Estuary Marine Protected Area
2023 Data Analysis Report

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EMPA
Monitoring Program

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COUNCIL

Primary Authors and Organizations

Kevin O'Connor	Central Coast Wetlands Group, Moss Landing Marine Labs
Brooke Fulkerson	Central Coast Wetlands Group, Moss Landing Marine Labs
Jan Walker	Southern California Coastal Water Research Project
Eric Stein	Southern California Coastal Water Research Project
Christine Whitcraft	California State University, Long Beach
Joel Huckeba	Sonoma State University

Contributing Authors and Organizations

Sarah Stoner-Duncan	Central Coast Wetlands Group, Moss Landing Marine Labs
Brent Hughes	Sonoma State University
David Jacobs	University of California, Los Angeles
Mira Abrecht	University of California, Los Angeles
John Largier	University of California, Davis, Bodega Marine Laboratory
Christina Toms	San Francisco Bay Regional Water Quality Control Board

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If you have questions contact:

Kevin O'Connor: kevin.oconnor@sjsu.edu

Jan Walker: janw@sccwrp.org

Program website:

https://empa.sccwrp.org

Executive Summary

The Estuary Marine Protected Area (EMPA) Monitoring Program was established with the overall goal to establish a monitoring framework to determine the health of estuaries in California and the efficacy of MPA designation in estuaries. Program development includes:

1. An overall monitoring approach
2. A set of monitoring protocols and standard operating procedures
3. A data management system that includes data templates, quality control checkers and a portal for accessing data and monitoring materials/information
4. Initial data collection at 16 estuaries distributed across the state
5. A sample data report that provides preliminary data analysis and provides recommendations for how data should be analyzed and presented in the future
6. An implementation blueprint that recommends approaches for supporting long-term implementation of the EMPA Monitoring Program.

With the completion of this report, all six elements of the EMPA are now available. Together, they provide the tools necessary for ongoing monitoring of California's estuaries with a structure that will provide the readily accessible information necessary to support management decisions at the state, regional and local levels. Examples include:

- *Statewide* – evaluation of the efficacy of the EMPA program and tracking progress toward achieving 30x30 goals for coastal wetlands
- *Regional* – providing information to help track performance of regional programs and develop regionally appropriate success criteria, serving as a platform for incorporation of traditional knowledge and practices
- *Local* - improving the ability to share information across local programs, providing standardized protocols and data approaches, supporting community-based monitoring programs

This report provides a summary of the initial monitoring efforts at 16 estuaries across the state of California. This demonstration of the application and utility of the EMPA program provides a foundation for the continued monitoring necessary to answer questions about estuary condition, stress and trends. It also provides examples that can be used by other agencies and organizations wanting to leverage this effort to address their specific management needs.

The EMPA monitoring framework assesses structural features (elements) that represent key ecological functions versus focusing on a single type of flora or fauna. This focus on function allows the framework to accommodate different estuary types and assimilate data from diverse existing monitoring programs, while maintaining underlying comparability.

In the fall of 2023, the project team implemented the monitoring framework across three geographic regions and sixteen estuaries (11 MPAs and 5 Non-MPAs) (Figure ES 1). Depending on the size of the system, one to three monitoring stations were sampled at each estuary. Placement of each station within an estuary was aimed at documenting the range of estuarine ecological functions present and landscape features that support them. Each assessment took approximately three days to complete with a team of 4 to 6 people. For this report, regional teams successfully collected one season of data needed to compile descriptive information about each individual site and allow for an initial comparison of estuaries across broad latitudinal gradients, by region and between those with perennial open mouth connection to the ocean and those experiencing seasonal mouth closure (which can affect function).

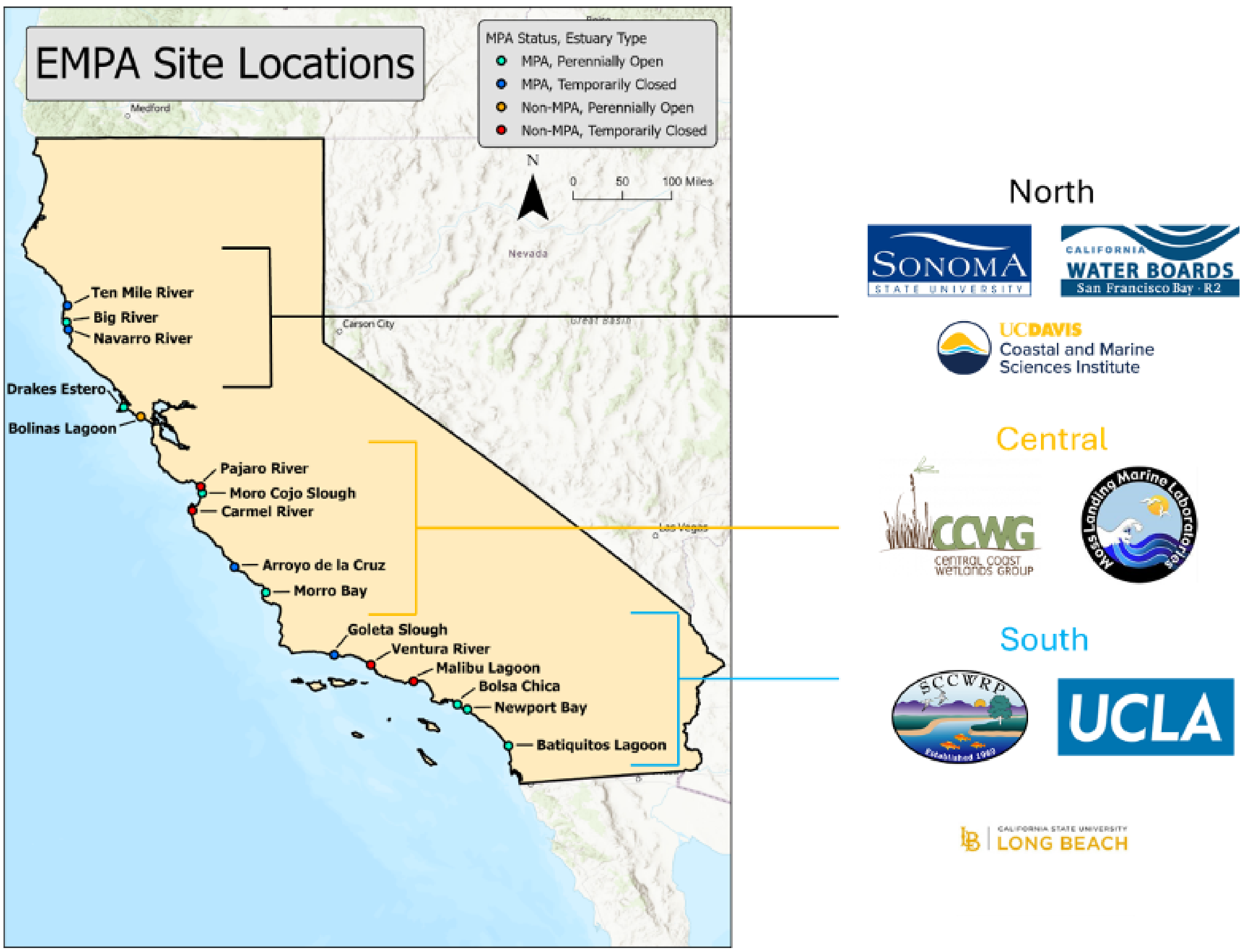

Figure ES 1. Map of EMPA monitoring sites and associated monitoring teams for each region of the state.

