidal habitat; Table 7).

Finally, we created 2 additional categories for indication of potential stressors: Human Subsidized and Invasive/Exotic. The Human Subsidized category contains native species for

which populations have grown in size and/or expanded in range due to human activities like development, open landfills, increased access to food through livestock feeding, etc. The Invasive/Exotic category contains non-native species that have been introduced to southern California.

Table 9. Total survey effort (number of surveys) broken out by survey protocol type for each of the 19 Bight '23 estuaries.

Estuary	PFSS	SONGS	eBird	Total Effort
SC-DEV	5	0	132	137
SC-GOL	0	0	4	4
SC-CARP	0	119	39	158
SC-VEN	0	0	34	34
SC-MUGU	10	109	33	152
SC-MAL	1	0	46	47
SC-COL	0	0	48	48
SC-SEAL	5	0	27	32
SC-BOL	5	0	285	290
SC-HBW	0	0	4	4
SC-NEW	8	0	107	115
SC-AGH	0	0	7	7
SC-BAT	0	0	66	66
SC-SEL	0	0	137	137
SC-SDL	0	100	57	157
SC-LPL	0	0	35	35
SC-KFR	1	0	82	83
SC-SWM	8	0	20	28
SC-TJE	5	120	96	221

Table 10. List of the 20 bird guilds used to develop the bird function indicator. Guilds are categorized as to general habitat in which they reside.

Possible Guilds (20 total)	
Terrestrial habitat (10 guilds)	Aquatic/Edge habitat (10 guilds)
aerial insectivore	dabbler
arboreal gleaner	diver
bird of prey	gull
corvid	marsh gleaner
ground gleaner	plunge diver
ground predator	prober
nectarivore	pursuit diver
shrub gleaner	surface picker
upland game	surface/scyther
woodpecker	wader

Table 11. Available bird data for southern California: number of bird species, number of observed guilds, proportion of observed to expected guilds, number of human subsidized species (5 possible species), and number of invasive/exotic species (14 possible species).

Site	# species	# guilds	prop guilds	# HumSub	# Inv/Exotic
SC-DEV	116	19	0.95	3	4
SC-GOL	37	17	0.85	2	1
SC-CARP	90	18	0.9	2	5
SC-VEN	93	18	0.9	4	4
SC-MUGU	122	18	0.9	2	4
SC-MAL	119	19	0.95	5	4
SC-COL	85	17	0.85	3	6
SC-SEAL	124	18	0.9	4	3
SC-BOL	153	19	0.95	3	4
SC-HBW	46	14	0.7	2	0
SC-NEW	139	20	1	3	4
SC-AGH	45	17	0.85	2	1
SC-BAT	139	19	0.95	4	3
SC-SEL	128	18	0.9	4	3
SC-SDL	119	18	0.9	5	5
SC-LPL	87	18	0.9	4	2
SC-KFR	107	18	0.9	3	4
SC-SWM	71	17	0.85	2	2
SC-TJE	134	18	0.9	4	6

