Santa Monica Bay National Estuary Program

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SOUTHERN CALIFORNIA COASTAL WATER RESEARCH PROJECT

Technical Report 1460

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List of Acronyms

BPJ – best professional judgement

CARI – California Aquatic Resources Inventory

CMP- comprehensive monitoring program

CRAM – California Rapid Assessment Method

CSULB – California State University, Long Beach

DO – dissolved oxygen

EMPA – Estuary Marine Protected Area

NEP -National Estuary Program

SAV – submerged aquatic vegetation

SLR – sea level rise

SMB – Santa Monica Bay

SMBRC – Santa Monica Bay Restoration Commission

SOTB – State of the Bay

TN – total nitrogen

TOC – total organic carbon

WRP RMP – Wetland Recovery Project, Regional Monitoring Program

Habitat Description

Coastal wetlands (herein also called estuaries) are low-lying areas of land that are frequently and regularly inundated with fresh and/or ocean water. They are habitats that can be perennially open to the ocean or function instead as bar-built lagoons that only have an intermittent connection to the ocean. Coastal wetlands often include habitats such as salt marsh wetlands and adjacent brackish and freshwater wetlands that do not necessarily have a direct connection to the ocean.

Santa Monica Bay supports 18 estuaries consisting of mostly small creek mouth estuaries (11 out of 18) but also including large embayments, such as the approximately 600-acre Ballona Wetland Ecological Reserve, and river mouth estuaries, such as Malibu Lagoon. Other significant estuaries in the region are Zuma Lagoon, Lower Topanga Creek and Lagoon, and Lower Trancas Creek. All of these smaller systems are periodically or permanently closed to the ocean. 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 to people who live in and visit the Bay and its watersheds.

Estuaries are among the most productive ecosystems, providing an essential habitat for a variety of species, including birds, fish, reptiles, invertebrates, mammals, and vegetation. In addition to the species common to most coastal wetlands in Southern California, the Bay's wetlands are home to several protected species, including, but not limited to, Belding's savannah sparrow (*Passerculus sandwichensis beldingi*, state endangered species), tidewater goby (*Eucyclogobius newberryi*, federal endangered species), and southern steelhead trout (*Oncorhynchus mykiss*, federal and state endangered species).

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. Climate change effects, such sea-level rise, altered sediment flux, drying and acidification further affect wetland health in the region. While federal and state policies are in place to minimize future loss, and while 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.

Habitat Assessment Summary

- Total area of coastal wetlands in Santa Monica Bay has declined by approximately 60% since ca. 1850 (from 740 to 335 ha, 1,830 to 877 acres). Moreover, the predominant habitat type has shifted from 68% tidal marsh to 76% subtidal water.
- Of the five focal estuaries evaluated, Big Sycamore, Arroyo Sequit, and Topanga Lagoon are in average condition, and conditions are relatively stable. The two estuaries that have been more actively managed or restored (Zuma Lagoon and Malibu Lagoon) are in good condition and have improved since 2015.
- Conditions vary by function, with the food web support functions showing the greatest differences between restored and unrestored estuaries.
- Conditions are expected to change in the future in response to recent fires and other catastrophic events such as drought, altered flow regimes, and floods. Long-term trajectories are expected to decline without management intervention to altered hydrology, mouth confinement, and impacts from excessive human use.
- Continued monitoring and assessment can be enhanced by increased frequency and resolution of stressor evaluation and development of structured condition indices with defined gradients of condition.

Introduction and Overview

Coastal wetlands in Santa Monica Bay (SMB) may be monitored under several nested monitoring programs. The statewide Estuary Marine Protected Area (EMPA) monitoring program covers a subset of the approximately 450 estuaries across California using a standard monitoring approach and protocols (Stein et al. 2023). The EMPA program is being implemented through 2027 with funding for additional implementation being considered. SMB estuaries may also be monitored as part of the southern California Wetland Recovery Project Regional Monitoring Program (WRP RMP), which covers the approximately 118 estuaries in southern California using the same protocols and indicators as the EMPA program. Finally, project specific monitoring associated with local restoration or management actions (e.g., Malibu Lagoon) may provide information on the health/condition of SMB estuaries. Increasingly, project specific monitoring is incorporating or adapting the EMPA indicators to allow consistency and comparability with the state and regional programs. *This assessment of SMB coastal wetlands takes advantage of the data collected as part of these existing monitoring programs to inform an expert-panel based approach to rating wetland conditions.*

The 2015 State of the Bay (SOTB) Coastal Wetlands Report evaluated wetlands based on extent, vulnerability, structure and disturbance, and biological responses. With the exception of Malibu Lagoon and Ballona wetlands, scores were assigned qualitatively, while the biological response indicators were not scored because indicators had not been developed, and data was not available. Moreover, there was no ability to contextualize individual wetlands due to the lack of consistent monitoring across the region.

For the 2025 report, we updated the scoring tables to better align with data collected by the EMPA and WRP RMP programs. The assessment is organized into four categories: (1) extent; (2) condition, function, biological response; (3) resilience and stressors; and (4) management considerations. For the first three categories, we identified indicators and associated metrics (from the EMPA and WRP RMP protocols) and developed combination algorithms. For the management considerations category, we focus on the presence of special status species and invasive species. The assessment was used to report on the extent and condition of estuaries in SMB, to estimate general trends since the 2015 report, and identify priority stressors for management consideration.

Methods and Approach

The Santa Monica Bay watershed (Figure 1) includes 55 miles of coastline stretching from the Ventura County line to Point Fermin on the Palos Verdes Peninsula.

The 2015 report provided a comparative assessment of key ecological indicators across multiple habitat types, including habitat extent, vulnerability, structural condition and disturbance, and biological responses. Each indicator was evaluated using standardized criteria for status (good, fair, or poor), trend (increasing, stable, or decreasing), and confidence (high, moderate, or low). For coastal wetlands, the report's evaluation of SMB conditions was based solely on data from the Malibu Lagoon and Ballona wetland as those were the only systems for which data was available at the time.

This 2025 report prioritized assessment of wetlands within SMB that lacked monitoring data at the time of the last SOTB report and have therefore been under-represented in past assessment. Specifically, the data collection focused on refining the estuary monitoring program at smaller lagoons to ensure applicability across system types. Small estuaries monitored under this assessment include Big Sycamore Canyon, Arroyo Sequit, Zuma Lagoon, and Topanga Lagoon (Figure 1 and Appendix B). All of these smaller systems are periodically or permanently closed to the ocean. In addition, we include Malibu Lagoon (as we did in 2015) because of ongoing data collection consistent with regional protocols. The Ballona wetlands were not included in this assessment because regionally consistent data is not currently being collected at

Ballona (and because the focus of this assessment was on small, previously unmonitored estuaries). Additional efforts focused on developing climate vulnerability metrics to evaluate estuarine inlet dynamics and overall wetland resilience. All resulting products were connected with and integrated with existing monitoring programs and data management systems to enhance regional coordination and long-term usability.

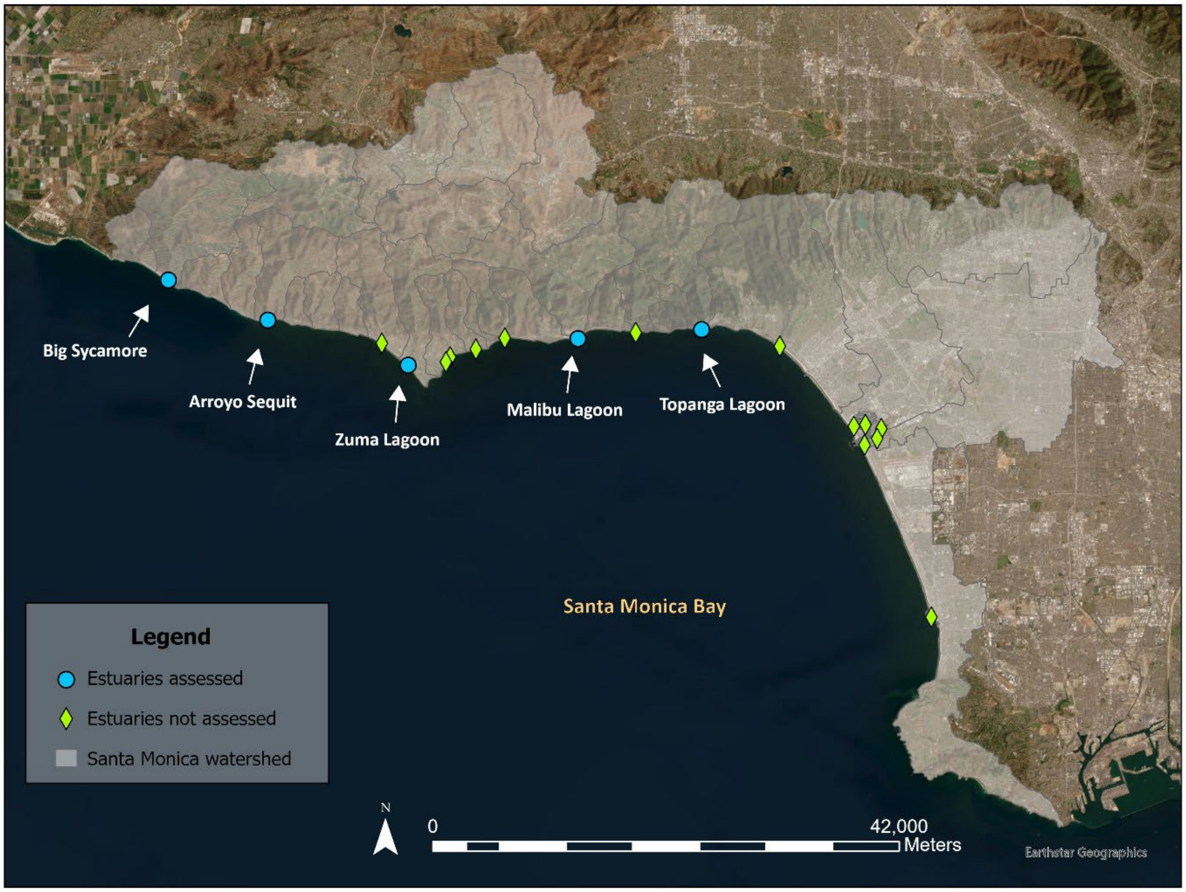


Figure 1. Santa Monica Bay Watershed with the estuary sites that were and were not assessed in 2023 for this analysis.

Contemporary estuarine extent was obtained from the California Aquatic Resources Inventory (CARI; https://www.sfei.org/projects/california-aquatic-resource-inventory-cari). Estuarine polygons were downloaded, and the boundaries clipped to match the limits of each SMB estuary as they are defined in the WRP Regional Strategy. Habitat extent was summarized for the region overall and by the estuarine archetypes established in the Southern California Wetland Recovery Project Regional Strategy (2018). Archetypes represent groups of wetlands that are similar in terms of form, function, and processes. Current estuarine extent was compared to the historical extent ca. 1850 using the southern California T-sheet atlas (https://www.caltsheets.org/). T-sheet polygons were downloaded and compared to the contemporary extent using the methods described by Stein et al. (2020). Change over time was calculated for the region as a whole and for each archetype.

To evaluate condition, we collected 15 of the 16 indicators recommended in the Santa Monica Bay Restoration Commission/National Estuary Program (SMBRC/NEP) Comprehensive Monitoring Program (CMP) following the EMPA protocols. The EMPA protocols have been developed by SCCWRP, CSULB, and other partners to take a broad, multi-trophic, multi-habitat approach to assess the ecological integrity of a given estuary framed around key ecosystem functions. Using an ecosystem function–based approach represents a major advancement in estuarine monitoring, overcoming limitations of structure-only or species-specific assessments. Estuaries, even within the SMB region, vary widely in geomorphology, hydrodynamics, and land-use context, making traditional cross-site comparisons challenging. By anchoring condition evaluation in ecological function, the framework provides a more universal lens through which diverse data types can be interpreted. The benefits of a function-based approach include holistic interpretation that can integrate abiotic, biotic, and habitat-level processes, scalable results that are applicable across local, regional, and statewide networks, management-aligned evaluation, and flexible indicators that can be incorporated as methods evolve (e.g., eDNA, remote sensing).

To assign condition scores, we first developed conceptual scoring rubrics that related specific indicators to more integrative “functions” and describe how the indicators interact to support overall function (Table 1). We also developed scoring rubrics that related individual stressor indicators to overall categories of stress and to priority management considerations (Table 2). Through iterative discussion, the expert workgroup developed consensus around the scoring rules ensuring that the scoring is done independently for condition, stressors, and key management considerations. A detailed description of each indicator and algorithm is provided in Appendix A, and individual indicator scoring by round is provided in Appendix C.

Table 1. Scoring rubric for condition indicators showing the indicator/function, related metrics, scoring algorithm and rationale.

Indicator	Metrics	Algorithm
Trophic Food Web Support	1. Fish species abundance 2. Invert species abundance	Trophic = (Fish + Invert)/2
Nursery Habitat Provisioning for Fish	1. Abundance of estuarine resident + juvenile fish size range by spp. 2. Presence of SAV 3. Invert species abundance 4. Percent of time temp > 25 C 5. Number of DO events below 3 mg/L	Nursery = (SAV (0 or 1 *density) + (temp+DO/-2)) * (fish + inverts)
Bird Habitat Support	1. Bird species/guild richness and abundance	Birds = (Bird richness and abundance)
Habitat Structure and Complexity	1. CRAM physical structure 2. CRAM biotic structure	Habitat Structure = CRAM phys + CRAM bio
Vegetation community	1. Percent native cover 2. Native richness 3. CRAM plant metric	Veg Comm = native richness + ((% native cover + CRAM plant)/2)
SLR Resiliency and Amelioration	1. Upland migration area 2. Marsh plain inundation area 3. Future wetland areal extent (1.2 ft SLR)	SLR = migration area + inundation + wetland extent

Table 2. Scoring rubric for stressor and management consideration indicators showing the indicator/function, related metrics, scoring algorithm and rationale.