Of the nine core estuary functions, we demonstrated the analytical process for four functions: Support of Vascular Plant Communities, Sea Level Rise Amelioration and Resiliency, Nekton Habitat, and Secondary Production. Each function was assessed via a series of condition statements that were analyzed using indicator data collected by the monitoring program. Each condition statement output (i.e., data interpretation) was binned into tertials and given a score of 1, 2, or 3. A score of 3 is considered high condition, while a score of 1 is considered low condition. The scores for each condition are then averaged for each estuary to give a final function score. Binning data into tertials and averaging scores allows the comparison of estuaries relative to one another or relative to regional sentinel sites. This does not produce an absolute score for each estuary (i.e., whether or not the estuary is in 'good' or 'bad' condition), which will require collection of data for a longer period of time. All results are based on data collected from a single year and should be interpreted with caution and tested as further data are collected. Given the inherently dynamic nature of estuaries, it will be necessary to continue data collection for up to ten years before definitive conclusions can be drawn about differences based on level of stress, management actions and trajectories over time.

For the Support of Vascular Plant Communities and Sea Level Rise Amelioration and Resiliency functions, we were able to conduct a complete functional assessment. For the Nekton Habitat and Secondary Production functions, we were only able to analyze a portion of the condition statements; additional data is necessary to calculate overall function results.

For the Support of Vascular Plant Communities function, larger and/or more remote estuaries (Ten Mile, Big River, Carmel) scored higher than estuaries that are managed open and/or in close proximity to stressors (Moro Cojo Slough, Goleta Slough, Ventura River). Additionally, the north coast estuaries overall scored higher than central and south coast estuaries, most likely due to increased stressors, adjacent development (urban and agriculture), and mouth management in the southern regions (Figure ES 2).

Figure ES 2. Statewide map of EMPA sites and their final score categories for Emergent Vascular Plant Support.

For the Sea Level Rise Amelioration and Resiliency function, the larger marsh plain estuaries as well as the less urban estuaries scored highest for this indicator (Figure ES 3).

Figure ES 3. Statewide map of EMPA sites and their final score categories for Sea Level Rise Amelioration and Resiliency.

For the Nekton Habitat function several condition statements were evaluated (vs. the overall function). In general, abiotic conditions are within expected ranges across the EMPA sites. Event-driven changes in temperature, dissolved oxygen (DO), and salinity occur regularly within the temporarily closed estuaries and have corresponding effects on fish communities. Benthic infauna and fish, across a range of taxonomic and functional groups, are present in high abundances in most estuaries and appear to match expected communities. Fish habitat complexity was higher in larger and more intact estuaries than those with limited size, highly urbanized watersheds, and/or fragmented landscape. None of the sites exceeded the threshold of 70% floating or intertidal macroalgae cover that indicates ecosystem impairment.

For the Secondary Production function, where data are available, abiotic conditions are within expected ranges within the EMPA estuaries. Unlike with the Nekton Function, fewer published ranges exist for decomposing communities. However, in southern CA, it is most likely that an estuary will exceed temperature thresholds as compared to central and north regions (due to a latitudinal effect). Event-driven changes in temperature, DO and salinity occur regularly within the temporarily closed estuaries and have corresponding effects on decomposer communities. There was insufficient data to produce overall function scores for this function.

This data report represents a first step in realizing the long-term benefits of the EMPA Monitoring Program. The framework is intended to be modified and expanded over time as information needs shift, new monitoring programs and partners come online, and monitoring methods are iteratively improved. Over the next few years, as resources allow, we recommend the following improvements and enhancements be considered.

Commitment to long-term mapping and monitoring

- More extensive follow-up assessments over time will improve our ability to evaluate functions and understand relationships between function, stress, and management actions.
- Long-term investment and funding for time-series water level and water quality collection and data management infrastructure is critical to fully realize estuarine assessment and how it varies over multiple time scales.
- Consistent statewide mapping, including use of remote sensing, which tracks the extent and distribution of estuarine resources, is critical in tracking trends, prioritizing management actions, and serving inputs to assessment.

Ensuring support for training and enhancement of protocols

- Regular team intercalibration is critical for consistent, high quality data collection across regions and partners.
- Standard Operating Procedures (SOPs) may have to be adjusted based on mouth state (open vs closed), especially for systems with extreme inundation. Remote sensing tools to track estuary mouth state, extent over time, and other habitat metrics should be considered for future use in assessments.
- eDNA is an effective tool to track species composition over time, however method improvement is needed.

Exploring new partnerships to enhance data collection

- Birds and megafauna represent a critical ecological indicator for habitat quality and are of management concern. Partnerships should be pursued with existing programs focused on these taxa to better understand relationships between estuary function and the support of birds and megafauna.
- The EMPA program should develop community science protocols to expand outreach efforts and leverage public participation in monitoring.

Enhancing outreach and communication

- Report cards and dashboards should be developed in tandem with managers and the California Estuary Monitoring Workgroup to generate easy to use interpretive frameworks.
- The EMPA Monitoring Program should enhance partnerships with other ongoing regional monitoring efforts and leverage these programs to help answer management questions.
- Coordinated outreach with local communities and stakeholders will build awareness of the EMPA Monitoring Program and promote the application of the tools, resources and data to support local activities and improve understanding and appreciation of California's estuaries.

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List of Acronyms

NC-TEN - Ten Mile River

NC-BIGR - Big River

NC-NAV - Navarro River

NC-BOL - Bolinas Lagoon

NC-DRA - Drakes Estero

CC-PAJ - Pajaro River Lagoon

CC-MCS - Moro Cojo Slough

CC-SAL - Salinas River Lagoon

CC-MOR - Morro Bay Estuary

CC-CAR - Carmel River Estuary

CC-ADLC - Arroyo de la Cruz

CC-ELK - Elkhorn Slough

SC-GOL - Goleta Slough

SC-VEN - Ventura River

SC-MAL - Malibu Lagoon

SC-NEW - Newport Bay

SC-BAT - Batiquitos Lagoon

NEP - National Estuary Program

NERR - National Estuarine Research Reserve

EPA - Environmental Protection Agency

NPS - National Park Service

PO - Perennially Open estuary

TC - Temporarily Closed estuary

USGS - United States Geological Survey

CDFW - California Department of Fish and Wildlife

EMPA- Estuary Marine Protected Area

SOP- Standard Operating Procedure

Introduction

California's Estuary Marine Protected Area (EMPA) Monitoring Program aims to provide data necessary to answer critical statewide management questions about both MPA and non-MPA estuaries. To accomplish this, OPC and its technical team (working with a statewide Management Advisory Committee or MAC) have developed an integrated monitoring framework, sampling design, standard protocols, and data management tools to facilitate collection, integration, and dissemination of data in a consistent and accessible manner.