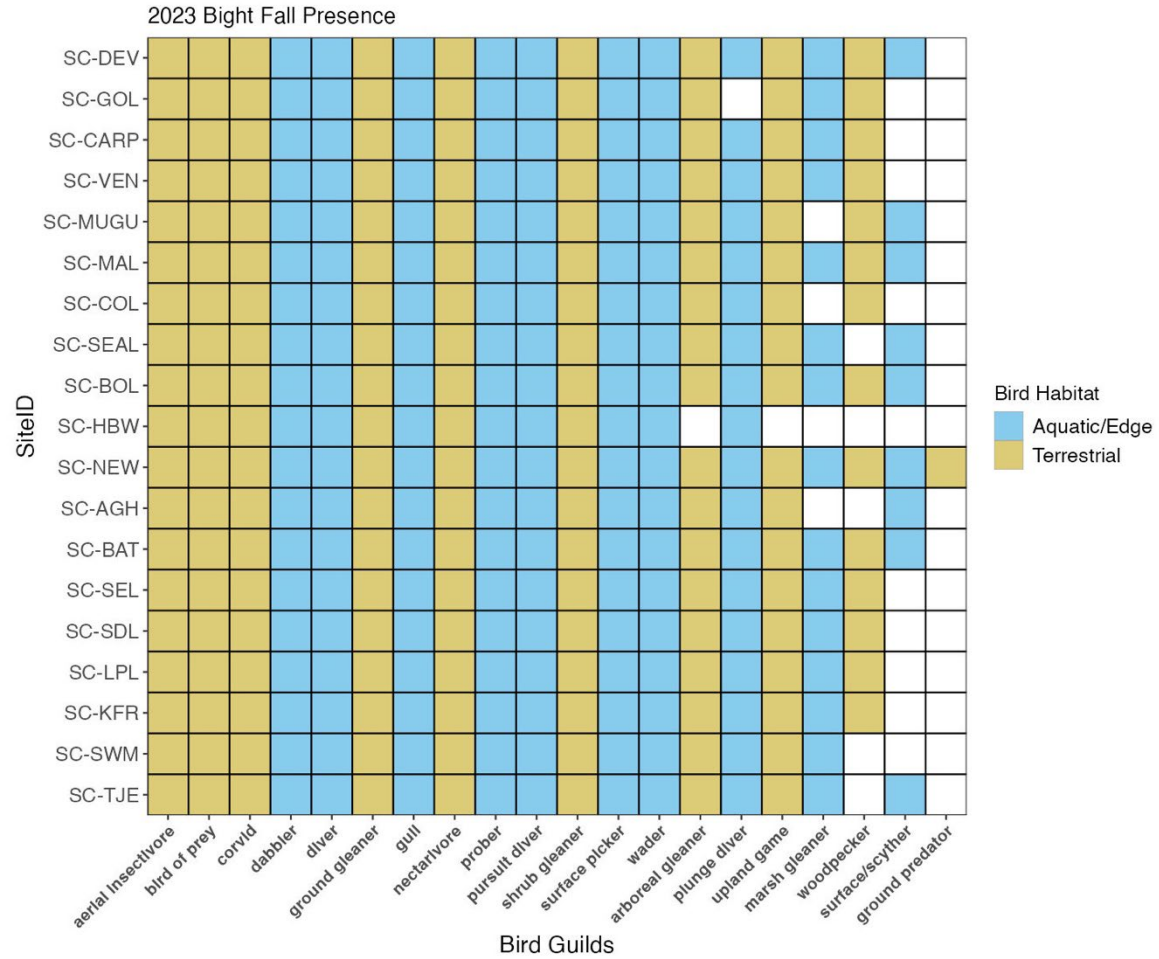


Figure 33. Bird guild presence across all 19 southern California estuarine. Bird presence is indicated by color squares, where the guilds in the aquatic/edge habitats are in blue and the terrestrial habitats are in gold.

Table 12. Species assignments for each bird guild.