Indicator	Metrics	Algorithm
Eutrophication	1. Macroalgae cover 2. Avg. TN 3. Avg. TOC	Eutroph. = macroalgae + TN + 0.5*TOC
Anthropogenic Disturbance and Land Use	1. CRAM physical structure 2. CRAM buffer and landscape context	Disturbance = CRAM Phys + CRAM buffer
Altered Hydrology	1. CRAM hydrology 2. Percent inlet open (relative to expected) 3. Artificial breaching	Alt Hydro = CRAM hydro * inlet open * breaching
Non-native species	1. Percent non-native plants 2. Percent non-native fish 3. CRAM plant metric	Non-native = ((% NN plants + CRAM plant)/2) +% NN fish
Contaminant & excessive sediment loading	1. Mass loadings (e.g., metals, organics, microplastics) 2. Total trash in 10min search 3. Percent plastic to non-plastic 4. Loadings from recent stochastic events (e.g., fires, spills)	Con = (mass loading + (total trash/plastic)) +stochastic loading

Once the scoring rules were developed, each of the experts on the workgroup independently rated each focal estuary from 1-5 using their best professional judgement (BPJ). Ratings were absolute scores for each estuary not relative ranks among all estuaries. We also asked the experts to document the basis of their scoring (e.g., past experience, recent observations) and to indicate uncertainty/confidence around their initial scoring. Following this initial scoring, we provided organized datasets for all available indicators in the region compiled from previous monitoring efforts and asked each member to re-score the estuary based on their review of the data provided. In all cases, experts were asked to use the appropriate metrics and scoring algorithms determined through our iterative process. Several algorithms were adjusted to account for data limitations, but the full agreed-upon algorithms were retained to ensure transparency in the conceptual relationships between indicators and functions. We then compared both the BPJ and data-informed scoring and identified points of agreement and disagreement. Using several rounds of iterative discussion, we reconciled differences to develop consensus among the expert workgroup members on the scores for each function in each estuary and then averaged function scores within each estuary to produce an overall score for each assessment category.

Condition scoring was accompanied by an evaluation of potential stressors. A similar process was used to score stressors where each stress indicator was related to a series of metrics (Table 2). As with the condition assessments, expert panel members were asked to initially score stressors using their BPJ. Stressor scores were compiled, summarized, and shared with the expert panel members, who were then provided with summaries of available stressor data. Given the limited availability of systematically collected stressor data, the expert panel decided to provide general stressor ratings based largely on their experience and BPJ.

Results for the five focal estuaries were summarized by estuary type: 1) Seasonally dry, small lagoons (Big Sycamore and Arroyo Sequit), 2) sandy beach, usually wet lagoons (Zuma Lagoon and Topanga Lagoon) and 3) larger, usually wet lagoons (Malibu Lagoon). Given the lack of consistent data over time, trends from the prior State of the Bay analysis (2015 vs. 2025) were scored qualitatively using the BPJ of the expert panel. Regional contextualization and trend analysis should be revisited in future State of the Bay analyses based on the availability of data over time at estuaries throughout the Southern California Bight (i.e., both within and outside Santa Monica Bay).

For the final scoring, as presented in Figures 6 and 7 and discussed throughout the document, numerical scores (1-5) were assigned from experts and grouped into status categories with condition descriptors (poor – excellent) with 1 being POOR and 5 being EXCELLENT (Figure 2). In addition, expert scoring of trends from 2015 – 2025 are indicated in the text and figures as increasing or decreasing arrows and as IMPROVING, DECLINING, and CONSISTENT. Finally, expert confidence ratings are not discussed in the main body of the text but are discussed by individual indicator in Appendix A.

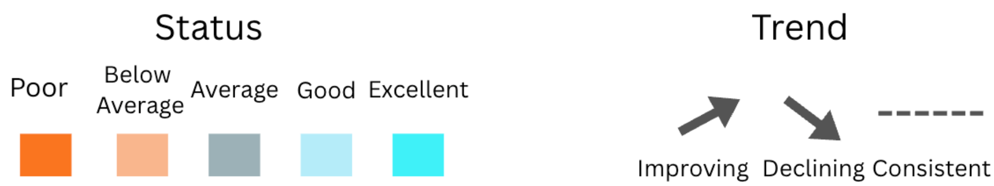


Figure 2. Scoring criteria used to score status and trends for each category.

RESULTS

Extent

Santa Monica Bay supports 18 estuaries across four major archetypes (as defined in the WRP Regional Strategy): 11 small creek estuaries, 4 river valley estuaries, 2 open bays and harbors and 1 intermediate lagoon estuary (Table 3). These 18 estuaries provide 335 ha of habitat across five major habitat types (Figure 3). Habitat composition varies by archetype with open bays and harbors consisting of primarily subtidal habitat, while river valleys are predominantly tidal marsh. Detailed habitat breakdowns are provided in Appendix B.

Table 3. List of Santa Monica Bay estuaries and archetype classification assessed in 2023 for this report.

Estuary	Assessed	Archetype
Arroyo Sequit	yes	small creek
Ballona Creek	no	fragmented river valley estuary
Ballona Lagoon	no	fragmented river valley estuary
Ballona Wetlands	no	fragmented river valley estuary
Big Sycamore Canyon	yes	small creek
Del Rey Lagoon	no	fragmented river valley estuary
Escondido Canyon	no	small creek
King Harbor	no	open bay/harbor
Las Flores Canyon	no	small creek
Malibu Lagoon	yes	intermediate estuary
Marina del Rey	no	open bay/harbor

Estuary	Assessed	Archetype
Ramirez Canyon	no	small creek
Santa Monica Canyon	no	small creek
Solstice Canyon	no	small creek
Topanga Creek	yes	small creek
Trancas Lagoon	no	small creek
West Paradise Cove	no	small creek
Zuma Lagoon	yes	small creek

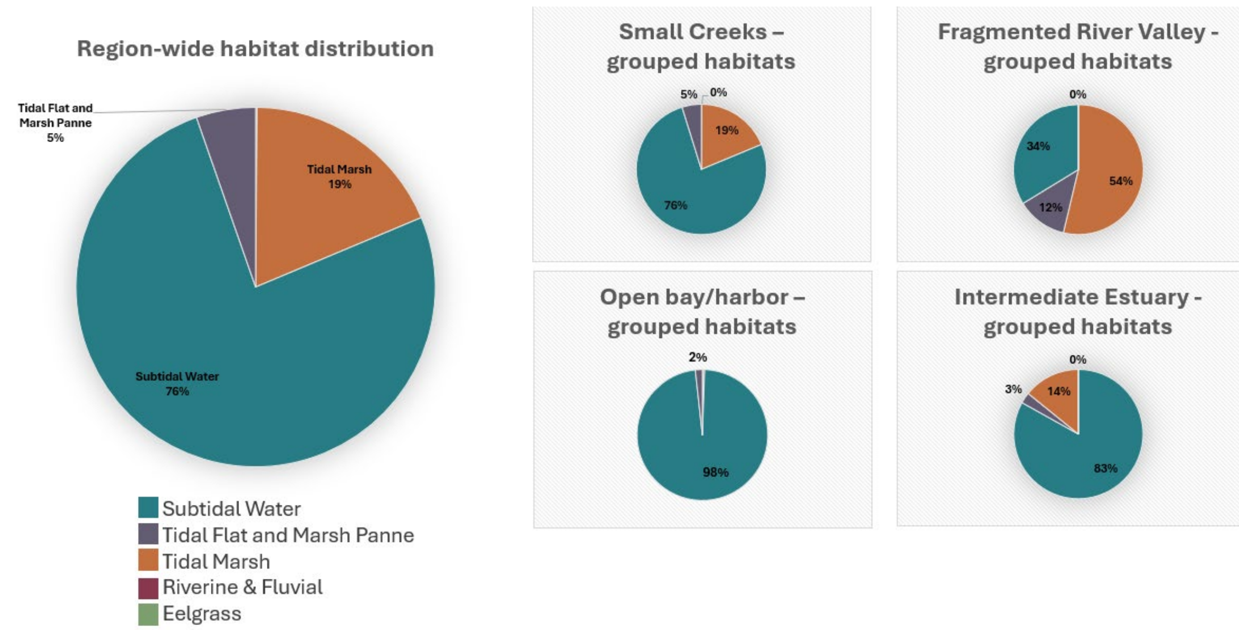
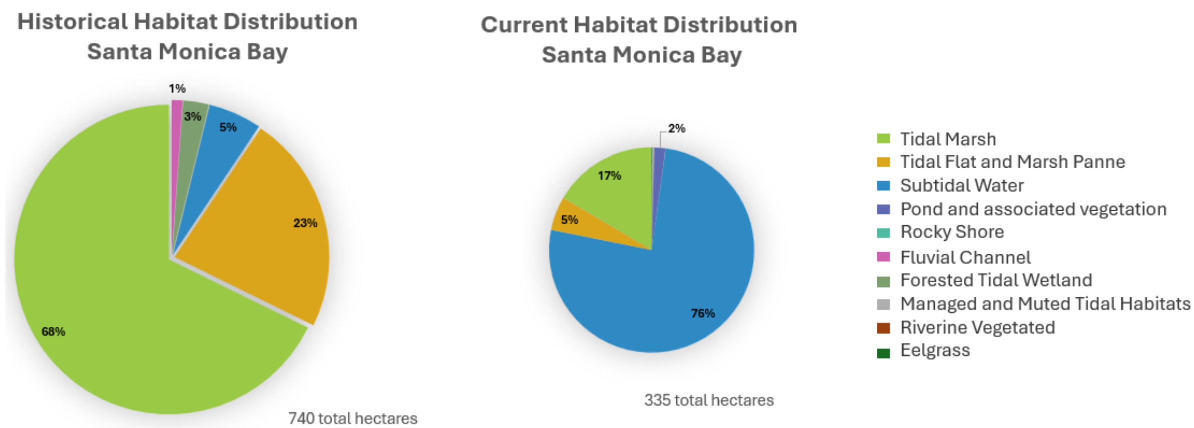


Figure 3. Contemporary distribution of habitat overall and by archetype for the 18 estuaries in Santa Monica Bay

Total area of coastal wetlands in Santa Monica Bay has declined by approximately 60% since ca. 1850 (from 740 to 335 ha, 1,830 to 877 acres). Moreover, the predominant habitat type has shifted from 68% tidal marsh to 76% subtidal water. This translates to a loss of 446 ha of tidal marsh and a gain of 213 ha of subtidal water (Figure 4). Most of this change was associated with conversion of much of the historic Ballona Wetlands for construction of Marina del Rey. According to the WRP Regional Strategy, habitat extent is not expected to change under 24 inches of SLR due to the current predominance of open bay habitat.



	Area (ha)	
	ca. 1850	2024
Subtidal water	41	254
Tidal marsh	501	55
Tidal flat and panne	169	18

Figure 4. Change in estuarine habitat area between ca. 1850 and 2024.

Based on this, the total area of coastal wetlands in the entire Santa Monica Bay is POOR (i.e., little remains of the former historic extent). However, in the last five years, restoration at Malibu Lagoon has increased habitat area and planned restoration and management at Ballona, Topanga and Zuma will likely result in additional increases in habitat area. Therefore, the extent is IMPROVING. Confidence in this assessment is HIGH, as quantitative data are readily available, and the availability of historical data provides a threshold by which to judge the current status.

Condition, Function & Biological Response

The expert panel was able to reach consensus on condition ratings for the focal estuaries through the iterative scoring process. Interestingly, deviations in scores between experts increased between the Round 1 scoring based solely on BPJ and Round 2 which was data informed. Further discussion revealed that this was due to differences in how experts perceived expectations for each estuary. Nevertheless, the panel was able to come to consensus following discussions that reconciled how expected conditions were interpreted (Figure 5). A summary of the expert panel scoring is provided in Appendix C.

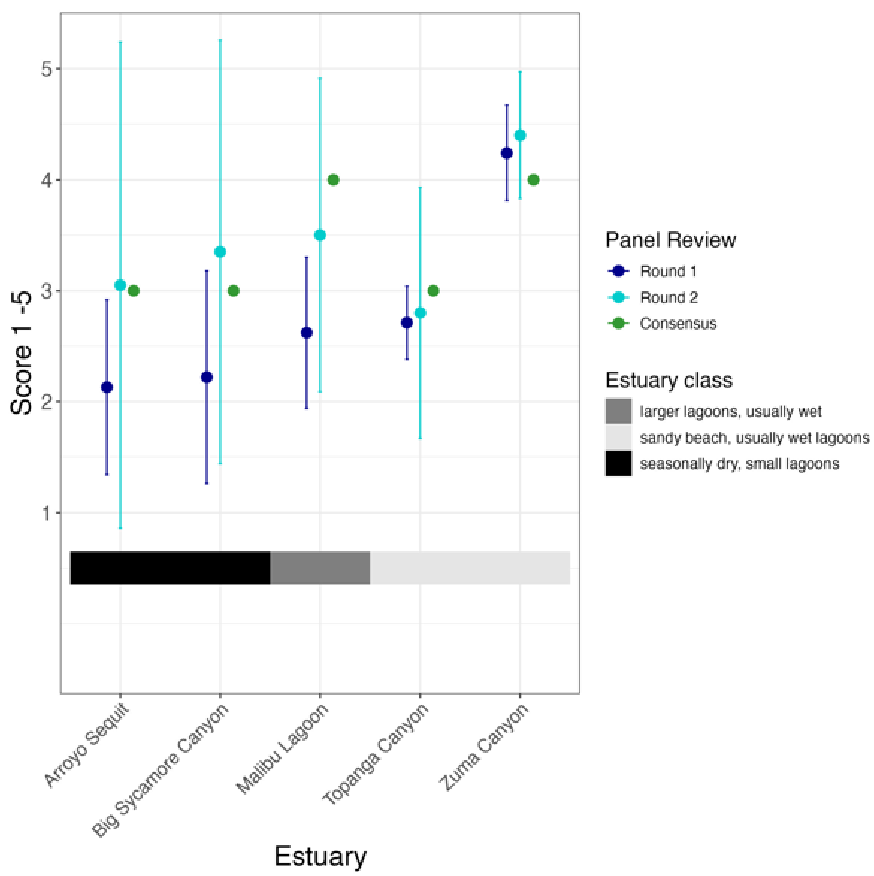


Figure 5. Median scores and standard deviations for each round of expert panel scoring along with consensus scores for SMB focal estuaries.

Six indicators (functions) were scored for each focal estuary (Figure 6). Arroyo Sequit and Big Sycamore scored BELOW AVERAGE and DECLINING for the trophic food web support and nursery habitat for fish functions. Higher scores were generally observed for habitat structure and vegetation community functions across most estuaries with scores being either CONSISTENT or IMPROVING. Zuma and Malibu Lagoons were rated as IMPROVING for many of the functions evaluated.