The EMPA Monitoring Program was established with the overall goal to establish a monitoring framework, including data collection, analysis, synthesis, and reporting to determine the health of estuaries in California and the efficacy of MPA designation in estuaries. A key element of the program was the development of a standardized monitoring protocol that can be used not only by the MPA program, but by any program aimed at assessing estuary function, condition, or health to provide data that can be easily compared across systems and between programs. The program had three overarching programmatic goals:

1. Monitor estuaries with a standard, comprehensive function-based assessment to determine the health of California's estuaries and the efficacy of MPA designation
2. Create an assessment framework that is modular, flexible, and adaptable to accommodate different programmatic needs and heterogenous landscapes
3. Develop an integrated, user-friendly data management system to increase transparency, accessibility, and quality control in data collection, upload, and publication

A monitoring manual and associated website[1] provide details and documentation of the scientific basis and the tools necessary to implement the monitoring program. The technical team has also produced an Implementation Blueprint[2] focusing on the elements necessary to sustain long-term implementation of the monitoring program, to illustrate how data collected through the monitoring program can be used to answer scientific and management questions about estuary health and stress, and how that information can inform management decisions.

This document focuses on how data collected through the monitoring program can be used to answer scientific and management questions about estuary health and stress, and how that information can inform management decisions. This data report describes the monitoring implementation, a summary of the sampling effort, a sample of function-based data analysis and interpretation, lessons learned from the second year of data collection (2023), and an inventory and characterization of the study sites (Appendix A: Inventory and Characterization of Studied Sites). It's important to note that this data report serves as a potential analysis framework for evaluating ecosystem function. All results and data represent a single year of data and should be interpreted with caution until additional years of data are collected.

[1] https://empa.sccwrp.org/

[2] https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/implementation_blueprint.pdf

Monitoring Program Importance and Goals

Estuaries are one of the most productive ecosystems, supporting essential biodiversity, and exhibiting prominent ecological services. At the interface of marine, freshwater, and terrestrial realms, estuaries provide important habitat to a diversity of resident and migratory species. Estuaries provide services such as food provisioning, sediment transport buffering, water purification, carbon storage, buffering against sea level rise and storm surge, recreation, and aesthetic values. Yet, 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. Estuaries are also influenced by stressors from the ocean, including fishing pressures, climate change, ocean acidification and sea level rise. Because of these ongoing risks to estuaries, there is a need to conserve and enhance existing ecosystem functions and restore lost values. Such actions should be informed by data on the condition/health of estuaries, the primary stressors affecting condition, and trajectories over time. A primary goal of the EMPA monitoring program is to provide this data via a statewide monitoring framework that documents the range of existing ecosystem functions and tracks changes driven by management decisions, local and regional stressors, and climatic patterns.

The purpose of this assessment framework is to develop a standardized approach to monitor and assess key functions of estuarine ecosystems to answer scientific and management questions. To be effective, this framework should account for the inherent differences in estuarine structure and form while still enabling meaningful comparisons of health and condition within individual estuaries.

The EMPA framework is designed to:

1. Assess baseline conditions and subsequent trends of key indicators (habitat condition, invasive species, special-status species)
2. Assess factors that affect condition (estuary designation (level of protection), recreation, watershed urbanization, climate change)
3. Develop information to support nature-based adaptation, mouth/inlet management, habitat restoration, migration of habitats, and infrastructure realignment
4. Identify appropriate reference or comparator locations for estuaries
5. Provide information that can be used to relate estuary function to adjacent offshore function

Framework and Approach

A key element of the monitoring framework is the development of standardized monitoring protocols that can be used not only by the MPA program, but also by any program aimed at assessing estuary function, condition, or health to provide data that can be easily compared across systems and between programs. A fundamental aspect of this program is a focus on structural features (elements) that represent ecological functions versus a single type of flora or fauna. This focus on function allows the framework to accommodate different estuary types and assimilate data from diverse existing monitoring programs, while maintaining underlying comparability. To assess functional performance, we have developed standard protocols to measure vital ecosystem features across different estuaries, coupled with standard data templates and guidance on analysis, synthesis, and reporting, focused on four guiding principles – flexibility, comparability, interpretability, and practicality.

1. **Flexibility: Assessing estuarine condition using a function-based approach**

Focusing an assessment framework on ecological functions allows for the creation of linkages between assessment results and ecological services, and designated beneficial uses for each estuary. Furthermore, an assessment framework built to evaluate ecological functions (Box 1) will have greater flexibility of application within a highly heterogeneous state, like California. The species of plants and animals that are the components of and are used as indicators of ecological functions may change between regions of the state (north, central, south) and estuarine types, but the focal estuarine functions should remain constant. Flexibility of the function-based approach will ultimately allow for comparative assessment across estuary types, while accounting for regional differences and anthropogenic impacts. This will ultimately allow for assessment of management actions and protected area designations.

2. **Comparability: Characterizing systems by geomorphic features**

California is a large state with a considerable diversity of coastal wetlands and estuaries, ranging from large seismic fault estuaries like Tomales Bay to small ephemeral bar-built estuaries like San Mateo Creek Lagoon. Different types of estuaries have different hydrodynamics (tidal inundation, freshwater inputs, and density-driven estuarine circulation) and consequently support different types of flora and fauna. While each system is unique, there are underlying environmental similarities in watershed size, morphology, and mouth dynamics among estuaries that influence their resident biota and allow them to be grouped together into different typologies. Classifying estuaries by geomorphic forms (embayments/bays, riverine, lagoons, etc.) and focusing on key landscape features (mudflats, marsh, subtidal channels, etc.), allows users to make comparisons across systems.

3. **Interpretability: Concentrating sampling in given areas rather than diffusely across the site**

Regional differences in annual precipitation, watershed and coastal geology, and land use drive tremendous variability in estuarine conditions and functions. To capture seasonal and interannual variation among and within estuaries, the assessment framework's sampling protocols concentrate multiple measurements around sampling zones or stations. Users establish several permanent sampling zones within their sites to concentrate multiple sampling methods (i.e., cluster sampling) in a given area and have the ability to resample the selected areas. Concentrating multiple measures within an area enhances our ability to interpret data and understand interactions.

4. **Practicality: Accomplishing sampling within three days**

To increase the feasibility of this sampling protocol, we have limited data collection to what can be reasonably accomplished in a three-day sampling campaign. A three-day campaign should reduce personnel costs and allow users to implement the protocol across multiple sites.