Aerial Insectivore	Arboreal Gleaner	Bird Of Prey	Dabbler	Ground Gleaner	Gull	Plunge Diver	Pursuit Diver	Surface Picker
n = 15	n = 20	n = 28	n = 23	n = 46	n = 20	n = 12	n = 21	n = 8
American Redstart	Black-and-white Warbler	Accipiter sp.	American Wigeon	American Pipit	Bonaparte's Gull	American White Pelican	Brandt's Cormorant	Black-bellied Plover
gnatcatcher sp.	Bullock's Oriole	American Kestrel	Blue-winged Teal	American Robin	California Gull	Belted Kingfisher	Clark's Grebe	Black-bellied Plover/golden-plover sp.
Barn Swallow	Bushtit	Bald Eagle	Blue-winged/Cinnamon Teal	blackbird sp.	Franklin's Gull	Black Skimmer	Common Loon	Killdeer
Black Phoebe	Cedar Waxwing	Barn Owl	Brant	Brewer's Blackbird	Glaucous x Glaucous-winged Gull (hybrid)	Brown Booby	Common Merganser	Pacific Golden-Plover
Blue-gray Gnatcatcher	Hutton's Vireo	Burrowing Owl	Cackling Goose	Brown-headed Cowbird	Glaucous-winged Gull	Brown Pelican	Common Murre	plover sp.
Cassin's Kingbird	large parakeet sp. (former Aratinga sp.)	Buteo sp.	Cackling/Canada Goose	Cactus Wren	gull sp.	Caspian Tern	comorant sp.	Semipalmated Plover
Cliff Swallow	Lesser Goldfinch	Cooper's Hawk	Canada Goose	California Thrasher	Heermann's Gull	Elegant Tern	Double-crested Cormorant	small plover sp.
Northern Rough-winged Swallow	Mitred Parakeet	falcon sp.	Cinnamon Teal	California Towhee	Herring Gull	Elegant/Royal Tern	Eared Grebe	Snowy Plover
Say's Phoebe	Mitred/Red-masked Parakeet	Ferruginous Hawk	dabbling duck sp.	Chipping Sparrow	Herring x Glaucous-winged Gull (hybrid)	Forster's Tern	Hooded Merganser	
swallow sp.	Monk Parakeet	Golden Eagle	Domestic goose sp. (Domestic type)	Clay-colored Sparrow	Iceland Gull	large tern sp.	Horned Grebe	Surface/Scyther
Tree Swallow	Mountain Chickadee	Great Horned Owl	Egyptian Goose	Dark-eyed Junco	jaeger sp.	Royal Tern	Horned/Eared Grebe	n = 3
Tropical Kingbird	Nanday Parakeet	hawk sp.	Eurasian Wigeon	European Starling	Larus sp.	tern sp.	loon sp.	American Avocet
Vermilion Flycatcher	Oak Titmouse	Loggerhead Shrike	Eurasian x American Wigeon (hybrid)	Fox Sparrow	Parasitic Jaeger		merganser sp.	American Flamingo
White-throated Swift	Purple Finch	Merlin	Gadwall	Golden-crowned Sparrow	Parasitic/Pomarine Jaeger		Pacific Loon	Black-necked Stilt
yellow-bellied kingbird sp.	Red-breasted Nuthatch	Northern Harrier	Greater White-fronted Goose	Grasshopper Sparrow	Ring-billed Gull	Prober	Pelagic Cormorant	
	Red-masked Parakeet	Osprey	Green-winged Teal	Great-tailed Grackle	Short-billed Gull	n = 30	Pied-billed Grebe	
	Ruby-crowned Kinglet	owl sp.	Mallard	Green-tailed Towhee	Western Gull	Black Oystercatcher	Red-breasted Merganser	Upland Game
	Swinhoe's White-eye	Peregrine Falcon	Northern Pintail	Hermit Thrush	Western x Glaucous-winged Gull (hybrid)	Black Turnstone	Red-throated Loon	n = 5
	White-breasted Nuthatch	Prairie Falcon	Northern Shoveler	Horned Lark	Western/Glaucous-winged Gull	Dunlin	Scripps's Murrelet	Band-tailed Pigeon
	White-fronted Parrot	Red-shouldered Hawk	Ross's Goose	House Finch	white-winged gull sp.	Greater Yellowlegs	Western Grebe	California Quail
		Red-tailed Hawk	Snow Goose	House Sparrow		Least Sandpiper	Western/Clark's Grebe	Eurasian Collared-Dove
		Sharp-shinned Hawk	teal sp.	House/Purple Finch		Lesser Yellowlegs		Mourning Dove
Corvid	Diver	Short-eared Owl	Wood Duck	Lapland Longspur		Lesser/Greater Yellowlegs		Rock Pigeon
n = 3	n = 17	small falcon sp.		Lark Bunting		Little Stint		
American Crow	American Coot	Swainson's Hawk		Lark Sparrow	Shrub Gleaner	Long-billed Curlew	Wader	Woodpecker
California Scrub-Jay	Aythya sp.	Turkey Vulture		Lincoln's Sparrow	n = 17	Long-billed Dowitcher	n = 14	n = 7
Common Raven	Black Scoter	Unid. Sharp-shinned/Cooper's Hawk		Mountain Bluebird	American Goldfinch	Marbled Godwit	American Bittern	Acom Woodpecker
	Bufflehead	White-tailed Kite		Nelson's Sparrow	Bewick's Wren	peep sp.	Black-crowned Night Heron	Downy Woodpecker
	Canvasback			new world sparrow sp.	Black-throated Gray Warbler	Red Knot	Great Blue Heron	Downy/Hairy Woodpecker
	Common Gallinule			Northern Waterthrush	California Gnatcatcher	Red Phalarope	Great Egret	Hairy Woodpecker
	Common Goldeneye	Ground Predator	Nectarivore	Palm Warbler	Common Yellowthroat	Ruddy Turnstone	Green Heron	Northern Flicker
	Greater Scaup	n = 1	n = 5	Pin-tailed Whydah	House Wren	Sanderling	Least Bittern	Nuttall's Woodpecker
	Greater/Lesser Scaup	Greater Roadrunner	Allen's Hummingbird	Red-winged Blackbird	Nashville Warbler	Short-billed Dowitcher	Little Blue Heron	Red-breasted Sapsucker
	Lesser Scaup		Anna's Hummingbird	Rock Wren	new world warbler sp.	Short-billed/Long-billed Dowitcher	Reddish Egret	
	Long-tailed Duck		Costa's Hummingbird	Sage Thrasher	Northern Mockingbird	Spotted Sandpiper	Snowy Egret	
	Redhead		hummingbird sp.	Savannah Sparrow	Orange-crowned Warbler	Surfbird	Western Cattle Egret	
	Ring-necked Duck	Marsh Gleaner	Rufous/Allen's Hummingbird	Scaly-breasted Munia	Townsend's Warbler	Unid. Greater/Lesser Yellowlegs	white egret sp.	
	Ruddy Duck	n = 4		Song Sparrow	vireo sp.	Unid. Long-billed Curlew or Godwit	White-faced Ibis	
	scoter sp.	Marsh Wren		Spotted Towhee	Wilson's Warbler	Unid. Long-billed/Short-billed Dowitcher	Yellow-crowned Night Heron	
	Surf Scoter	Ridgway's Rail		Tricolored Blackbird	wren sp.	Unid. Western/Least Sandpiper	Yellow-crowned/Black-crowned Night Heron	
	White-winged Scoter	Sora		Vesper Sparrow	Wrenit	Unid. Western/Least Sandpiper or Dunlin		
		Virginia Rail		Western Bluebird	Yellow Warbler	Wandering Tattler		
				Western Meadowlark	Yellow-rumped Warbler	Western Sandpiper		
				White-crowned Sparrow		Whimbrel		
				White-throated Sparrow		Willet		
				Yellow-headed Blackbird		Wilson's Snipe		