Overall conditions were rated as AVERAGE and STABLE/CONSISTENT for Big Sycamore, Arroyo Sequit and Topanga Lagoon and GOOD and IMPROVING for Zuma and Malibu Lagoons (Figure 7). Differences between estuary conditions may reflect the fact that Malibu and Zuma have been restored and/or managed to improve conditions and reduce stress, leading to higher scores. In addition, the seasonally dry estuaries (Big Sycamore and Arroyo Sequit) likely have lower trophic support and nursery functions due to the lack of habitat for invertebrates and fish during the dry season. Although most conditions were rated as consistent or improving, the expert panel noted that conditions are expected to change in the future in response to recent fires. The extent and intensity of the recent Woolsey, Franklin and Palisades fires will likely alter hydrology and cause excessive sedimentation and pollutant loading to the estuaries beyond the magnitudes and frequencies of "typical" fire regimes experienced in the past. This may alter future habitat conditions and make recovery more difficult.

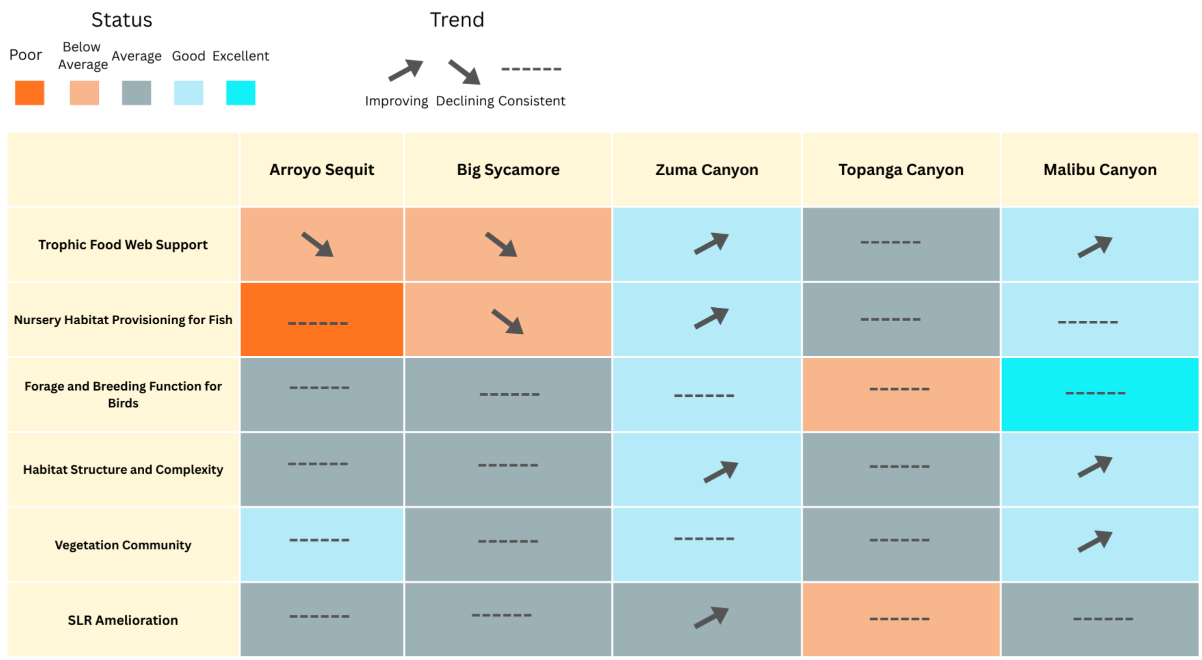


Figure 6. Results of expert panel scoring for status and trends for the six indicators/functions evaluated for each focal estuary.

Class	System	Overall Condition	Trend	Notes
Seasonally dry, small lagoons	Big Sycamore	Average	------	Dry period getting longer, confined by infrastructure, intense recreation, likely to decline over time
	Arroyo Sequit	Average	------	
Sandy beach, usually wet lagoons	Zuma Canyon	Good	↗	Recharged due to recent rains, flows may be augmented, increasing habitat
	Topanga Canyon	Average	------	Reflects pre-fire conditions, may decline over time
Larger lagoons, usually wet	Malibu Canyon	Good	↗	Mouth dynamics somewhat natural, recently restored

Figure 7. Overall condition scores from Round 3 consensus and trend for each focal estuary.

Stressors and Resilience

The primary stressors affecting the SMB estuaries are altered watershed hydrology, mouth confinement, and excessive human visitation. Over the long-term conditions are expected to degrade without consistent long-term stressor management. The effect of these stressors will likely be exacerbated by extended droughts and longer annual dry periods, which will further stress the estuarine biological communities. In contrast, eutrophication is likely to be less of concern due to the natural intermittency of many of the SMB estuaries, except for Malibu Lagoon which is subject to ongoing eutrophication due to nutrient enrichment from watershed runoff into the lagoon. Overall stressor status for SMB is AVERAGE and stress is INCREASING.

Stressors have differential effects on the functions evaluated (Figure 8). Constrained mouth conditions have a greater effect on habitat structure and complexity, trophic food web support, and habitat provisioning for fish functions. In contrast, excessive human visitation has a greater effect on bird forage and breeding and vegetation community structure functions. Constrained mouth condition and excessive sedimentation affect more functions than the other stressors evaluated.

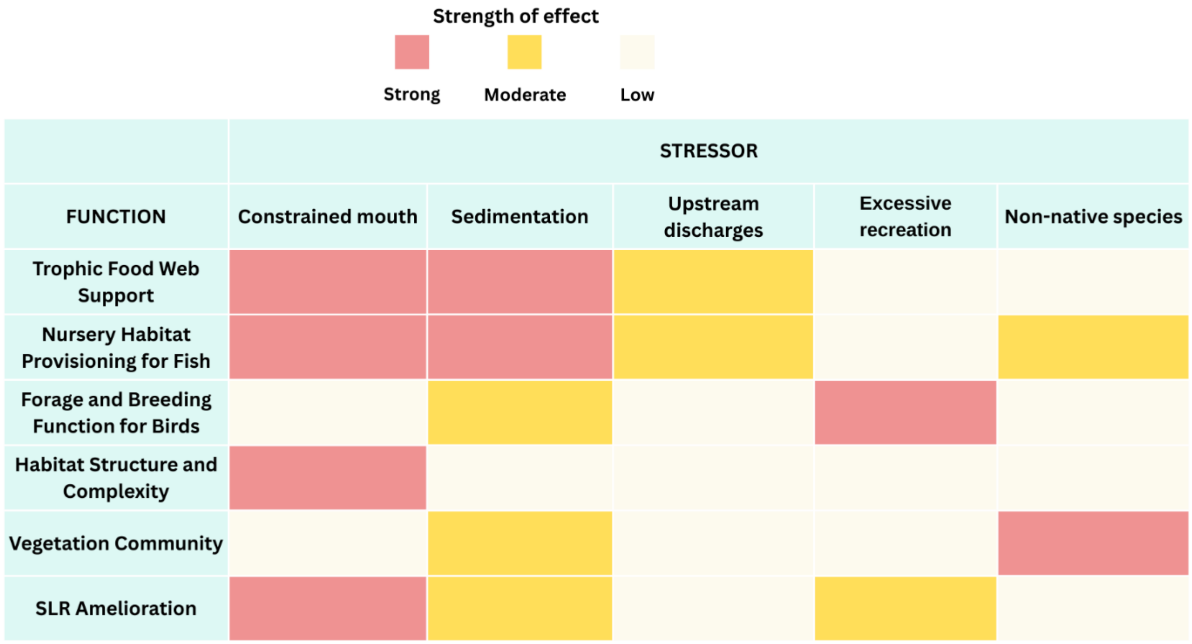


Figure 8. Relationship between stressors and the functions they most affect.

Management Actions and Needs

Assessment results should be aligned with the Comprehensive Monitoring Program (CMP) to inform site-level management with regional priorities. This alignment strengthens adaptive management cycles by ensuring that restoration planning, implementation, and evaluation are grounded in comparable metrics, shared expectations, and regionally informed thresholds of success. This integrative process supports consistent decision-making, clarifies where intervention is most needed, and enhances the long-term sustainability of estuarine habitats across the region.

SMB monitoring is most useful when it integrates with regional and statewide frameworks and programs (e.g., Bight, EMPA, WRP RMP), which provides opportunities to apply lessons learned across systems. A first step of integration is adoption of shared methodologies to make it possible to compare conditions across sites and track trajectories relative to regional “optimum” or “expected” conditions. This was accomplished with this iteration of the SOTB assessment. Next step should be to sample a wider range of estuarine systems within and outside of SMB over multiple years to incorporate both spatial context (e.g., how a site performs relative to estuaries with similar hydrologic or geomorphic characteristics) and temporal context (e.g., seasonal shifts, interannual climate variability, and long-term climate-change trends). This increasing sampling effort should be considered in the next assessment effort for SMB.

Protection and restoration measures across habitats (e.g., tidal marsh, mudflat, subtidal, riparian) can then be evaluated within this framework to assess whether these ecosystems/estuaries are supporting desired ecosystem functions and resilience.

While individual sites will need individual management plans, this regional assessment identified management needs related to chronic (consistent) and acute (periodic) stressors. Chronic stressors affecting most estuaries in SMB include:

- ***Altered condition of an estuary's connection to the ocean (inlet status)***. Inlet condition influences the physical, chemical, and biological dynamics of Santa Monica Bay estuaries. Many estuaries in this region are naturally intermittently open and closed systems, with episodic sandbar formation and breaching that regulate tidal exchange, salinity gradients, water levels, and sediment transport (Largier et al. 2020, Jacobs et al 2011; Behrens et al. 2013; McSweeney et al. 2017). However, climatic variability, coastal engineering, and management intervention (or lack thereof) have modified these natural cycles of opening and closing, often resulting in prolonged closures or artificial permanence of open inlets. During prolonged closures, reduced tidal flushing can lead to elevated water levels behind barrier berms, lowered dissolved oxygen, increased residence time of nutrients and contaminants, and hypoxic conditions that can stress estuarine biota (e.g., Kennish 2002). Based on inlet status and frequency of opening and closing, these estuaries also experience altered salinity regimes, shifts in habitat availability, and diminished connectivity for migratory and estuarine-dependent species. Conversely, converting historically intermittently open systems to permanently open mouth states through structures like jetties or routine dredging can reduce habitat heterogeneity, alter sediment budgets, and impair marsh accretion by changing sediment deposition patterns.
    - Within the Santa Monica Bay estuaries, infrastructure, such as roads, bridges, and berms, significantly constrains the natural opening and closing cycles of the estuarine inlets, especially the smaller and less managed systems. By physically limiting the connectivity and mobility of inlets, these structures can restrict tidal exchange, reduce channel width and depth upstream, and increase the likelihood of mouth closure during periods of low streamflow or high wave activity. Constrained inlets often exhibit prolonged or unseasonal closures, which in turn elevate water levels within the estuary, degrade water quality through reduced flushing, and intensify hypoxia, eutrophication, and sediment accumulation. Thus, while conditions in the smaller, less-managed estuaries in the region are neutral at this time, management actions around

inlet management should be considered if conditions are to persist or improve.

- ***Altered sediment inputs.*** Changes in sediment inflow has emerged as a significant driver of ecological and geomorphological change in these estuaries. Human activities, such as watershed vegetation removal or planting, urbanization, channel incision and water regulation, have altered the volume, timing and particle size distribution of sediment delivered to the estuaries. These altered sediment inputs commonly increase turbidity, reduce light availability, and suppress primary productivity, particularly in eelgrass beds (Kennish 2002). Composition change to finer-grained sediments can smother benthic communities, modifying food webs and degrading critical nursery grounds for fish and invertebrates (Thrush et al. 2004). Sediments also serve as vectors for nutrients, heavy metals, and persistent organic pollutants, thereby exacerbating eutrophication and facilitating contaminant accumulation within food webs (Bilotta & Brazier, 2008). At the geomorphological scale, elevated sedimentation rates accelerate channel infilling, reduce tidal prisms, alter estuarine hydrodynamics, and influence salinity regimes (e.g., Dalrymple & Choi 2007). Thus, controlling excessive sedimentation in the watershed should be a management priority.
    - Potential management strategies in southern California should focus on reducing watershed-derived sediment loads and restoring natural sediment dynamics in the watershed and estuaries. Watershed-level actions such as erosion control, riparian buffer restoration, and the implementation of green infrastructure in urban areas can help limit fine sediment and pollutant delivery. Within the estuaries themselves, management could include targeted dredging to maintain tidal channels, restoration of hydrologic connectivity with riparian areas, and prevention of sediment infilling of sensitive habitats. Managing freshwater inflow from water management or stormwater discharge, which would also serve to reduce pollutant loading.

- ***Altered freshwater flow regimes.*** Changes in the volume, timing, and duration of freshwater inflows from watersheds can result from urbanization, channelization, groundwater extraction, stormwater infrastructure, and wastewater discharges. These flow alterations influence estuarine salinity patterns, hydroperiods, and the frequency and duration of wetting–drying events. Because the region's estuaries are naturally intermittently opening and closing systems (as discussed above) with low seasonal freshwater inputs, anthropogenic reductions in baseflow and increased flow flashiness reduce the hydraulic pressure needed to breach coastal sandbars.

This, combined with altered inlet status, can result in more frequent and prolonged mouth closures (Behrens et al. 2013; Largier et al. 2020). Extended closure increases residence time, enhances evaporation-driven salinity accumulation, and prolongs dry-down events across mudflats and low marsh surfaces (Fong & Kennison 2010). Conversely, artificially elevated dry-season inflows, especially from wastewater effluent or persistent urban runoff, can dampen natural salinity variability, increase estuarine water levels, and shift hydroperiods toward longer inundation durations that alter vegetation zonation and sediment biogeochemistry (Stein et al. 2010; El-Khoury et al. 2014). Episodic stormwater pulses rapidly freshen estuaries, mobilize sediments, and often force inlet openings that temporarily reset salinity gradients but may also scour marsh substrates and disrupt benthic communities (Brown et al. 2018). These hydrologic modifications interact strongly with inlet state, creating feedbacks that shape the spatial extent of wetting–drying cycles, the persistence of hypoxic conditions, and the distribution of habitats such as tidal marsh, mudflats, and submerged aquatic vegetation.