A function-based assessment strategy is used to assess the condition of each estuary, integrating multiple indicators to quantify each ecological function. Given the ecological and hydrological complexity of estuaries, there are a vast number of potential indicators one could use to evaluate the health and condition of estuaries. However, the modular nature of the framework allows users to adjust the choice of functions and indicators based on program needs or management objectives.

The backbone of the program is the identification of priority ecological functions to monitor. We define ecosystem function as a natural process or set of processes that occur within an ecosystem, contributing to the maintenance and sustainability of that system. These functions include the physical, chemical, and biological interactions that enable ecosystems to sustain life, cycle nutrients, regulate climate, and provide essential services to living organisms (Braat & de Groot 2012). We recommend nine priority ecological functions to begin with, however functions can be added based on program needs and management questions (see EMPA Technical Memo[3]). The underlying principle is that all estuaries should provide a variety of ecological functions at some ideal rate in the absence of anthropogenic disturbance and alteration. These priority ecological functions were selected to present a mix of true ecological functions (processes with limited direct society value) as well as ecosystem services (processes with direct, often commodifiable, society value; Table 1).

Table 1. Priority estuarine ecological functions with a brief definition of each function.

Function	Definition
Nekton Habitat Provision	Support for a variety of resident and transitory fishes and crustaceans by providing appropriate water quality, habitat diversity and food sources.
Primary Production	Production of organic material from carbon input to the system that supports development of diverse microbial, algal, and macrophyte (plant) communities.
Secondary Production	Transformation of allochthonous and autochthonous organic matter into meiofauna and macrofauna, which in turn are consumed by the resident nekton of the estuary or are exported out to the nearshore coastal zone.
Nutrient Cycling	Processing of nitrogen, phosphorous, and carbon from their elemental or detrital forms to support primary production by algae and vascular plants. Nutrient cycling is often high in estuaries because of high inputs, density/tidally driven estuarine circulation patterns, and geomorphology.
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.
Bird Habitat Provision	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).
Shellfish Support	Provision of habitat for establishment and growth of shellfish. Estuaries are obligate habitats for a variety of societally, economically, and ecologically important shellfish species that rely on the basin morphology, mesohaline/oligohaline salinities, reduced competition and predation from invasive species, and large amounts of primary production only available in estuaries.
Nursery Habitat	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.

[3] https://empa.sccwrp.org/pages/technical-reports-and-memos

Function	Definition
Support of 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.

Each function can be evaluated by one or more indicators providing flexibility to use indicators appropriate for the specific estuary, while still allowing the standard set of functions to be evaluated (Table 2). Functions are linked to the field indicators that are used to assess the function, represented in a matrix. Shaded green boxes indicate which indicators correspond to each function. The matrix indicates that each indicator can support multiple functions and each function can be assessed by a combination of indicators.

Table 2. A function-based assessment is 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.

		Indicators													Level 1
		Water quality (DO, temp, salinity)	Sed. nutrient conc. (TOC/TN)	General community composition	Sediment characteristics (grainsize)	Benthic infauna community	SAV distribution	Fish community	Mobile Invertebrate community	Marshplain vegetation community	Marshplain elevation and inundation	Sediment accretion	Macroalgae distribution	General habitat condition	Level 1 (see Table 3 below)
Ecosystem Functions	Primary Production	X	X				X			X			X		
	Secondary Production	X	X	X		X	X			X					X
	Nutrient Cycling	X	X		X	X	X			X		X	X		
	Nekton Habitat Provision	X		X		X	X	X	X				X	X	X
	Nursery Habitat Provision	X				X	X	X	X	X	X				X
	Bird Habitat Provision			X		X	X	X	X	X	X		X	X	X
	Shellfish Support	X		X	X	X	X						X		
	Support Vascular Plants									X	X			X	X
	SLR Amelioration									X	X	X		X	X

Table 3. Map-based (Level 1) inventory indicators.

		Level 1 Indicators			
		Adjacent land use	marshplain topography-DEM	Habitat mapping	Marshplain migration potential
Ecosystem Functions	Primary Production				
	Secondary Production			X	
	Nutrient Cycling				
	Nekton Habitat Provision			X	
	Nursery Habitat Provision			X	
	Bird Habitat Provision			X	
	Shellfish Support				
	Support Vascular Plants		X	X	
	SLR Amelioration	X	X		X

To support implementation of the monitoring framework and program, the project team produced a monitoring manual that includes 15 standard operating procedures (SOPs) to ensure consistent data collection. The SOPs are supported by a data portal[4] that includes standard data templates, automated quality control routines, and data query capabilities.

[4] https://empa.sccwrp.org/

Monitoring Implementation

Sampling Site Selection

Different types of estuaries will have different hydrodynamics (tidal inundation, freshwater inputs, and density-driven estuarine circulation) and consequently will exhibit different water chemistry characteristics and support different types of flora and fauna. Latitudinally accentuated variability in hydrogeomorphic dynamics drives seasonal salinity changes within many of the smaller bar-built estuaries that become disconnected from the ocean during low rainfall /calm ocean conditions. Regional differences in annual precipitation, watershed and coastal hydrology and geology, and land use (i.e. urbanization, dams, forestry practices, etc.) also drive tremendous variability in estuarine conditions and functions.

Included within the estuaries of California's MPA network are embayment/bays, riverine estuaries, and lagoonal estuaries (Coastal and Marine Ecological Classification Standard-CMECS)[5]. Embayment/bays (referred to in this document as perennial estuaries) are typically large estuaries with permanently open connections to marine waters, with high proportions of open water relative to other habitat types (e.g., Tomales Bay, Morro Bay, and Newport Bay). Riverine estuaries in wetter portions of the state, such as the extreme North Coast, may be permanently open to the ocean (e.g. the Klamath River Estuary), while further south, these systems often close to the ocean during the driest months of the summer and early fall. Lagoonal estuaries (referred to in this document as bar-built estuaries or temporarily closing estuaries) are typically smaller and shallower than riverine estuaries, and form where smaller coastal watersheds meet the sea. Lagoonal estuaries tend to be separated from the ocean by a wave-built berm (bar), except during periods of high watershed flow and/or wave action (e.g., Navarro River Estuary, Carmel River Estuary, and Malibu Creek Lagoon), or where the lagoon mouth is anthropogenically managed to be permanently open to the ocean (e.g., Batiquitos Lagoon). For the purposes of data analysis and reporting we group the estuaries by mouth condition: perennially open estuaries and temporarily closing estuaries.

The Technical Team generated a set of guidelines/filters[6] to select 15 estuaries from the initial list of 50 MPA and non-MPA (reference) estuaries[7] for inclusion in this study (see Appendix A: Inventory and Characterization of Studied Sites). The list of possible reference[8] (non-MPA) estuaries in California was generated from the MPA Monitoring Action Plan with additional sites added by the EMPA Project Team. The final list of sites for monitoring in the study included 10 MPA estuaries and 5 Reference estuaries, with 5 sites in each region of the state (north, central, south). In fall 2023 a sixth site was added in the southern region of the state (Figure 1).