Habitat Indicator

California Rapid Assessment Method

Rapid Assessment methods assess the existing condition of a wetland relative to its broadest suite of suitable functions, services, and beneficial uses, such as flood control, groundwater recharge, pollution control, and wildlife support, based on the consensus of best professional judgment. In this regard, a rapid assessment represents the overall functional capacity of a wetland. To be valid, rapid assessments must be strongly correlated to measures of actual functions or services. Once validated, rapid assessments can be used where intensive data are lacking or too expensive to collect. Rapid assessments can thus lessen the amount and kinds of data needed to monitor wetlands across large areas over long periods.

We used the California Rapid Assessment Method for Wetlands (CRAM), which is a rapid wetland habitat condition assessment tool and is the most completely developed and tested rapid method for California at this time. CRAM is a standardized tool for wetland monitoring, developed with support from EPA. CRAM provides a cost-effective assessment tool for wetlands that can be used to assess the condition on a variety of scales, ranging from portions of individual wetlands to assessments of wetland condition throughout watersheds and climatic regions.

CRAM is based on the concept that the structure and complexity of a wetland is indicative of its capacity to provide a range of functions and services. It is designed for assessing ambient conditions within watersheds, regions, and throughout the State. It can also be used to assess the performance of restoration projects. CRAM requires a team of 2-3 trained practitioners in approximately three hours to assess a representative wetland Assessment Area. Monitoring practitioners should refer to the CRAM Technical Bulletin for guidance on the placement of assessment areas. In general, CRAM assessment areas should be co-located with the sampling stations that are designated as part of the regional monitoring effort.