- Management actions to regulate altered freshwater flows in the Santa Monica Bay region should generally focus on restoring more natural hydrologic patterns, reducing excessive anthropogenic inflows, and improving watershed–estuary connectivity. One major approach involves stormwater management reforms, such as low-impact development, green infrastructure, and infiltration-enhancing practices that restore more gradual baseflows. At the same time, changes to water flow patterns through flow reduction, seasonal flow diversion, can reduce the dry-season freshwater loading that artificially elevates water levels and depresses salinity variability. Watershed-scale actions such as riparian restoration, erosion control, and channel naturalization can also help moderate flow velocities and stabilize sediment delivery, improving estuarine salinity dynamics and hydroperiods. It was noted that restoring natural inflows have improved plant communities and increased stability for benthic communities for some of the systems (e.g., Zuma Lagoon).

Management must also account for stochastic events, including floods, fires, and other climatic shifts. These episodic disturbances can rapidly alter geomorphology, water quality, and biological communities and should therefore be captured through flexible sampling designs and post-event assessments. Comprehensive regional datasets will play a critical role in informing local planning by providing context for expected ranges of variability. For example, understanding how similar estuaries respond to seasonal changes, wet versus dry years, or larger climatic patterns can guide site-specific decisions such as inlet management, restoration design, and adaptive stewardship strategies.

Conclusions and Next Steps

The 2025 assessment of Santa Monica Bay estuaries resulted from expert elicitation and consensus informed by uniformly collected monitoring data. This assessment is also the first to explicitly evaluate the condition of small creek mouth estuaries, some of which are intermittent and have largely been excluded from past assessments due to lack of available protocols and data.

The expert panel process was highly effective at providing a mechanism to reach consensus. The ability to consider monitoring data influenced the decision-making process and improved agreement and defensibility in the conclusions. Through the iterative process, the expert panel agreed on scoring algorithms for condition and stress and was able to apply those algorithms to reach consensus on their evaluation. Through this structured process, the panel scored overall condition as AVERAGE and STABLE/CONSISTENT for Big Sycamore, Arroyo Sequit and Topanga Lagoon and GOOD and IMPROVING for Zuma and Malibu Lagoons. Differences in condition reflect the effect of restoration and management actions which have improved conditions at Zuma and Malibu over time. Overall stress status for SMB was rated as AVERAGE and stress is INCREASING. The primary stressors affecting the SMB estuaries are altered watershed hydrology, mouth confinement, and excessive human visitation.

A key knowledge gap identified through the evaluation process is the ability to relate short and long-term stressors to condition and to inform management responses based on those relationships. Future research efforts should better elucidate the effects of fires on estuary conditions and understand how those effects may interact with expected trends of more frequent, longer and severe dry periods. Research should focus on the combined effects of these short and long-term stressors which have the potential to alter the structure and function of the SMB estuaries. Future iterations of the State of the Bay analysis should consider not only how to evaluate long-term effects by how assessments but also should evolve over time based on changing conditions (e.g., runoff patterns, drought cycles, fire frequencies). Research should also be conducted to better understand how the small estuaries in relatively close proximity function to support regional metapopulations and how their condition and mouth status contribute to regional resiliency of habitats and species.

Index development is a key need for future assessments. The scoring algorithms developed by the expert panel relate field metrics to indicators of function and provide a structured and transparent assessment approach that can be adapted and refined over time. The ability to assess condition and stress would be greatly enhanced by operationalizing these algorithms through development of structured indices for each function. These indices should include defined gradients of condition, be anchored to a level of expectation (e.g., reference or best-attainable condition), and be broadly applicable in a consistent and repeatable manner. Indices could also be combined to provide overall condition/function measures for each estuary and for the region as a whole.

As with past State of the Bay analysis, the 2025 assessment could not 1) fully evaluate all SMB estuaries, 2) adequately contextualize them relative to other southern California systems, and 3) assess trends. However, the current assessment did improve over previous ones by taking advantage of the data collected through the Estuary Marine Protected Area (EMPA) and Bight Regional monitoring programs, which both use standard protocols developed for the statewide EMPA program. However, the ability to conduct a more comprehensive assessment of all estuaries in SMB, to place them in the context of other estuaries in the region and to track trends in condition over time will require investment in an SMB focused monitoring program. This program can partner with (and leverage) the recently adopted Wetland Recovery Project Regional Monitoring Program but will require additional resources to ensure the SMB estuaries are fully represented. Future monitoring should also include monitoring of key stressors and frequencies and durations necessary to relate them to condition metrics. Priority should be given to the primary stressors identified by this study, watershed inflows, sedimentation, mouth dynamics, and human visitation. Commitment to sustained long-term monitoring will be particularly important to better understand and adapt to the effects of more frequent and severe dry periods and increased fire frequency and intensity. Long-term trajectories are expected to decline without management intervention to address key stressors, so future monitoring should be used to evaluate the efficacy of management actions and to inform adaptive management. All data compiled through any future monitoring efforts should be uploaded to the designated regional data portals to ensure data access and compatibility with other regional and statewide monitoring efforts.

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Appendix A – Descriptions of Indicators, Metrics and Stressors

FUNCTIONAL INDICATORS AND METRICS

Trophic Food Web Support

Definition Provision of food sources for higher trophic level consumers found in estuaries, such as resident or transient species of fish and crustaceans.

Scoring Algorithm

Trophic Food Web Support Indicator = (Fish Abundance + Benthic Invertebrate Abundance)/2

Data availability and condition

Fish abundance was measured by adding all seine replicates within an estuary for both spring and fall. Macroinvertebrate abundance was measured by adding all core replicates within an estuary in both spring and fall. Indicator values are not available for Topanga Creek and Arroyo Sequit estuaries in the fall season due to (1) fish abundance - lack of water (a normal occurrence within these bar-built estuaries) and (2) macroinvertebrate abundance – not sampled due to planned effort only once per year. Expert confidence in scoring this indicator in both rounds was low for the two seasonally dry estuaries due to discrepancies around expected conditions for these small systems, but confidence was high in scoring other estuary archetypes.

Discussion

This indicator included metrics on food sources available to higher trophic level consumers (e.g., larger fish and birds) within each estuary. While not used in this manner for scoring in this report, longer-term this could also be extended to determine the average trophic level within the estuary. Use of trophic level estimation can simplify and explain the dynamic interactions between organisms within these systems and allow relative comparisons of the amount of trophic support available to consumers between systems. Future steps should include more mechanistic exploration of trophic level and niche partitioning that would validate this index development.

Nursery Habitat Provisioning for Fish

Definition Provision of habitat for spawning and nursery support for marine or anadromous species based on the structural complexity and high primary/secondary productivity found in estuaries.

Scoring Algorithm

Ideal: Nursery Habitat Provisioning for Fish Indicator = (SAV(0 or 1*density) + (%time > 25°C + # DO events<3 mg L^{-1})/-2) + (% of abundance of juvenile resident fish + % of abundance of estuarine migrant fish + abundance of benthic invertebrates)

Actual: Nursery Habitat Provisioning for Fish Indicator = (SAV(0 or 1*density) + (%time > 25°C + # DO events<3 mg L^{-1})/-2) + (% of abundance of juvenile fish + abundance of benthic invertebrates)

Data availability and condition

This indicator includes the presence or absence of submerged aquatic vegetation (SAV), and the abundance of juvenile fish based on minimum adult length by species recorded in FishBase, the abundance of benthic invertebrates as a food source, the number of recorded events of dissolved oxygen below 3 mg L^{-1}, and the percent of time with water temperatures greater than 25°C. Data was collected at three different stations at each of the five estuaries in both spring and fall in each year. Temperature and dissolved oxygen continuous data were collected via loggers deployed at one station in each estuary. In some instances, there was no water present in Big Sycamore Canyon (BSC) or Arroyo Sequit Estuary (ASE), so no seine nets were used to sample. Missing fish data at these locations lowered our ability to accurately score this indicator. In addition, seine net size failed to capture juvenile fish, which lowered expert confidence in estimates of percent of juvenile fish. Our survey likely underestimated the proportion of juvenile fish supported by each estuary. Similar to trophic support (which used similar data sources), expert confidence in scoring this indicator in both rounds was relatively low for the two seasonally dry estuaries due to discrepancies around expected conditions for these small systems, but confidence was high in scoring other estuary archetypes.

Discussion

Estuaries provide habitat for a multitude of fish species, including migrant species, which often depend on estuarine habitat as a nursery at juvenile life stages. This subset of estuarine fish includes certain federally endangered species, including tidewater goby (*Eucyclogobius newberryi*) and southern steelhead trout *(Oncorhynchus mykiss*) as well as spotted sand bass, croakers, California halibut, and many other species. This indicator was developed to assess the level of habitat and nutritional support for juvenile fish mesopredators, while accounting for conditions that are known to limit the success of juvenile fish, such as hypoxia and high temperatures. In addition, SAV was included in this metric as it provides unique structure and enhancement of biogeochemical processes. SAV, such as eelgrass (*Zostera* sp.), can form expansive beds or meadows in the shallow, soft sediments and for juveniles, provide temporary refuge from predators and serve as a productivity hot spot. Similar to trophic support, quantifying macroinvertebrates provided an indicator of trophic support for juvenile fish, which typically incorporate large numbers of benthic invertebrates into their diets. Additional data collection for this metric should include more accurate extent assessments for SAV, quantification of water column food sources, and better determination of juvenile versus adult fish abundance.

Bird Habitat Support

Definition Provision of physical and biological structure for resident and migratory birds to support predator evasion or nesting (via their associated wetlands) and abundant food (via high secondary and tertiary (nekton) productivity).

Scoring Algorithm

Ideal: Birds Habitat Support Indicator = (Bird richness and abundance) + (Bird abundance * activity)

Actual: Bird Habitat Support Indicator = (Bird richness and abundance)

Data availability and condition

Bird richness and abundance data are available for all five estuaries in both seasons, but these data were based on just several days of bird watching. However, bird activity (% of birds foraging/feeding) was not recorded as part of the survey. The indicator could not be scored using the ideal scoring algorithm based on this round of data collection, so the algorithm was amended to exclude bird activity. The actual indicator scores are available, but expert confidence in this metric for how each estuary supports bird habitat is low due to data gaps discussed below.

Discussion

Birds (resident and migratory) and charismatic wildlife such as seals, otters, and sea lions are indicators of habitat quality in estuaries because they depend on these habitats for reproductive success, sufficient foraging opportunities, and protection from predators. The general public also broadly perceives the presence or absence of these species to reflect the overall health of an estuary; opportunities to view these species frequently drive public interest in estuarine conservation and stewardship. Thus, suggestions for future data collection involve more frequent bird counts, using participatory science to enhance datasets, and including bird activity surveys.

Habitat Structure and Complexity

Definition Provision of habitat based on physical and biotic structure across topography and vegetation for activities such as foraging, nesting, and hiding for birds, fish, and benthic invertebrates.

Scoring Algorithm

Habitat Structure and Complexity Indicator = CRAM Physical Structure + CRAM Biological Structure

Data availability and condition

This indicator was a combination of relevant CRAM (California Rapid Assessment Method) scores from the 2022 assessment at one location within each estuary, including the individual physical and biotic structure scores, ranging from 25 to 100, where 100 is the best attainable condition (Sutula et al. 2008). Scores that represent a number of metrics and sub-metrics for both physical and biotic structure were added to obtain indicator values for each estuary. While data were available for this indicator, expert confidence was low for both Topanga Canyon and Big Sycamore Canyon, potentially related to the specific areas of CRAM assessment (i.e., the exact assessment area (AA) chosen by surveyors).

Discussion

High habitat complexity across estuarine ecosystems can provide a variety of physical habitats for nekton and bird species, as well as habitats that trap and support the transformation of allochthonous and autochthonous organic matter. These two factors contribute to the overall structural diversity of the environment, creating a wide range of niches for different species and supporting the overall biodiversity and productivity of the ecosystem. Given the importance of this indicator as well as the relative simplicity of calculating the index score, CRAM assessments could be redone and/or repeated more frequently to inform a more temporally accurate index score as well as to raise confidence in best professional judgement scoring.

Vegetation Community

Definition 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.

Scoring Algorithm

Vegetation Community Indicator = native richness + ((% native cover + CRAM Plant Community Metric)/2)

Data availability and condition

The CRAM Plant Community sub-metric (measured in the 2022 CRAM assessment) was averaged with percent native cover taken from surveys (measured in each season 2023-2024) and added to native plant richness. All five estuaries were scored for this indicator. All data was available for this indicator, but expert confidence was low for the two seasonally- dry estuaries: Arroyo Sequit and Big Sycamore Canyon.

Discussion

Marsh plain vegetation is a key component of overall estuarine health and function. Native species dominance and robust vegetation cover within the marsh plain directly enhance the estuary's function for vascular plant support by promoting ecological stability and habitat complexity. Native emergent vegetation is adapted to the estuary's dynamic environmental gradients, including spatial and temporal shifts in water depth, salinity, sediment composition, and elevation. This adaptation ensures a diverse assemblage of fresh and salt-tolerant species can establish and persist across different marsh zones, maintaining a resilient plant community structure. Furthermore, well-established native 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. The wetland vegetation cover and species richness recorded at each estuary were used as a proxies for this indicator.

SLR Resiliency and Amelioration

Definition the capacity to absorb and protect adjacent uplands from rising sea levels based on the geomorphology and habitat associated with the marine-freshwater-terrestrial interfaces

Scoring Algorithm

SLR Resiliency and Amelioration Indicator = mitigation area + inundation + wetland extent

Data Availability and Condition

Upland migration area was calculated from an average of three sub-metrics using the National Land Cover Database (2025 data): Buffer land cover, Perimeter Land Cover, and Perimeter Contiguity. All three sub-metrics evaluate the amount of open cover surrounding an estuary that can migrate in the event of rising sea levels. Open cover was defined as any non-developed land cover class. Buffer land cover evaluated the amount of open land cover within 500 meters of the estuary footprint, while Perimeter land cover evaluated open cover within 30 meters. Perimeter contiguity evaluated the amount of contiguous open land cover (large patches of open cover next to each other) within 30 meters of the estuary. Inundation and wetland extent were calculated using a Digital Elevation Model (DEM) (1996 to 2019 from NOAA at 3-5m resolution). The DEM was then compared to the vegetation transects collected at each estuary to establish habitat elevation zones for mid, low, and high marsh. Any upland area above high marsh was excluded from this analysis. For estuaries that had limited or unavailable transect information, habitat elevations were determined through visual desktop interpretation. Once habitat elevation zones were determined, the percent cover of area (based on pixel count) for each habitat were added up to calculate Marsh Plain Inundation Area. More information on these calculations can be found in the EMPA 2023 Data Report[1]. Given the reliance of this indicator on numerical metrics, overall confidence in scoring was high for this metric.