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[5] Note: there are challenges in the use of CMECS classification for CA systems, especially in SoCal, where some permanently open lagoons are classified as embayment/bays.

[6] https://empa.sccwrp.org/pages/technical-reports-and-memos

[7] 2018 Marine Protected Area Monitoring Action Plan, Appendix C.

[8] "Reference" here is used to describe non-EMPAs. These systems don't necessarily represent "reference" (optimal) conditions for estuaries.

Monitoring Station Selection

The selection of sampling locations within each estuary is critical to increase the comparability of the assessment framework and interpretability of the data across estuaries. Estuaries are composed of a diversity of habitats or landscape features from salt marsh platforms to intertidal channels and subtidal channels to seagrass beds. We recommend establishing sampling stations or zones that encompass a variety of habitat types and therefore monitoring can inform multiple functions.

To select sampling stations, we created a multi-step process to standardize the selection of sampling stations within each estuary. The overarching goal of this process is to develop a standardized process for the placement of sampling stations, which will allow users to identify and prioritize the main landscape features that will allow them to assess ecological functions, given their specific estuary. The degree of replication needed to accurately capture these processes will vary with the size of the sampling area, but also the diversity of habitats contained within it. The purpose of these sampling stations is to pre-determine the areas for focused or concentrated sampling. Depending on the size of the estuary, two to three sampling stations are selected for focused monitoring efforts within each estuary. For more details on the process, see the Estuary MPA Monitoring Protocol (Walker et al. 2023[9]).

Modifications to Stations in 2023

As program implementation continues, slight adjustments might have to be made to the sampling stations due to shifting landscape features or program priorities. During fall 2023 sampling the monitoring stations of the north coast estuaries were adjusted. To accommodate discrepancies between station locations in 2021 and 2023, we aggregated data based on latitude and longitude, rather than station label. For more details, see Appendix B: Modifications to Stations in 2023.

Summary of Sampling Effort in Fall 2023

In fall of 2023, the project team implemented the monitoring framework across three geographic regions and sixteen estuaries (11 MPAs and 5 Non-MPAs) (Figure 1). Sampling took place starting in September and ending in December. The recommended temporal sampling frequency and number of replicates for each method is presented in Table 4. Figure 2 depicts the layout of a typical estuarine monitoring station where the SOPs are implemented. Depending on the size of the system, one to three monitoring stations were sampled at each estuary. Placement of each station within an estuary was aimed to document the range of estuarine ecological functions present and landscape features that support them (as described above). Each assessment took approximately three days to complete with a team of 4 to 6 people. Our regional teams successfully collected one season of data needed to compile descriptive information about each individual site.

[9] https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/monitoring_manual.pdf

Figure 1. Map of EMPA monitoring sites and associated monitoring teams for each region of the state.

Table 4. Suggested temporal sampling frequency and number of replicates for each sample method.

SOP	Method	Replication per estuary	Continuous	Monthly	Seasonal	Annual	Periodic
SOP 1: Continuous monitoring	VanEssen CTD-Driver with the PME MiniDot	1-2	x				
	Rugged Troll	1	x				
SOP 2: Discrete monitoring – Point water quality measurements	YSI	6-8		X	x		
SOP 3: Water and sediment quality – nutrient concentrations	Freshwater nutrient replicates + Field Blank (FB)	1			x		
	Estuary ambient nutrient replicates + FB	3			x		
	Sediment nutrient samples	6			x		
SOP 4: eDNA	eDNA water samples	9			x	x	
	eDNA surface sediment samples	9			x	x	
	eDNA benthic core sediment samples	9			x	x	
SOP 5: Sediment grain size	Sediment grain size core	9				x	
SOP 6: Benthic invertebrates - small	Intertidal benthic core	9			x	x	
SOP 6: Benthic invertebrates - large	Subtidal benthic core	9			x	x	
	Intertidal benthic core	9			x	x	
SOP 7: SAV & macroalgal surveys	Transects	Dependent on # of beds		X	x		
SOP 8: Fish	BRUV	3-6		X	x		
SOP 9: Fish	Seines	15		X	x		
SOP 10: Crab traps	Shrimp pots	3			x	X	
	Minnow traps (floating and bottom)	6			x	X	
SOP 11: Marshplain vegetation surveys	Transects (2 per monitoring station)	Minimum 6				X	
SOP 12: Topographic surveys	GPS	Varies					x
SOP 13: Sediment accretion rates	Feldspar	9					x
SOP 14: Trash and Microplastics	Transects	3				x	
CRAM	CRAM	Depends on estuary size					x