CRAM provides an Index score of the condition of a wetland relative to other wetlands of that type throughout the state. This Index score is calculated as an average of four Attribute scores. The Attribute scores are the result of a combination of metrics scores based upon visual and easily measured indicators of ecological and physical conditions in the field. The metrics assessed in CRAM are similar across various wetland classes but are adapted as necessary to fit the characteristics unique to each wetland type.

Table 13. The most recent CRAM surveys conducted at the Bight sites.

Site ID	Year	Avg. Index	SD
SC-AGH	2007	67	NA
SC-ASE	2015	57	NA
SC-BAT	2022	65	NA
SC-BSC	2023	66	NA
SC-CARP	2026	85.42	9.24
SC-DEV	2022	86	NA
SC-GOL	2022	61.66667	3.21455
SC-HBW	2026	66.72	18.91
SC-KFR	2026	74.87	16.11
SC-LPL	2015	68.75	5.560276
SC-MAL	2022	64.66667	4.50925
SC-MUGU	2021	74	NA
SC-NEW	2021	58	NA
SC-SDL	2026	72.27	9.71
SC-SEAL	2026	76.52	16.63
SC-SEL	2026	64.4	14.51
SC-SSP	2007	69	NA
SC-SWM	2021	67	NA
SC-TJES	2015	72	8.3666
SC-VEN	2022	71.33333	6.027714

APPENDIX 2. SITE DESCRIPTIONS

Table 14. Grouping Factors.

Site ID	Estuary type	Archetype	Management
SC-AGH	Perennially Open	Large Lagoon	City
SC-BAT	Perennially Open	Large Lagoon	State
SC-BOL	Perennially Open	Large Lagoon	State
SC-CARP	Temporarily Closed	Intermediate Estuary	State
SC-COL	Perennially Open	Small lagoon	City
SC-DEV	Temporarily Closed	Large Lagoon	UC Nature Reserve
SC-GOL	Temporarily Closed	River Valley Estuary	State
SC-HBW	Temporarily Closed	Large Lagoon	Private
SC-KFR	Perennially Open	Bay Estuary	UC Nature Reserve
SC-LPL	Temporarily Closed	River Valley Estuary	State
SC-MAL	Temporarily Closed	Intermediate Estuary	State
SC-MUGU	Perennially Open	Intermediate Estuary	Federal
SC-NEW	Perennially Open	Bay Estuary	State
SC-SDL	Perennially Open	River Valley Estuary	State
SC-SEAL	Perennially Open	Large Lagoon	Federal
SC-SEL	Perennially Open	River Valley Estuary	State
SC-SWM	Perennially Open	Bay Estuary	Federal
SC-VEN	Temporarily Closed	Intermediate Estuary	State
SC-TJE	Temporarily Closed	River Valley Estuary	Federal

APPENDIX 3. NARRATIVE SYNTHESIS

A critical component to the assessment framework was the inclusion of data-informed best professional judgement by the Data Subcommittee and Field Teams. This best professional judgement was critical to help provide validation to the assessment framework and provide a gut check to make sure the numeric function scores align with the panel's expectations.

Table 15. Data-informed best professional judgement to qualitatively describe the condition of each site based on these functions. Cells are colored according to four categories: Low Function (dark purple; 0–25 for Marsh Vascular Plant and SLR Amelioration, 0–40 for Bird Habitat), Moderate (teal; 26–50, 41–80), Good (green; 51–75, 81–120), and High Function (yellow; 76–100, 121–160+).