Discussion

One key element of the methodology for this indicator is the importance of clear definitions of habitat types. Thus, our method description is more detailed than other section; in addition, clear definitions are essential to ensure comparability and accuracy moving forward. Generally, estuaries that scored high on upland migration area had higher open cover within 30m and 500m of the estuary as well as larger contiguous open patches. Low scoring estuaries had a higher area of development, including industrial and residential areas, within 30m and 500m meters. Additionally, any open space was more spread out than higher scoring estuaries (less contiguous open cover). A higher scoring estuary has a higher total land cover percentage compared to open water (ex: 84% land cover, 16% open water cover). A lower scoring estuary has a higher open water cover compared to land cover.

STRESSOR INDICATORS AND METRICS

Estuaries suffer heightened stress from development and alteration because human populations are often focused in coastal areas. Being at the bottom of catchments, estuaries accumulate environmental stresses from the entire watershed, including altered flows of water and sediment, pollution, and eutrophication.

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

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

[1] https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/1430_EMPADataAnalysisReport.pdf

Actual: **Eutrophication Indicator =** % macroalgae cover + TN + 0.5*TOC

Data availability and condition

This indicator included dissolved oxygen continuous data, quadrat surveys of percent macroalgae cover, and sediment TOC/TN measurements. These data were combined using a regression model proposed by Sutula et al. (2008) to obtain eutrophication indicator values that can be compared across estuaries. Dissolved oxygen measurements were not collected consistently at each estuary, so the scoring algorithm was adjusted to omit this component. Seasonal lack of water at Big Sycamore Canyon and Arroyo Sequit limits the comparative use of this indicator. Confidence scores for reviewers were relatively low as the stressor data and continuous monitoring data were not complete datasets.

Discussion

Eutrophication can stress coastal wetlands in a number of ways, including the creation of conditions that enable Harmful Algal Blooms (HABs), hypoxia, and shading out of SAV. Future data collection in the region should focus on ensuring that continuous data collection for water parameters (DO, depth, salinity, temperature) is possible.

Anthropogenic Disturbance and Land Use

Definition The extent and quality of 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 = CRAM Physical Structure Score + CRAM Buffer and Landscape Context Score

Data availability and condition

The Anthropogenic Disturbance and Land Use indicator values were calculated by adding scores from a 2022 CRAM survey of Physical Structure and Buffer in each estuary. Each survey was scored from 25 to 100, with 100 as the highest value. Use of quantitative landscape metrics plus validated CRAM scores helped the confidence scores of the expert panel to be high.

Discussion

The level of anthropogenic disturbance and land use in each estuary is a function of both the internal physical structure and external buffer of the wetland. Complex physical surfaces and protection from anthropogenic disturbances such as development, noise, and pollution create conditions that facilitate ecological complexity. The external buffer offers landscape context regarding the transition zone between the wetland and its surrounding environment by providing a combined measure of the Stream Corridor Continuity, average buffer width, and the condition of the buffer. An estuary with an indicator value close to 200 denotes wetlands with complex internal structure, high levels of stream corridor continuity, and a wide and high-quality transition zone between wetlands and the surrounding environment.

Altered Hydrology

Definition Physical modifications to the water source(s) or channels within an estuary to impact the natural dry season conditions, particularly those modifications which create inconsistent flow conditions.

Scoring Algorithm

Altered Hydrology Indicator = (CRAM Hydrology Score)*(% time inlet open)*(artificial breaching)

Data availability and condition

The Altered Hydrology Indicator was developed as the product of CRAM Hydrology scores, percent of time with the estuary inlet open to the ocean, and artificial inlet breaching events. CRAM Hydrology scores, which consider water sources, hydroperiod/channel stability, and hydrologic connectivity, summarizes the degree of alteration that has occurred within an estuary. These three metrics are multiplied since they are known to amplify one another. CRAM Hydrology Scores from the 2022 survey were used alongside inlet opening data from 2023 satellite imagery. Since no known instances of artificial breaching were recorded during this time, this indicator was not scored for this round of sampling.

Discussion

Altered hydrology is common across the heavily urbanized coastline of Santa Monica Bay. Small estuaries, especially those that are seasonally closed to the open ocean, are subject to stress associated with altered hydrology. Dry or stagnant conditions, channelization of tributaries, and unnatural/inconsistent water sources can all have negative impacts on the functioning of coastal wetlands. The focus of this indicator is to evaluate hydrological conditions, and in particular, how they are altered during the dry season. An estuary with a high indicator value has a natural hydroperiod, a direct and natural water source, and connectivity into and out of the wetland, as well as a significant amount of time open to the ocean and a low instance of artificial breaching.

Non-Native Species

Definition

Pressure of encroachment from terrestrial and aquatic 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 + CRAM plant)/2) +% non-native fish

Data availability and condition

This indicator was developed using the CRAM Plant Community Metric from 2022, and the percentage of non-native plans and non-native fish. The percentage of non-native plants was averaged with the Plant Community Metric score and the result was added to the percentage of non-native fish recorded from replicate seines done within each estuary. The CRAM Plant Community Metric evaluates the non-native plant influence as co-dominant vegetation (large spatial scale), whereas the EMPA seasonal survey assessed non-native vegetation at the quadrat-scale (small spatial scale).

Discussion

Non-native species have been identified as one of the biggest threats to coastal wetlands. Biological invasions from both plants and animals can displace native species and have negative unintended ecosystem-wide impacts on sensitive habitats of concern. A high indicator value for an estuary would indicate a high degree of invasion from both plants and fish.

Contaminant and Excessive Sediment Loading

Definition

A wetland or estuary with abnormal loads of sediment, metals, organics, and microplastics, which apply stress to the ecosystem in a number of ways via the health of plant and animal communities.

Scoring Algorithm

Contaminant Loading Indicator = (mass loading + (total trash/plastic)) +stochastic loading

Data availability and condition

Metrics that are used to calculate this indicator are not all available. Ten-minute trash search data is available from two seasons of EMPA monitoring at each estuary, as well as the ratio of plastic to non-plastic material within each search. However, mass loadings of metals, organics, and microplastics for each estuary, and supplemental data on loadings from stochastic events (fires, floods, spills etc.) are not available. As a result, this indicator was not scored.

Discussion

Due to lack of data, this indicator could not be scored. However, the expert panel felt that future monitoring should be designed to ensure that data around episodic stressors like floods that carry contaminants or regular input of contaminants, are important.

MANAGEMENT CONSIDERATION INDICATORS AND METRICS

During the expert panel meetings, it became evident that certain management concerns or objectives did not align well with the indicator scoring system. Specifically, these included presence of key native species that are threatened or endangered as well as invasive species that are known to cause disproportionate harm. Thus, these indicators were added to the overall algorithm scoring system but little data were available for the panel to review. These indicators were not scored as part of this report. Future State of the Bay reports and condition evaluations should focus more on how to develop these indicators.

Native Species of Management Concern

Definition

California native species that are either state or federally listed as threatened or endangered (e.g., tidewater goby, steelhead trout, Light-Footed Ridgway Rail, Belding's sparrow).

Scoring Algorithm

Species scores = Presence (1 or 0) x Density (abundance/unit area)

OR

Heavily skewed sites = Weighted Score = P x log(D+1)

Data availability and condition

The metrics needed to score this indicator include the presence and abundance of threatened and endangered species as well as the presence of special status plants. This species-specific information is not directly collected but is contained within EMPA seine data and bird count data, and vegetation surveys from spring/fall of 2024. However, this indicator has not been scored.

Discussion

This indicator was not scored due to lack of data. However, each species of concern would be evaluated on an individual level at each estuary.

Invasive Species of Management Concern

Definition Species listed as invasive or non-native (e.g., crayfish bullfrogs) and their prevalence/degree of invasion.

Scoring Algorithm

Species scores = Presence (1 or 0) x Density (abundance/unit area)

OR

Heavily skewed sites = Weighted Score = P x log(D+1)

Data availability and condition

The metrics needed to score this indicator include the presence and abundance of systemic invasive plants and animals, including crayfish bullfrogs. This species-specific information is not directly collected through the EMPA monitoring program but may be opportunistically available in data from fish seines, benthic macroinvertebrate cores, vegetation surveys, and field notes from sampling teams. This indicator has not been scored.

Discussion

This indicator was not scored due to lack of data. However, each species of concern would be evaluated based on its degree of invasion at each estuary. Species with high scores would be considered most problematic.

Appendix B – Detailed Habitat Inventory and Site Maps

Detailed habitat mapping used the California Aquatic Resources Inventory (CARI; https://www.sfei.org/projects/california-aquatic-resource-inventory-cari map layer clipped to the boundaries of the SMB estuaries. Habitat classifications are as defined by CARI

Table B1. Total habitat area for Santa Monica Bay estuaries as of 2024.

HABITAT	Area (ha)
Beach	1.32
Dune	0.03
Eelgrass	0.41
Fluvial Channel	0.00
Forested Tidal Wetland	0.29
Managed and Muted Tidal Habitats	0.74
Pond and associated vegetation	5.85
Riverine Vegetated	0.00
Rocky Shore	0.12
Subtidal Water	253.90
Tidal Flat and Marsh Panne	17.87
Tidal Marsh	55.16

Table B2. Total area of each habitat type by archetype for the Santa Monica Bay region as of 2024.

HABITAT	ARCHETYPE	AREA (ha)
Beach	Small creek	0.56
Beach	Intermediate estuary	0.75
Dune	Small creek	0.03
Eelgrass	Open bay/harbor	0.41
Fluvial Channel	Fragmented river valley estuary	0.00
Fluvial Channel	Small creek	0.00
Fluvial Channel	Intermediate estuary	0.00
Forested Tidal Wetland	Intermediate estuary	0.09
Forested Tidal Wetland	Small creek	0.21
Managed and Muted Tidal Habitats	Open bay/harbor	0.74
Pond and associated vegetation	Fragmented river valley estuary	5.85
Riverine Vegetated	Intermediate estuary	0.00
Rocky Shore	Fragmented river valley estuary	0.09
Rocky Shore	Open bay/harbor	0.00
Rocky Shore	Small creek	0.02
Subtidal Water	Intermediate estuary	10.58
Subtidal Water	Fragmented river valley estuary	36.94
Subtidal Water	Open bay/harbor	203.71
Subtidal Water	Small creek	2.67
Tidal Flat and Marsh Panne	Fragmented river valley estuary	13.74
Tidal Flat and Marsh Panne	Intermediate estuary	0.35
Tidal Flat and Marsh Panne	Open bay/harbor	3.61
Tidal Flat and Marsh Panne	Small creek	0.17
Tidal Marsh	Fragmented river valley estuary	53.00
Tidal Marsh	Intermediate estuary	1.72
Tidal Marsh	Small creek	0.44

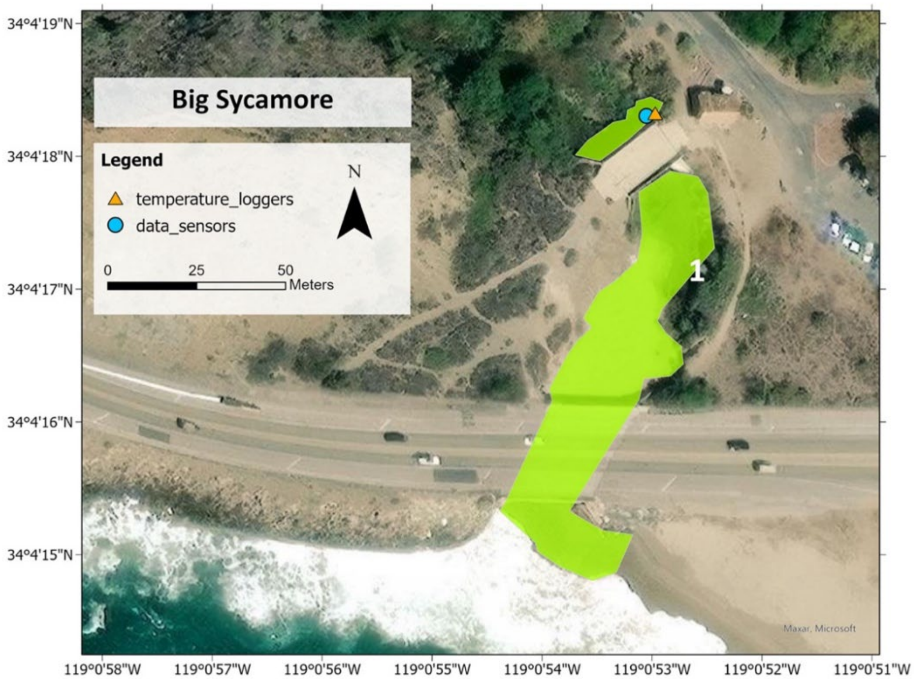

Figure B1. Map of Big Sycamore Canyon with one sampling station (indicated by the 1 symbology) and one data logger location.