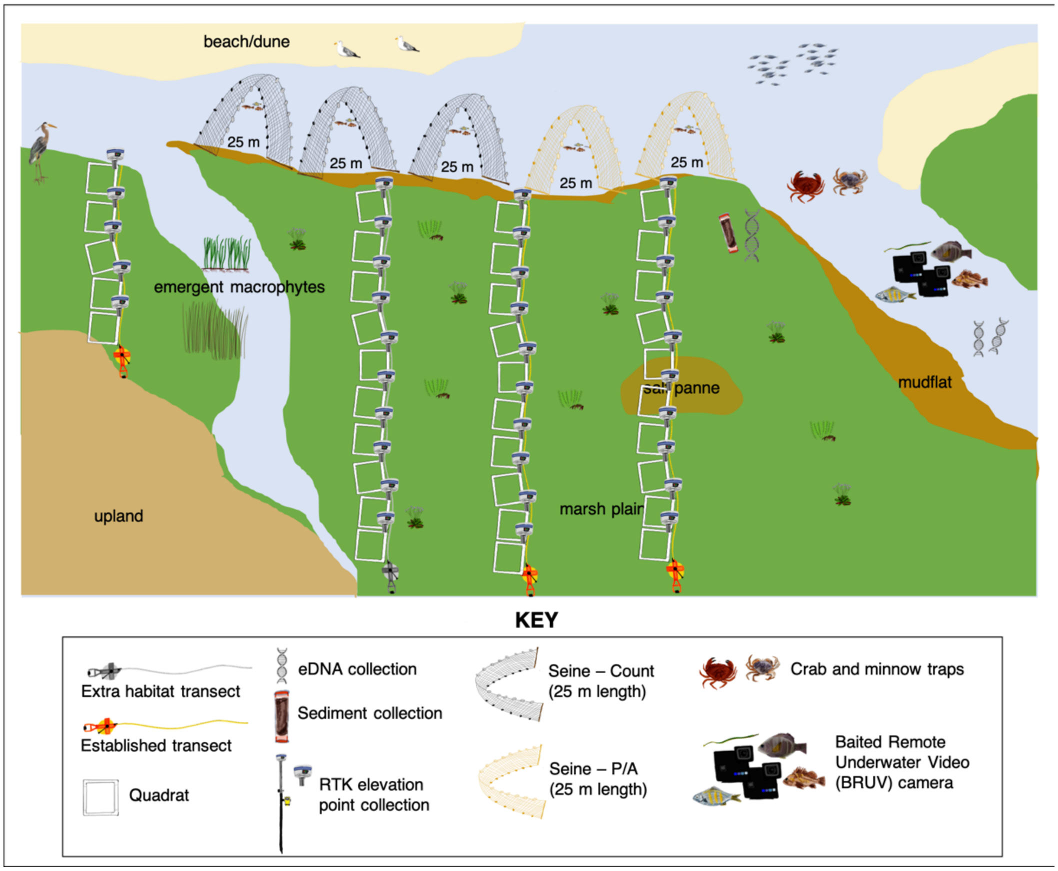

Figure 2. Depiction of a typical monitoring station layout within an estuary. Icons, shapes and colored lines represent each of the SOPs.

Summary of Data QA, Entry and Submission

The EMPA program is a cooperative, integrated state and regional monitoring program with many participating agencies. Because of the diversity in agencies generating data, information management (IM) plays a vital and fundamental role. These data generators need to collate program data in a common data set that is robust and flexible enough to include all data types, but rigorous enough to ensure data quality and integrity. To accomplish this, the EMPA program utilizes standardized data transfer formats (SDTF) to upload data to a common database using the EMPA data portal[10].

The EMPA IM strategy is to maintain a high level of data quality assurance and quality control from field collection through laboratory analysis to data submission and subsequent data analysis.

To this end, the program has worked to improve IM by providing updated MS Excel templates for all SOPs, as well as including data checks in the data portal to ensure the final dataset is complete and of the highest quality. Data checkers include: logic checks, completeness checks, range checks, syntax checks, duplicate checks, qualifier checks, checks for calculated parameters, and QA/QC checks. Program

[10] https://empa.sccwrp.org

participants input their data into the Excel templates and submit them through the EMPA data portal. All files run through the appropriate data checkers. If a file fails one of the data checks, the error is highlighted on the Excel form with a note on how to correct the error. Once all errors have been corrected, the file can be re-uploaded through the checkers (which should now be satisfied) and into the database. This process should expedite the data submittal process, allowing for more rapid access to the final dataset.

Over the last three years of program implementation, SCCWRP has provided training sessions on how to use the Excel templates and the data portal. These sessions demonstrate the data submission process and allow users hands-on experience in using the data portal before submitting their data. Trainings will continue to be updated as improvements are made to the data portal.

In a large, multi-agency program, a data policy is necessary for how and when data becomes accessible. The EMPA database is currently a public database. Therefore, once data is submitted into the portal, it becomes readily available and searchable. We recommend using the query tool for ease in data access.

Data is served up in two ways:

1. Individual datatype retrieval[11]
2. Query tool[12]: Categorical search spanning multiple datatypes

Data is available upon immediate submission, except logger data (SOP 1), which goes through a post-processing procedure before release. Continuous water quality data is available upon request and will soon be available in an accessible NOAA ERDDAP server.

Data is also published yearly to OPC's data repository on DataOne[13]. The 2023 data associated with this report is available on DataOne.

[11] https://empa.sccwrp.org
[12] https://nexus.sccwrp.org/empadataquery/
[13] https://opc.dataone.org/

Function-based Data Analysis

The assessment strategy focuses on linking individual indicators to specific functions in order to evaluate estuary condition via functional performance. To standardize the assessment of each ecological function, each function is assigned a suite of condition statements that can be analyzed using the indicator data collected by the monitoring program. Condition statements help direct data analysis to quantify the function supported by each estuary. In young monitoring programs (e.g., under 5 years of data collection), each condition statement output (i.e., data interpretation) is binned into tertials and given a score of 1, 2, or 3. A score of 3 is considered high condition, while a score of 1 is considered low condition. The scores for each condition are then averaged for each estuary to give a final function score. By binning data into tertials and averaging scores, this allows the comparison of estuaries relative to one another. This does not produce an absolute score for each estuary (i.e., whether or not the estuary is in 'good' or 'bad' condition).

As monitoring programs mature, 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 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.

Below we demonstrated this process and the outputs for two select functions: Support of Vascular Plant Communities and Sea Level Rise Amelioration and Resiliency. We also outline the development process for two additional functions: Nekton Habitat and Secondary Production. As new interannual data are collected at selected estuaries, analysis for other ecosystem functions will be possible. It's important to note that these condition statements and assessment of collected data serve as an initial analysis framework for evaluating ecosystem function and will be modified as our data collection and analysis techniques improve. All results are based on data collected from a single year and should be interpreted with caution and tested as further data are collected.

For each function we present the following information:

- Definition of the function
- List of indicators used to assess the function
- Condition statements developed utilizing data from each indicator
    - Justification for the inclusion of the condition statement
    - Main findings of the condition statement
    - Confidence level of the condition statement
    - Recommendations to enhance confidence in the assessment of each condition statement

For a complete description of the data analysis process please see Appendix C: Data Analysis Methods.

Inherent Variability in Estuaries Influences Ability to Draw Conclusions Related to Management Objectives

Estuaries are inherently dynamic systems. Conditions vary due to tidal, day-night, weather-related (including waves and river flow), seasonal, interannual, and decadal cycles. Consequently, plant and animal communities have responded to this site-specific environmental variability. This high degree of variability among estuaries makes it difficult to discern patterns driven by anthropogenic disturbance from patterns driven by natural system variability. Specifically in intermittently closed estuaries, conditions can be dramatically different between wet and dry years - exceeding and obfuscating human impacts. Because estuaries integrate environmental stress from watersheds and the ocean, it can be difficult to identify primary stressors and document clear stress response relationships. Given this variability, monitoring over many years is essential to identify and assess human-induced trends.

Modeling can serve as a complement to field assessment by providing tools that can help disentangle the relative contributions of different stressors to health. Modeling can also help identify reference expectations and develop long-term expected trajectories that can provide context for monitoring data.

However, models rely on robust field data for calibration and validation. Moreover, untangling the complexities of trends in functions and associated causative factors requires a commitment to long-term monitoring. Only through consistent monitoring over time scales that capture variable conditions can the complex stress response patterns be understood. This project has developed a robust assessment framework and demonstrated its application through initial sampling. Over time and with continued data collection, we will be able to provide the data needed to make more informed management decisions.

There is a need to be cautious about making management decisions with limited data. We estimate you will need 10 years of data before you can start making sound management decisions. Once the program gets to 5 years of data collection, we can start investigating trends in the data. Until then we will report years individually.