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
SC-DEV	60.13	50.15	110.2	SC-DEV was monitored in the northeast portion of the lagoon for Bight '23. The 'Good' scores reflect the efforts of consistent restoration over the last five years. The 'Good' score for SLR amelioration reflects a relatively undisturbed buffer and room to retreat.
SC-GOL	74.95	44.05	31.45	The 'Good' score for Marsh Vascular Plant Support for SC-GOL reflects a range of habitat types with the estuary (low, mid, high marsh plus sandy areas) and a low percentage of non-native plants. The 'Moderate' score for SLR reflects disturbed buffer area (including airports, parking lots etc.), modified water flow, and steep edges. Finally, the 'Low Function' score for Bird Habitat is lower than expected for SC-GOL based on perceptions but could reflect lack of access for birders or seasonal use not captured in methods.
SC-CARP	NA	NA	81	The 'Good' score for bird habitat is lower than expected for SC-CARP relative to historic monitoring data from the SONGS MMP. Although SC-CARP is in the same 'Good' bin as the other SONGS sites, it scored 20-30 points lower than SC-MUGU and SC-SDL. Over the past 15 years, SC-CARP has generally had comparable bird abundance to SC-SDL and comparable bird richness to the other SONGS sites (SC-SDL, SC-MUGU, SC-TJE).

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
SC-VEN	51.58	43.97	83.7	The 'Good' score for Marsh Vascular Plant Support for SC-VEN reflects a range of habitat types within the estuary (low, mid, high marsh plus brackish and sandy areas). SC-VEN does contain non-native plants in some areas so could be scored lower if those expand. The 'Moderate' score for SLR reflects disturbed buffer area (including railroads, parking lots etc.), modified water flow, and steep edges. Finally, the 'Good' score for Bird Habitat is consistent with field observations and a variety of salinity ranges within the estuary.
SC-MUGU	NA	NA	109.8	The 'Good' score for bird habitat is consistent with historic monitoring data at SC-MUGU from the SONGS MMP. SC-MUGU is a hot-spot for bird abundance among the SONGS sites and has had comparable bird richness to the other SONGS sites over the last 15 years (SC-SDL, SC-CARP, SC-TJE).
SC-MAL	56.80	46.77	113.05	The 'Good' score for Marsh Vascular Plant Support for SC-MAL is higher than expected due to the narrow range of marsh plain available at the site, but could also reflect recent restoration efforts and low non-native plant cover. The 'Moderate' score for SLR reflects disturbed buffer area (including roads, paths, parking lots etc.), modified water flow, and lack of retreat room. Finally, the 'Good' score for Bird Habitat is consistent with field observations although lower than expected for SC-MAL relative to historic monitoring data from community science.
SC-COL	NA	NA	72.25	The 'Moderate' score for Bird Habitat is consistent with field observations. This is likely accurate as birder access is easy at this site.
SC-SEAL	74.99	42.52	111.6	The 'Good' score for Marsh Vascular Plant Support for SC-SEAL reflects a range of habitat types within the estuary (low, mid, high marsh plus ponded areas). SC-SEAL has few non-native

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
				plants. The 'Moderate' score for SLR reflects disturbed buffer area (including military installations, roads etc.), modified water flow, low rugosity, and low elevation marsh extent. Finally, the 'Good' score for Bird Habitat is consistent with field observations and a variety of available habitats (ponds, vegetated plains) within the estuary.
SC-BOL	68.09	52.67	145.35	The 'Good' score for the Marsh Vascular Plant function is surprising, given the highly fragmented areas with small marsh plain areas. The 'Good' score for SLR reflects disturbed buffer area (including paths, roads, oil infrastructure etc.), modified water flow, and steep edges. However, if allowed, the site could retreat into oil fields. Finally, the 'High Function' score for Bird Habitat is consistent with field observations and a variety of habitats (full tidal basin, marsh, brackish) within the estuary. In addition, SC-BOL had a high effort for birding as a key birding destination and lots of viewing access for birders.
SC-HBW	66.39	36.75	32.2	The 'Good' score for Marsh Vascular Plant Support for SC-HBW reflects a range of habitat types within the estuary (low, mid, high marsh areas). This likely reflects recent restoration efforts as well as ongoing non-native removal efforts. The 'Moderate' score for SLR reflects disturbed buffer area (including roads, flood control channel, power plants, etc.), modified water flow, and little retreat room. Finally, the 'Low Function' score for Bird Habitat is lower than expected based on field observations. This likely reflects lack of access for viewing for birders.
SC-NEW	71.64	36.90	139	The 'Good' score for Marsh Vascular Plant Support for SC-NEW reflects a range of habitat types within the estuary (low, mid, high marsh) and wide marsh plain. SC-NEW contains few non-native plants. The 'Moderate' score for SLR reflects disturbed buffer area (including roads, paths, parking lots etc.), modified