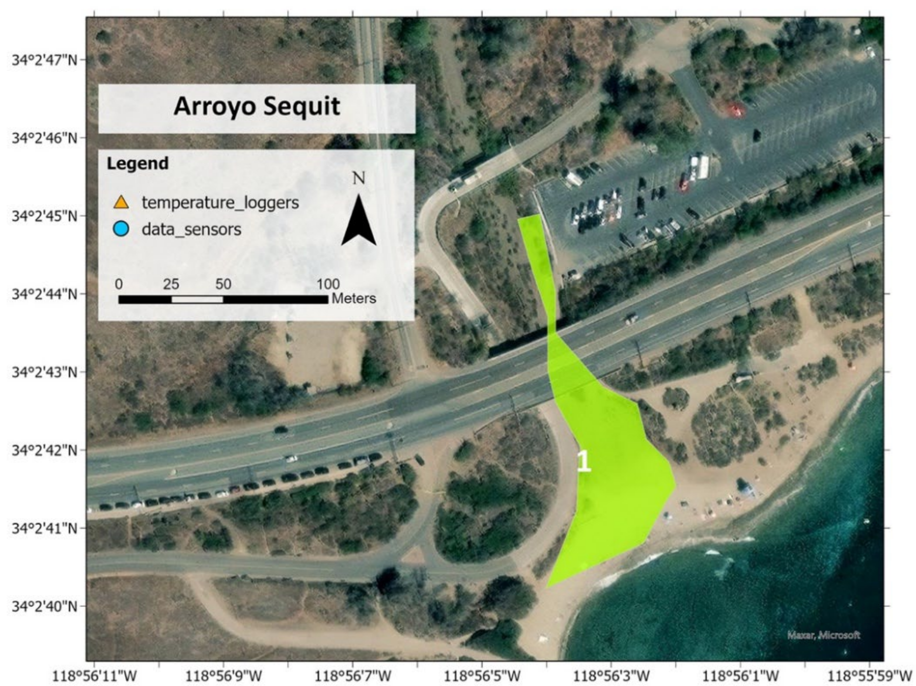

Figure B2. Map of Arroyo Sequit with one sampling station (indicated by the 1 symbology).

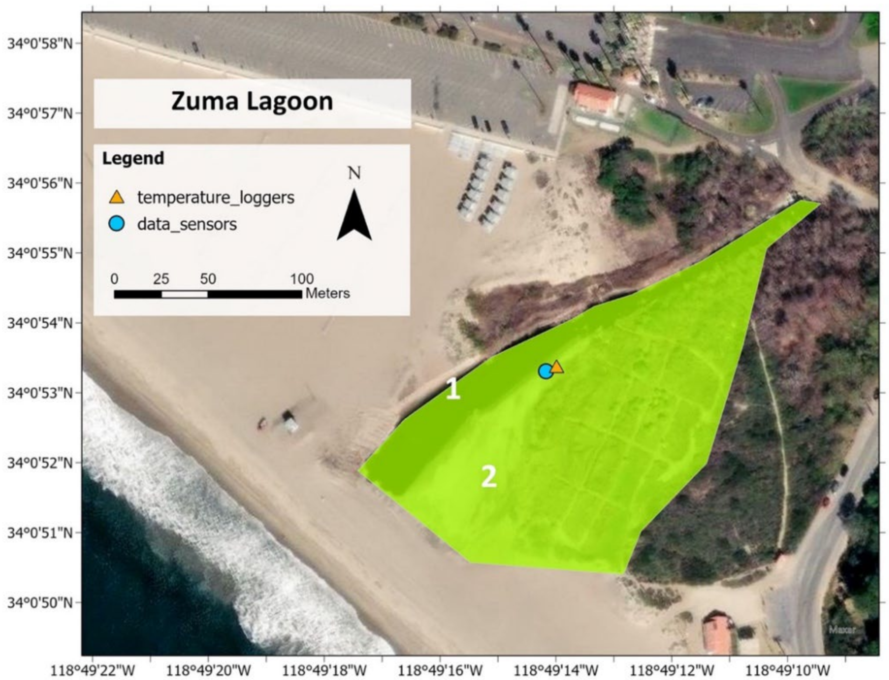

Figure B3. Map of Zuma Lagoon with two sampling stations (indicated by the 1 and 2 symbology) and one data logger location.

Figure B4. Map of Malibu Lagoon with three sampling stations (indicated by the 1, 2, and 3 symbology) and two data logger locations.

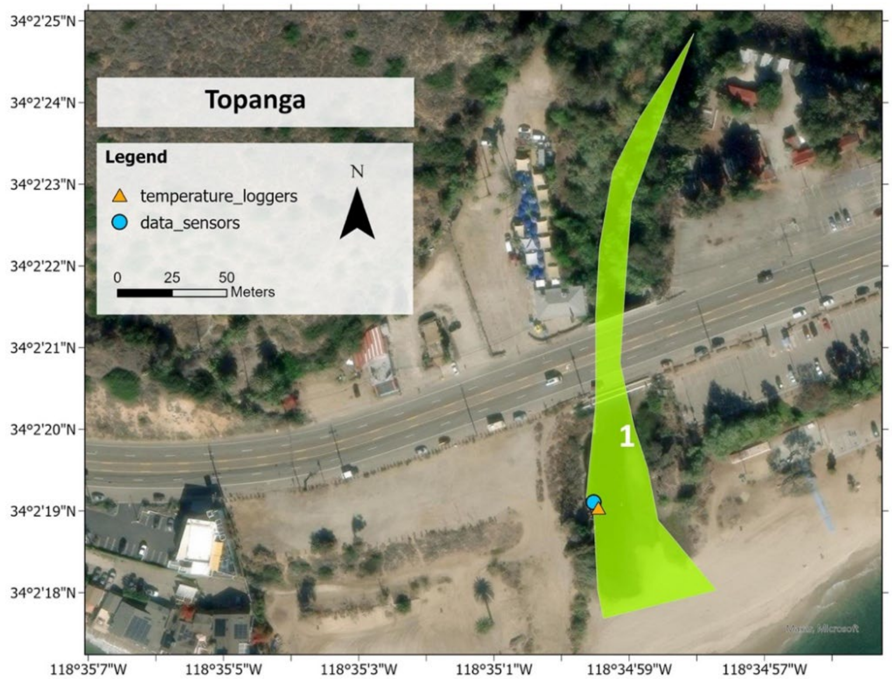

Figure B5. Map of Topanga Lagoon with one sampling station (indicated by the 1 symbology) and one data logger location.

Appendix C – Summary of Expert Panel Scoring

The following tables show the averaged scores, standard deviations, and ranges of expert panel scores from Round 1 by indicator and by estuary (Tables C1,2,3). These summary tables were presented to the expert panelists before Round 2 scoring. After Round 2, through iterative discussion, the expert workgroup developed consensus for final scores (as presented above).

Table C1. Round 1 scoring by the expert panel. Average (n=6) scores are presented for each indicator by estuary. Round 1 scoring was done only by best professional judgement without the data documents.

AVG	Trophic Web Support	Nursery Habitat Provisioning for Fish	Forage and Breeding Function for Birds	Habitat Structure and Complexity	Vegetation Community	SLR Amelioration	Overall Condition score
Big Sycamore Canyon	2.10	1.70	1.75	2.10	3.00	5.00	2.22
Arroyo Sequit	2.00	1.40	1.88	2.30	3.60	5.00	2.13
Zuma Canyon	4.40	4.40	4.30	4.00	4.00	3.00	4.24
Topanga Canyon	3.40	3.10	2.40	2.50	2.80	3.00	2.71
Malibu Lagoon	2.90	2.60	3.00	2.80	2.80	4.00	2.62

Table C2. Round 1 scoring by the expert panel. Standard deviations are presented for each indicator by estuary.

STDEV	Trophic Web Support	Nursery Habitat Provisioning for Fish	Forage and Breeding Function for Birds	Habitat Structure and Complexity	Vegetation Community	SLR Amelioration	Overall Condition score
Big Sycamore Canyon	1.14	0.97	0.96	1.14	1.00		0.96
Arroyo Sequit	0.35	0.82	0.85	0.67	1.14		0.79
Zuma Canyon	0.55	0.55	0.45	0.71	0.71		0.43
Topanga Canyon	1.08	0.89	0.42	1.12	0.76		0.33
Malibu Lagoon	0.55	1.34	0.00	0.84	0.84		0.68

Table C3. Round 1 scoring by the expert panel. Range of 6 scores are presented for each indicator by estuary.

Range	Trophic Web Support	Nursery Habitat Provisioning for Fish	Forage and Breeding Function for Birds	Habitat Structure and Complexity	Vegetation Community	SLR Amelioration	Overall Condition score
Big Sycamore Canyon	1-4	0.5-3	1-3	1-4	2-4		1.5-3.8
Arroyo Sequit	1-2.5	0.5-2	1-3	1.5-3	2-5		1.5-3.4
Zuma Canyon	4-5	4-5	4-5	3-5	3-5		4-5
Topanga Canyon	2.5-5	2-4	2-3	1-4	2-4		2.4-3.1
Malibu Lagoon	2-3.5	1-4	3	2-4	2-4		2-3.6

Appendix D – Monitoring Results

Data were collected on 15 of the 16 indicators recommended in the CMP. Below we provide summaries for a variety of indicators. For details on methodology, SOPs are available on the EMPA portal page - https://empa.sccwrp.org. All data can be downloaded directly from the EMPA Database - https://nexus.sccwrp.org/empadataquery/

Fish: Seines

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. The majority of data presented below was collected by pulling a 30ft l, 6ft h, 1/8in mesh beach seine (no bag) parallel to shore for 25 meters.

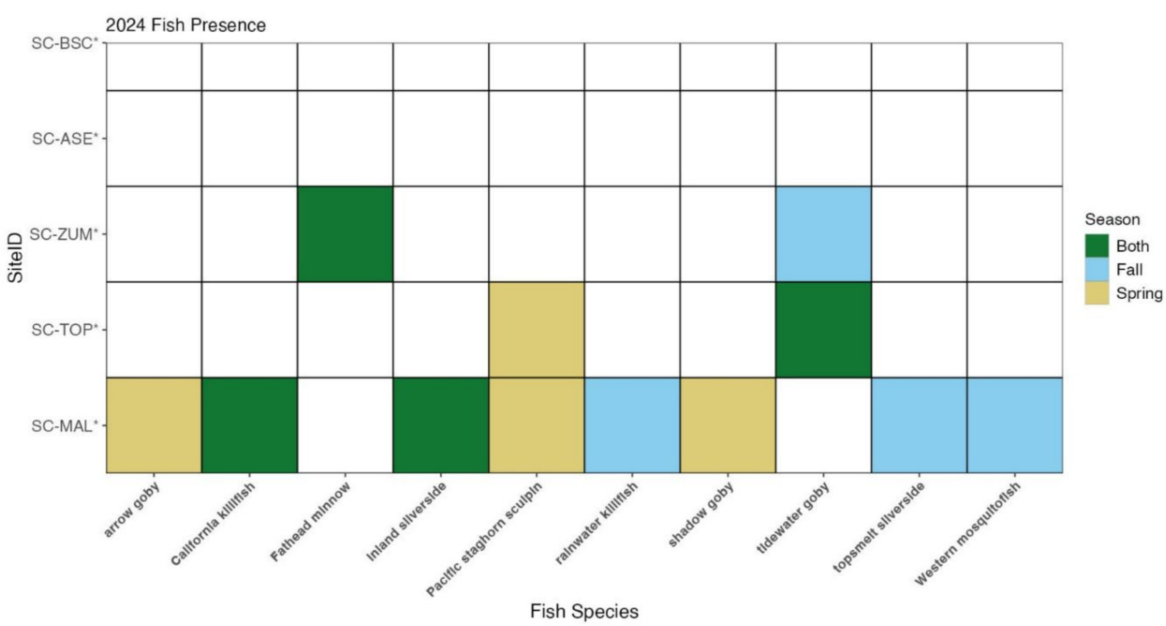

Figure D1. Heatmap of fish captured in seine nets across all estuaries in spring and fall seasons.

Fish: 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. Methods were adapted from the California Molecular Methods Workgroup. In short, replicate water samples (3) were collected at each station in each estuary in both spring and fall. To isolate extraction material from samples, we passed 500mL of water from each sample bottle through a 0.45um nitrocellulose filter using a vacuum pump. If material clogged the filter and prevented water from passing through, we replaced the clogged filter with a new one and resumed filtering until all 500mL of water was processed. This yielded up to two filters per sample. As a negative control, we filtered 500mL of pure water during each filtering event.

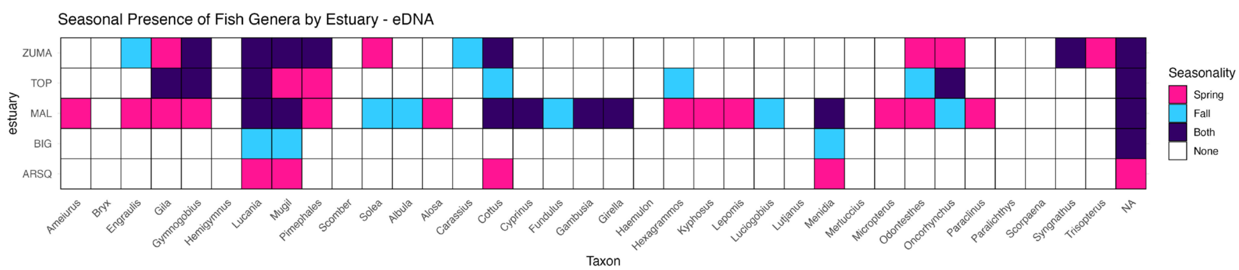

Figure D2. Heatmap of fish genera detected using eDNA water samples in each estuary across both spring and fall seasons.

Benthic Invertebrates

Benthic invertebrate taxa are useful ecological indicators because they provide a reflection of the state of the environment, especially at the transition from water to land, and can indicate local biodiversity (Hilty and Merenlender 2000). Long-term changes are often assessed by looking at the invertebrate community at a higher taxonomic level or by evaluating the community as a whole (Hodkinson and Jackson 2005). This sampling method for collecting and assessing the density and composition of benthic infauna is the minimum sampling one should take when assessing the benthic community. This method only extracted three cores per sampling zone, thus the data was used alone to characterize individual estuaries, rather to make gross comparisons among estuaries. Sediment cores were washed through a 300 µm sieve, and infauna were identified to the lowest possible taxonomic level. Overall abundance of infauna as well as species richness were calculated for each sample.