Functional Analysis 1: Support of Emergent Vascular Plant Communities

The estuary function for Emergent Vascular Plant Support has been defined as: *Support of a diversity of emergent fresh and salt tolerant plant species distributed throughout the system based on the geographic and temporal variability in water depth, sediment composition, marsh elevation, salinity gradient, and submergent conditions.*

Indicators Used to Assess this Function Include:

- General habitat condition (CRAM)
- Marshplain vegetation community
- Marshplain elevation and inundation
- Level 1 indicators
    - Marshplain topography-DEM
    - Habitat mapping

Five condition statements have been drafted to help direct data analysis to quantify the level of Emergent Vascular Plant Support provided by each estuary. Each condition statement was analyzed separately and the resulting scores were averaged to give each estuary a final score for this function.

Condition Indicator 1: Assessments of the marshplain using the California Rapid Assessment Method (CRAM) show high values for the Index score, along with the Physical, and Biotic attribute scores.

Justification of Condition Statement:

The EMPA Monitoring Program incorporates the USEPA Level 1-2-3 monitoring framework into its assessment of estuarine functions[14]. Maps of wetland location, area, and elevation correspond to Level 1, while more intensive measures of estuarine condition (fish seines, vegetation transects) correspond to Level 3. The California Rapid Assessment Method (CRAM) is an established level 2 (rapid) assessment method in California. 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, as well as the individual physical and biotic attribute scores, are relevant when evaluating vascular plant support[15]. Specifically, the 'Physical Structure' attribute consists of two metrics - structural patch richness and topographic complexity. Structural patch richness is the number of different obvious types of physical surfaces or features that may provide habitat for aquatic, wetland, or riparian species. Patches can include: abundant wrackline or organic debris, pools or depression in channels, shellfish beds, submerged vegetation, algal mats, etc. Topographic complexity refers to the micro- and macro-topographic relief and variety of elevations within a wetland due to physical features

[14] https://www.mywaterquality.ca.gov/wetland-monitoring/wramp.html

[15] https://www.cramwetlands.org/sites/default/files/2013.03.19_CRAM%20Field%20Book%20Estuarine%206.1_0.pdf

and elevation gradients that affect moisture gradients or that influence the path of flowing water. A variety of habitat types and topography can support a diversity of vascular plants.

The biotic attribute score consists of three metrics - plant community composition, horizontal interspersion, and vertical biotic structure. Plant community composition measures the number of plant layers based on height, the number of dominant plant species within each layer, and the number of dominant invasive plants. Horizontal interspersion refers to the variety and interspersion of plant "zones." Plant zones are obvious multi-species associations (in some cases zones may be plant monocultures; for instance, pickleweed) that remain relatively constant in makeup. The vertical component of biotic structure consists of the interspersion and complexity of plant layers. For estuarine wetlands this metric is assessed as the amount of living vegetation, entrained litter, or detritus across the marshplain and the amount of space beneath it. Together, these elements help assess whether the site is supporting vascular plants.

The habitat condition of each estuary was determined by comparing the average condition scores for each estuary with the population of condition scores from all California estuaries using the statewide estuary CRAM data from 2014-2024, which were downloaded from EcoAtlas.org.

Main Findings:
A high average score for the three elements of CRAM (overall CRAM score, physical attribute score, biotic attribute score) indicates that the general habitat condition of the estuary is appropriate for supporting emergent vegetation. In general, larger and/or more remote estuaries (Ten Mile, Big River, Carmel) scored higher than estuaries that are managed open and/or in close proximity to stressors (Moro Cojo Slough, Goleta Slough, Ventura River). Additionally, north coast estuaries overall scored higher than central and south coast estuaries, most likely due to increased stressors, adjacent development (urban and agriculture), and mouth management.

Level of Confidence in Findings:
Our level of confidence in these findings is high. The California Rapid Assessment Method has been extensively tested and validated since 2005. This is a reliable tool to assess habitat condition.

Recommendations to Enhance Confidence:
Next steps include ensuring that locations for CRAM evaluations align with monitoring stations for estuaries that were previously scored and conducting CRAM surveys for all estuaries in the project (e.g., Bolsa Chica, Morro Bay, Bolinas Lagoon, Drakes Estero). Additionally, each station should be surveyed every 2-3 years to ensure that accurate data is being used in these analyses.

Condition Indicator 2: The marshplain vegetation is dominated by native species and robust cover.

Justification of Condition Statement:
Marshplain vegetation is a key component of overall estuarine health and function. Native species dominance and robust vegetation cover within the marshplain 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.

A marshplain dominated by native species also enhances estuarine connectivity and functional integrity by supporting natural successional processes and resisting invasive species encroachment. High native cover prevents the establishment of non-native plants that can disrupt habitat heterogeneity, outcompete native flora, and alter sediment dynamics. This robust vegetation structure ensures that species distributions remain reflective of natural environmental gradients, allowing for a continuous transition of plant communities from subtidal to supratidal zones. By maintaining these gradients and supporting a high diversity of emergent vegetation, a native-dominated marshplain maximizes the estuary's capacity to support vascular plant communities and sustain ecosystem functions under varying hydrodynamic and climatic conditions. The EMPA Monitoring Program conducts vegetation transects at multiple locations in each monitoring station to capture the species richness and density of marshplain vegetation across elevation gradients.

Main Findings:

Central California estuaries, especially the temporarily closed central coast sites, have a higher abundance of invasive and non-native plants than southern and northern California estuaries. Vegetation cover in the upper elevations is uniformly high in most monitored estuaries.

Level of Confidence in Findings:

Our level of confidence in these findings is high. Local experts are able to accurately identify plant species on the ground.

Recommendations to Enhance Confidence:

Potential ways to improve our confidence would be to include more vegetation transects per station, or to sample vegetation in both seasons. Currently these transects are only being sampled in the Fall season. Another option would be to randomly select a number of additional vegetation plots throughout the estuary to sample, in concert with the topographic surveys, rather than whole transects.

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

Justification of Condition Statement:

Varied marshplain topography directly enhances the estuary's function for vascular plant support by creating diverse microhabitats that accommodate a wide array of emergent plant species. Variability in marsh elevation influences key environmental factors such as water depth, hydroperiod, sediment deposition, and salinity gradients, all of which shape plant community composition and distribution. Different elevation zones provide varied habitats including tidal flats, salt marshes, and upland zones, each supporting unique vegetation communities leading to higher diversity and resilience within an estuary. Higher-elevation areas experience less frequent inundation and support salt-tolerant and transitional species, while lower-elevation zones remain more frequently submerged, favoring submergent and emergent vegetation. This topographic complexity ensures that the estuary can sustain a diverse assemblage of vascular plants that are spatially distributed according to their physiological tolerances and ecological requirements.