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
				water flow, and steep edges. Finally, the 'High Function' score for Bird Habitat is consistent with field observations and excellent birder access at various points along a long linear, shaped estuary.
SC-AGH	60.92	42.35	38.25	The 'Good' score for Marsh Vascular Plant Support for SC-AGH reflects the large salt marsh in the eastern edge of the lagoon. However, a large part of the site is developed or sloped. The 'Moderate' score for SLR reflects disturbed buffer area (including roads, infrastructure, flood control channel, agriculture, etc.), modified water flow, and little retreat room. Finally, the 'Low Function' score for Bird Habitat is consistent with field observations due to recreational use and lack of habitats.
SC-BAT	56.91	39.12	132.05	The 'Good' score for Marsh Vascular Plant Support for SC-BAT reflects a range of habitat types with the estuary (low, mid, high marsh plus brackish and panne areas). SC-BAT does have limited marsh plain area so could be scored lower if those shrink or become more inundated. The 'Moderate' score for SLR reflects disturbed buffer area (including highways, bridges, walking paths etc.), and little retreat room. Finally, the 'High Function' score for Bird Habitat is consistent with field observations, good access for birders as well as an active non-profit leading bird walks.
SC-SEL	58.71	52.12	115.2	The 'Good' scores across all categories appear to accurately reflect condition based on these functions, and highlight the improvement of SC-SEL through restoration.
SC-SDL	50.78	39.60	107.1	The 'Good' score for Marsh Vascular plant support at SC-SDL is consistent with the fact that this estuary is a restoration site with historically low plant cover. Adaptive management through a large-scale planting program has increased vegetation cover at SC-SDL over the last 15 years, but in 2023, this

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
				site still lagged the SONGS reference sites for vegetation cover. The 'Moderate' score for SLR amelioration is also consistent with field observations that there is limited space available for landward marsh migration. The 'Good' bird score for SC-SDL is consistent with historic monitoring data from the SONGS MMP. Over the past 15 years, SC-SDL consistently has the highest bird richness of the SONGS sites and has comparable bird density to SC-CARP.
SC-LPL	65.18	56.57	78.3	The 'Good' to 'Moderate' scores for SC-LPL reflect a system that has been highly modified by anthropogenic activities but is being managed to support various ecosystem functions.
SC-KFR	70.64	41.57	96.3	The 'Good' score for Marsh Vascular Plant Support for SC-KFR reflects an expansive low and mid marsh. The 'Moderate' score for SLR reflects disturbed buffer area (including highways, bridges, walking paths, development etc.), and little retreat room. Finally, the 'Good' score for Bird Habitat is consistent with field observations and good access for birders via both walking paths and kayak access.
SC-SWM	59.36	44.77	60.35	The 'Good' score for Marsh Vascular Plant Support for SC-SWM reflects an expansive low and mid marsh with fringing high marsh. The 'Moderate' score for SLR reflects disturbed buffer area (including highway 5, bridges, walking military and marina infrastructure, development etc.), and little retreat room. Finally, the 'Moderate' score for Bird Habitat is lower than expected and most likely due to access for birders.
SC-TJE	75.97	60.22	120.6	The relatively high scores across all categories appear to accurately reflect condition based on these functions, but also highlight potential complexities. Sewage-contaminated transboundary flows have had severe impacts on some aspects of estuarine conditions (e.g.

Estuary	Marsh Vascular Plant Support	SLR Amelioration	Bird Habitat	Narrative Synthesis
				hypoxia), but may have neutral or even positive effects on Marsh Vascular plant support. The high scores for SLR Amelioration and Bird Habitat reflect the relatively large and intact nature of the estuary, with a diversity of habitat types (and associated) birds supported.