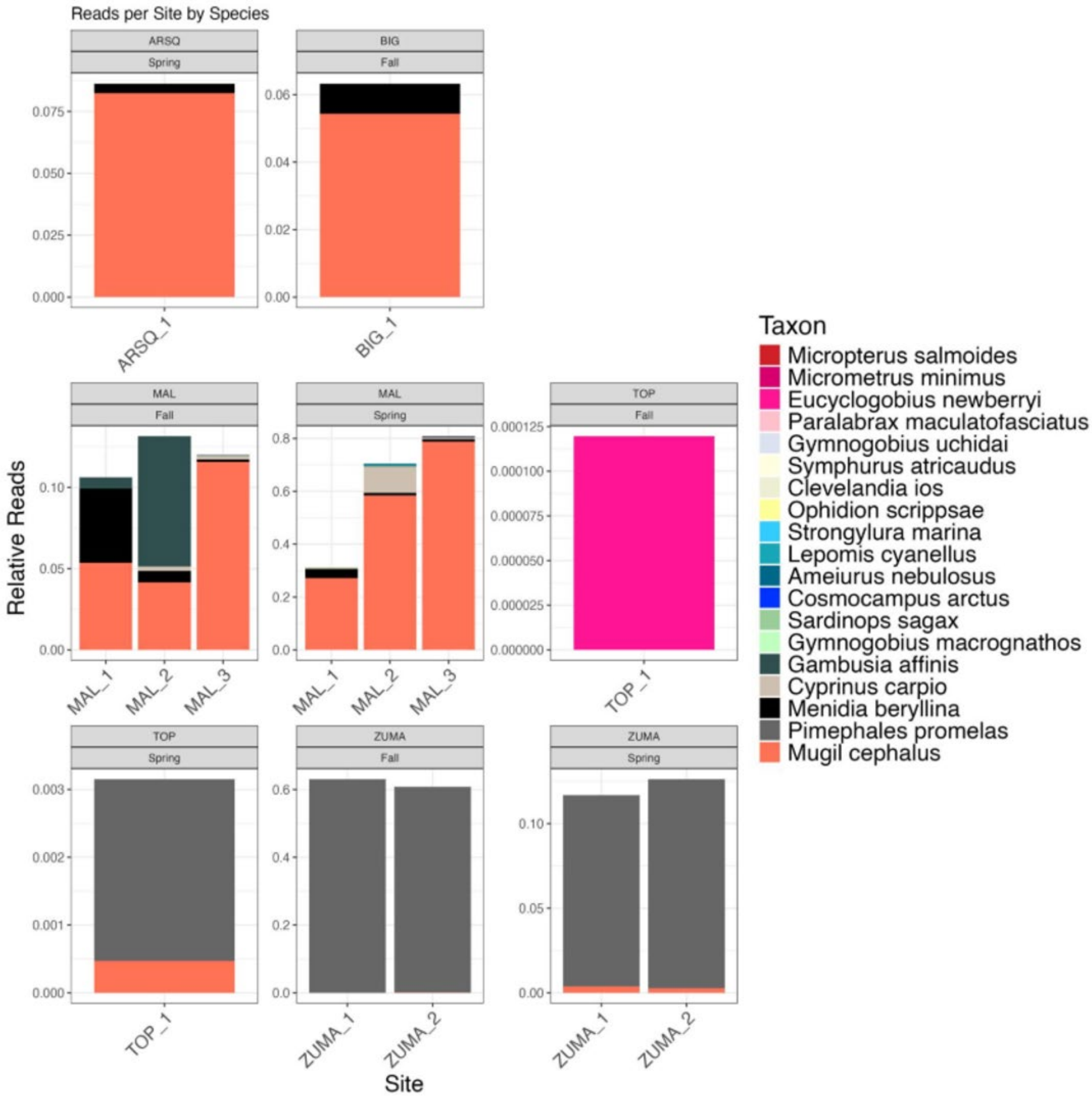

Figure D3. Relative reads of fish species detected using eDNA at each site within each estuary

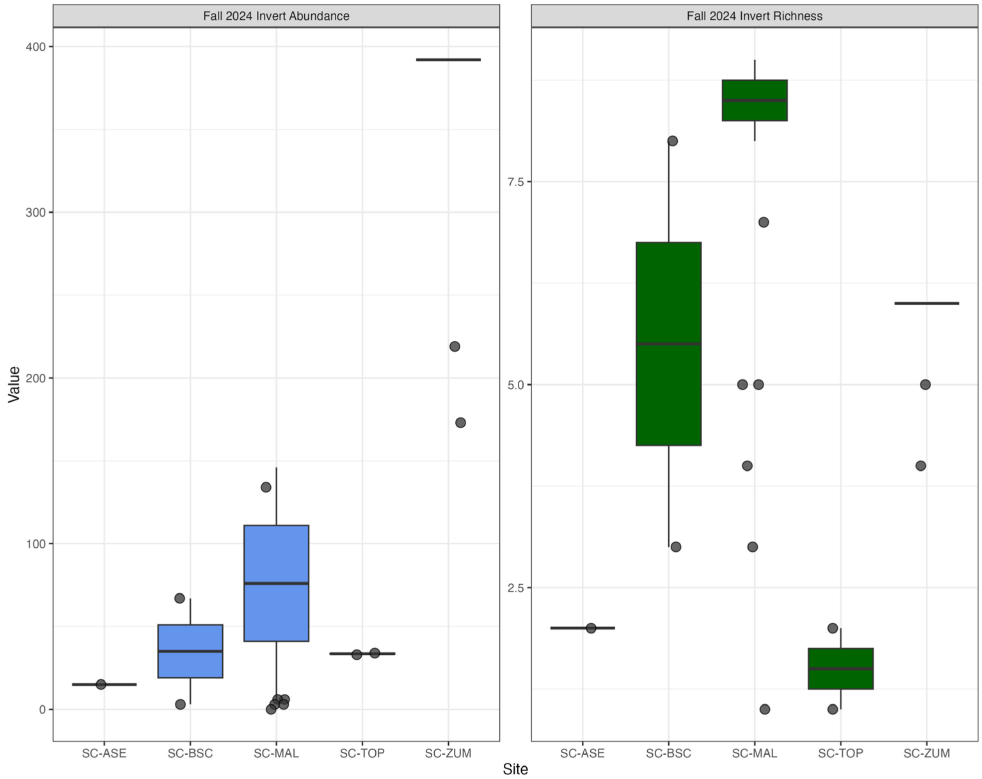

Figure D4. Abundance and richness of benthic invertebrates taken from estuaries during the fall 2024 season.

Birds

Counts of birds seen, heard, or captured are commonly used to answer many research questions including describing avian-habitat relationships, investigating responses of avian populations to management or to environmental stressors, estimating spatial distribution of species, and monitoring population trends. For this study, bird point count surveys were conducted visually using binoculars and spotting scope. At each estuary, survey effort was standardized as 20 minutes per sampling zone. Surveys covered approximately a 100 m area around the sampling zone including the marsh, beach, nearshore, and upland habitats. Bird abundance by species was assessed during these surveys and in the event high density, mixed species flocks, abundances were estimated using standardized flock estimation methods. Due to seasonal variation in bird assemblages, estuaries were sampled in Spring (April and May) and Fall (October and November). During these seasons, 1 to 3 surveys were conducted on different sampling days, in different months if conditions permit. Replicates of bird counts were averaged across survey replicates to produce an average abundance and species richness by season for each estuary.

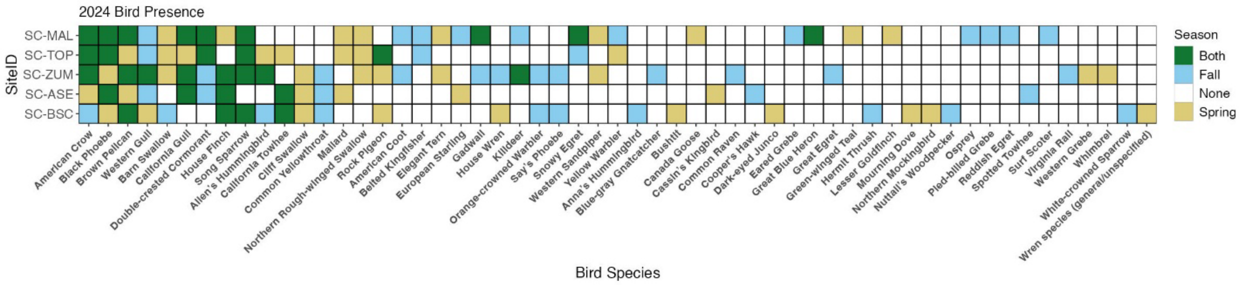

Figure D5. Heatmap of birds sighted at each estuary across both spring and fall seasons.

CRAM

The California Rapid Assessment Method (CRAM) is an established level 2 (rapid) assessment method in California (https://www.cramwetlands.org). It is a cost-effective and scientifically defensible tool for monitoring the conditions of wetlands and is designed for assessing ambient conditions within watersheds, regions, and throughout the State. The overall CRAM index score is composed of four attribute scores: physical, hydrology, buffer and landscape, and biotic. Specifically, the physical structure attribute consists of two metrics - structural patch richness and topographic complexity. The hydrology attribute consists of three metrics – water source, hydroperiod, and hydrologic connectivity. The buffer and landscape context attribute consists of two encompassing metrics – aquatic area abundance and buffer condition. The biotic attribute score consists of three metrics - plant community composition, horizontal interspersion, and vertical biotic structure. We used CRAM scores from the 2022 assessment. All available data can be downloaded from EcoAtlas.org.

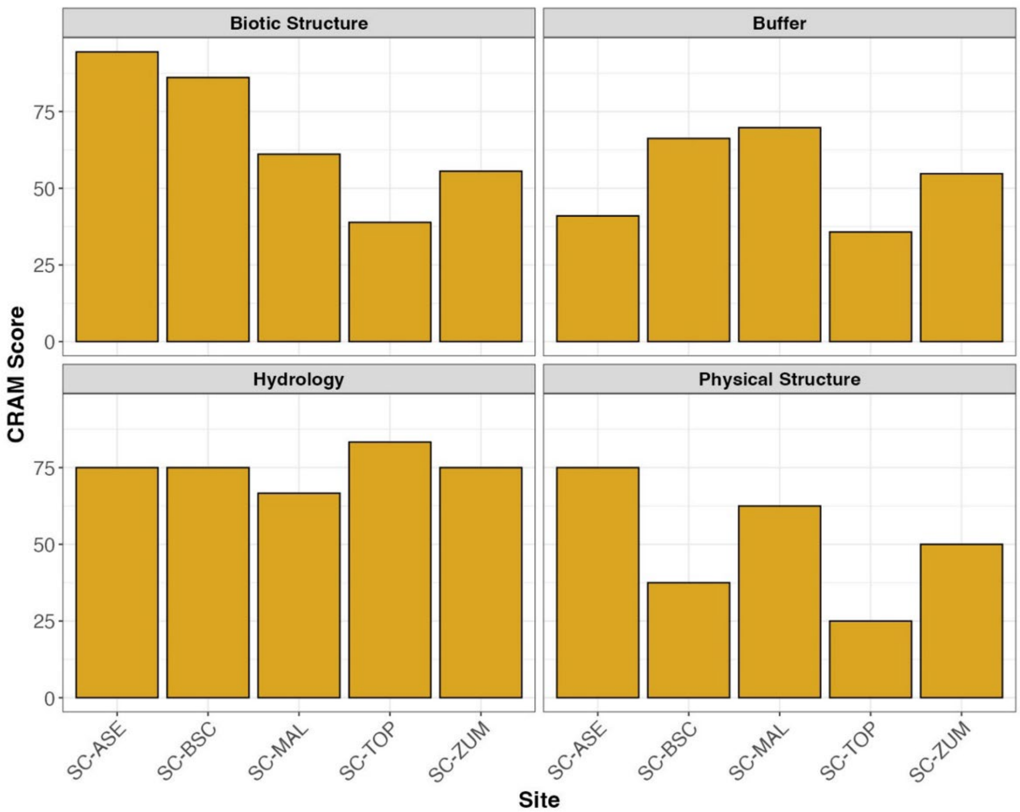

Figure D6. CRAM Metric scores measured across five estuaries.

Vegetation

The habitat was assessed at each sampling station with one to seven transects run across tidal elevations from the start of the low marsh to the upland transition zone (Table 1). This vegetation data collection served as ground truthing for habitat characteristics representative of each elevation zone identified in GIS landscape analysis (discussed below). Along each transect, a $1m^2$ quadrats was placed at regular intervals (e.g., 5 or 10 meters depending on the length of the transect) to capture as many different vegetation communities as possible. Within each $1m^2$ quadrat, percent cover was recorded for each of several cover types including vegetation, wrack, coarse woody debris, thatch and algae. Percent cover by vegetation species was also recorded along with maximum height of each species. In the case where marsh area was limited (e.g., smaller estuaries), visual surveys were conducted in the assessment area, and a species list was assembled.

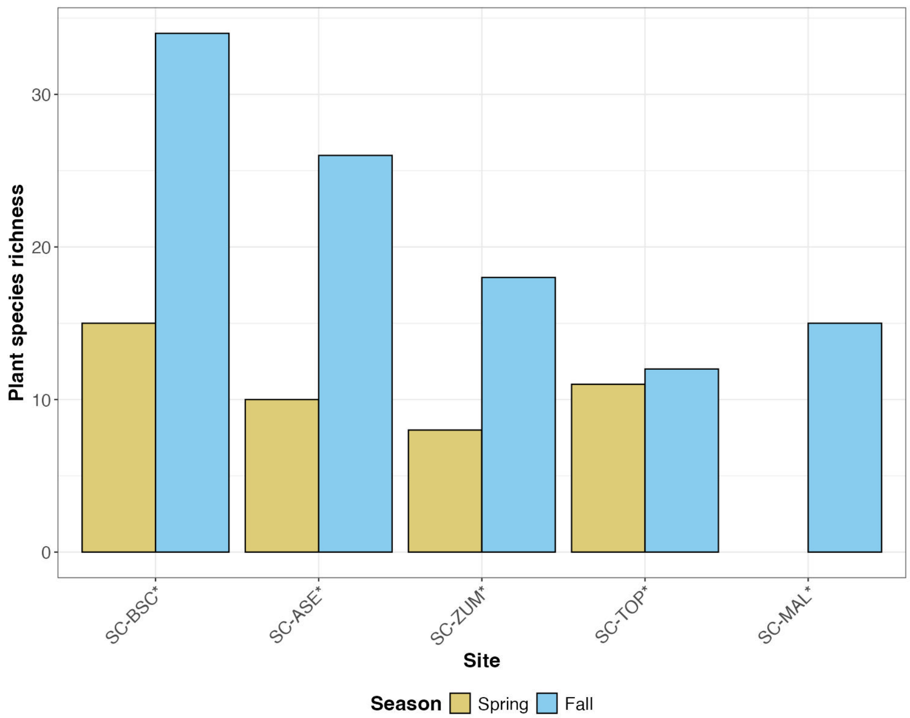

Figure D7. Vegetation species richness measured across five estuaries in both spring and fall.

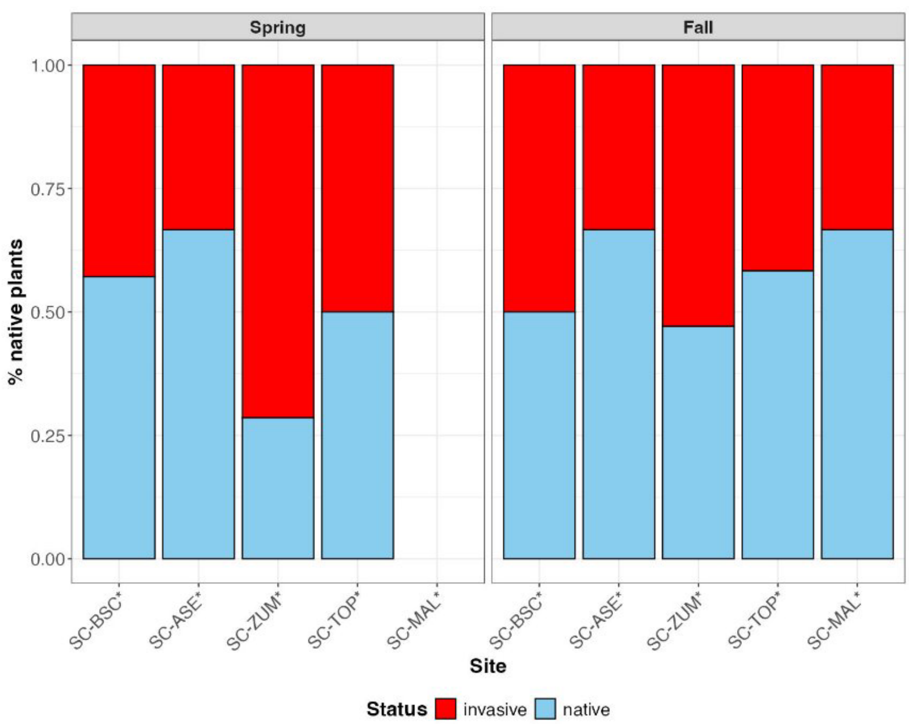

Figure D8. Percent non-native plant species measured across five estuaries in both spring and fall.

Macroalgae

Field methods for macroalgae surveys adapted from McLaughlin et al. (2019). Three transects per station were established along the shore with one transect near the emergent vegetation, another transect between the vegetation and MLLW, and below the MLLW (if the intertidal zone was large enough). Quadrats, placed every 5 m, were evaluated for percent cover of total macroalgae as well as percent cover by macroalgae species (if possible). In addition, the percent floating macroalgae was described in a 100 m section of the main channel for each estuary (if water was present).

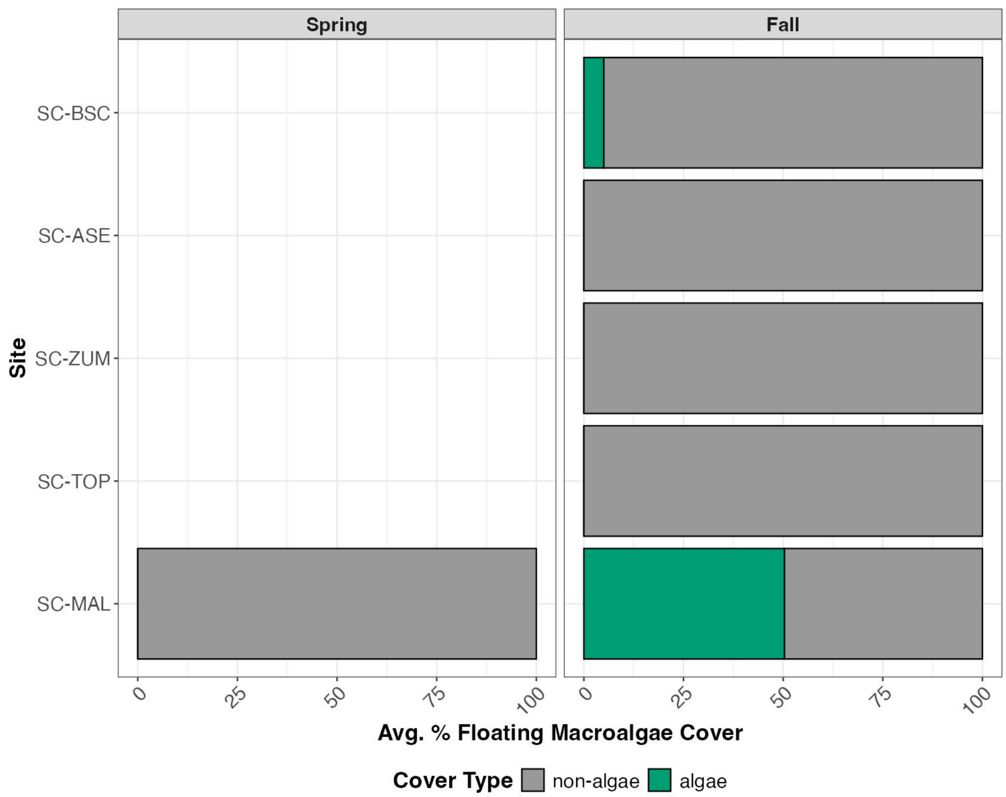

Figure D9. Average percent floating macroalgae cover estimated in five estuaries in fall, and in one season at Malibu Lagoon.

Sediment parameters (TOC/TN)

Grain size and organic matter are important features to measure because they are proxies for flow and settling rate within estuaries. Larger grain sizes and lower organic matter correlate with higher flow, whereas smaller grain sizes and higher organic matter are easier to move and correlate with lower flow (Christiansen et al. 2000). Combined with TOC/TN ratio, these parameters can differentiate sediment sources (e.g., terrestrial sources versus marine sources). Higher ratios can suggest a greater contribution of terrestrial organic matter (e.g., cellulose, lignin) compared to marine organic matter (e.g., proteins) (Pardo et al. 2023). Past and future sediment samples are from the top 6 cm of the marsh surface at each sampling location. These samples were/will be returned to the laboratory and frozen until analysis. Total organic carbon (TOC) and total nitrogen (TN) analyses will be performed on dried and homogenized samples using an elemental analyzer, in which samples are combusted and separated by gas chromatography (e.g., SCCWRP Bight 2016). Grain-size will be determined in-lab using a hydrometer following dilution in 5% dispersion solution (sodium hexametaphosphate dissolved in deionized water and diluted to 1 liter) and subsequent measuring over time to determine percent clay, silt and sand within each sample (Bouyoucos 1962). Organic matter will be determined by calculating percent organic matter per sediment core from values determined through net weight loss upon ignition. QA/QC procedures will be followed as outlined in OPC 2022.

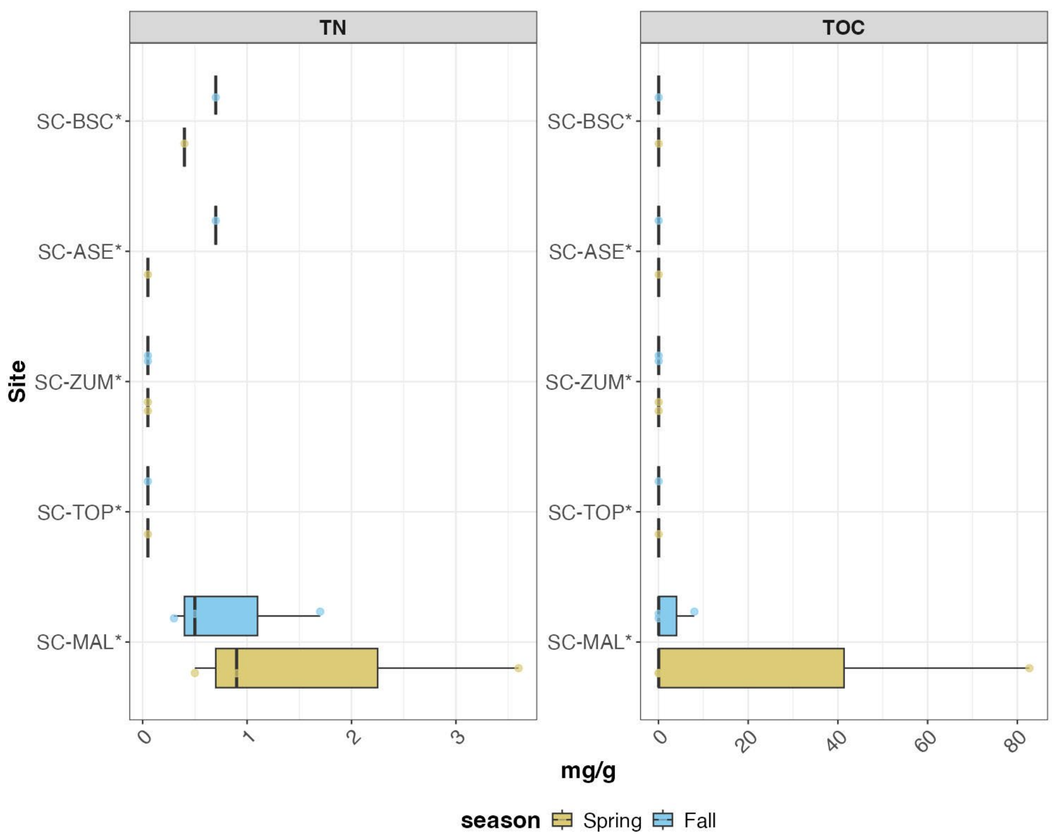

Figure D10. Average Total Organic Carbon (TOC) and Total Nitrogen (TN) measured in sediment at five estuaries in spring and fall.

Continuous water quality parameter monitoring

The use of estuaries by nekton, as well as other organisms, is influenced by various environmental factors such as water temperature, dissolved oxygen (DO), and salinity. Thus, tracking and measuring general water quality conditions of an estuary is extremely important in understanding how a particular system may support nekton habitat. The EMPA program deploys multi-instrument arrays in the main channels of the EMPA estuaries to measure temperature, salinity, dissolved oxygen (DO), and pressure (water level).

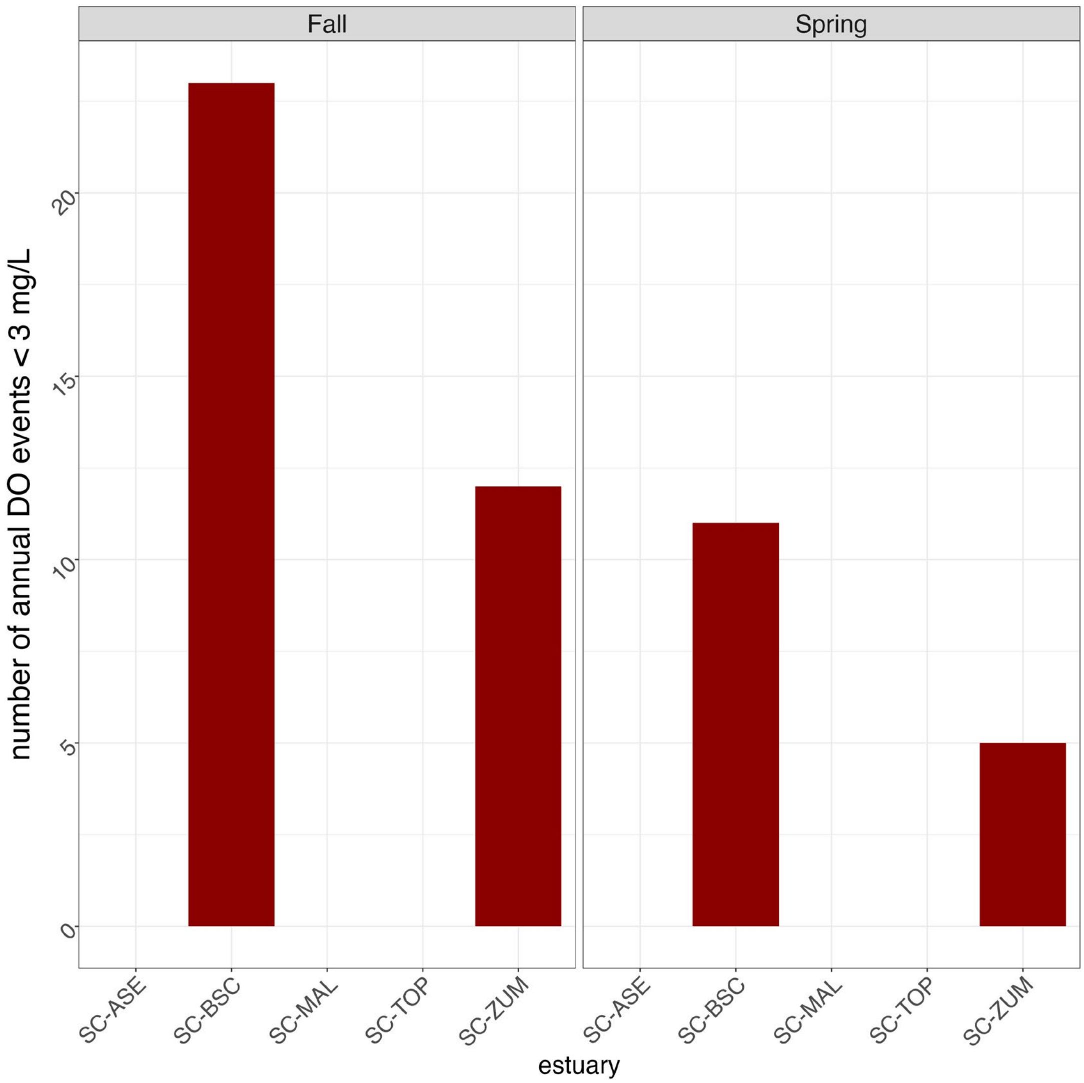

Figure D11. Average annual low dissolved oxygen (DO < 3 mg/L) events. Average temperature for all estuaries was less than 25°C, except for Zuma Lagoon, which experienced temperatures over 25°C for 5% of the time during 2024.