Additionally, a broad range of elevations supports long-term ecosystem resilience by facilitating natural adjustments to changing hydrodynamic and climatic conditions. Variability in marshplain height allows for differential sediment accretion and organic matter accumulation, helping to sustain elevation capital and buffer against sea level rise. It also promotes connectivity between different habitat zones, ensuring that plant species can migrate upslope or redistribute across the landscape in response to shifting water levels and salinity regimes. By maintaining a diverse topographic framework, the marshplain maximizes the estuary's ability to support emergent vegetation across spatial and temporal scales, reinforcing its capacity to provide critical ecological functions under both current and future environmental conditions. To estimate marshplain topographic variability needed to support a diverse plant community, GIS data of the marshplain were analyzed to quantify the relative amount of marshplain topographic variability (levels of ruggedness).

Main Findings:

Varied marshplain elevation is necessary for Emergent Vascular Plant Support because it provides multiple habitats for plants. Overall, bar-built estuaries (temporarily closed systems) in confined river valleys scored highest for variability in marshplain elevation, while larger perennially open estuaries scored lower.

Level of Confidence in Findings:

Our level of confidence in these findings is medium. The GIS tool is reliable but we need to make sure we are using the most appropriate data.

Recommendations to Enhance Confidence:

Ensuring that the most recent, high-resolution LiDAR dataset is being used will improve the accuracy of these results. The method of comparison could also be altered. Currently, these results are being compared and scored relative to each other. We could include other unmonitored estuaries, statewide or regionally, and see how they compare to other sites, similarly to our CRAM scoring method.

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

Justification of Condition Statement:

Fluctuating water levels influence soil moisture, sediment deposition, and nutrient availability, all of which shape plant community composition and zonation. Periodic inundation of higher marsh surfaces supports salt- and flood-tolerant vegetation, while lower-lying areas experience more prolonged submergence, favoring submergent and emergent species. This hydrologic variability ensures that emergent plants can establish across a range of elevation gradients, promoting a diverse and resilient plant assemblage adapted to changing conditions over time.

Furthermore, temporal variation in water elevations supports ecosystem resilience by facilitating natural successional processes and allowing plant communities to adjust to long-term environmental changes, including sea level rise and altered freshwater inputs. Intermittent flooding distributes sediment and organic material across the marshplain, reinforcing elevation capital and maintaining substrate conditions suitable for plant colonization and persistence. This variability also prevents the dominance of any single plant community by creating shifting habitat conditions that promote species turnover and spatial heterogeneity. By inundating multiple topographic surfaces across different timescales, the estuary maintains a functionally diverse and spatially structured plant community, ensuring the long-term sustainability of emergent vegetation across the system.

Main Findings:
Periodic inundation is necessary for plant diversity and overall vegetation health, but in this report, we were not able to link water elevations measured to a tidal datum to score this metric. This will be completed in subsequent reports.

Level of Confidence in Findings:
NA

Recommendations to Enhance Confidence:
NA

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

Justification of Condition Statement:
Plant alliances refer to the different species or communities of plants that coexist in an ecosystem, each forming distinct associations or "alliances" based on shared characteristics or ecological niches. These habitat alliances reflect the estuary’s capacity to sustain a broad range of emergent fresh and salt-tolerant plant species, each occupying specific ecological niches shaped by variability in water depth, sediment composition, marsh elevation, and salinity gradients. The presence of multiple plant alliances ensures that vegetation communities are distributed across the estuarine landscape in response to dynamic hydrologic and geomorphic conditions, allowing for the coexistence of species with differing physiological tolerances. This diversity in plant assemblages strengthens ecosystem stability and facilitates ecological interactions that support overall marsh health and resilience.

Additionally, the presence of numerous plant habitat alliances contributes to the estuary’s adaptive capacity under changing environmental conditions. As sea level rise, sediment flux, and hydrologic patterns shift over time, having a wide range of plant alliances allows for natural succession and redistribution of species across the system. This diversity enhances ecosystem functions such as sediment retention, nutrient cycling, and primary production, all of which are critical for sustaining emergent vegetation over time. By supporting a mosaic of plant communities across different zones, the estuary maintains its ability to provide suitable conditions for vascular plants under both current and future environmental variability, reinforcing its role as a dynamic and resilient ecosystem.

Main Findings:
Having multiple plant alliances within an estuary significantly enhances its ecological functions, resilience, and biodiversity. It is likely that high scores help withstand environmental changes and disturbances. The

northern estuaries typically scored lower than central or southern estuaries with only 1 plant alliance present.

Level of Confidence in Findings:
Our level of confidence in these findings is medium. We used the California Native Plant Society Manual of California Vegetation (CNPS 2024) to determine the alliances present in each vegetation plot. This classification system is recognized and used by organizations including NPS, USGS, and CDFW.

Recommendations to Enhance Confidence:
Next steps would include investigating placement of vegetation transects to consider how this influences alliances or if alliances could be determined from landscape images with ground truthing. This would also require recent high-resolution imagery. Increasing our knowledge of the CNPS alliance classification system is also necessary to determine accurate alliances. Intercalibration for our team on percent vegetated cover estimates would also improve accuracy with determining alliances since they are dependent on percent cover.

Summary of Results for Emergent Vascular Plant Support

Overall, the Emergent Vascular Plant Support function was able to be scored in this report and the function-based assessment resulted in a score for each estuary ranging from 1 to 3. In general, all surveyed estuaries scored very similarly with the highest score for Emergent Vascular Plant Support which was Newport Bay, while the lowest scoring estuary was Arroyo de la Cruz (Table 5, Figure 3).

Table 5. Emergent Vascular Plant Support function scoring results for each condition statement for all 16 EMPA sites. Scores are grouped into tertiles: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good). The score shown for marsh vegetation distribution is an average of two submetric analyses (see Appendix C: Data Analysis Methods).

Estuary	Region	General habitat condition	Marsh vegetation distribution		*Marsh plain elevation*	*Marsh plain inundation*	Vegetation alliances	Final Score
		High CRAM Index, physical, and biotic attribute scores	*Native plant cover*	*Vegetation cover*	*Varied marsh plain elevation (high ruggedness)*	*Appropriate levels of marsh plain inundation*	*High number of plant alliances*	
Ten Mile River	North	3.00	2.00	3.00	3.00	NA	1.00	2.40
Big River	North	3.00	3.00	3.00	3.00	NA	1.00	2.60
Navarro River	North	2.33	3.00	2.00	3.00	NA	1.00	2.27
Drakes Estero	North	NA	3.00	3.00	3.00	NA	1.00	2.50
Bolinas Lagoon	North	NA	2.50	3.00	2.00	NA	2.00	2.38
Pajaro River	Central	2.00	1.00	3.00	2.00	NA	3.00	2.20
Moro Cojo Slough	Central	1.33	2.00	3.00	1.00	NA	3.00	2.07
Carmel River	Central	3.00	1.50	3.00	3.00	NA	2.00	2.50
Arroyo de la Cruz	Central	2.67	1.00	2.00	2.00	NA	1.00	1.73
Morro Bay	Central	NA	2.00	3.00	2.00	NA	3.00	2.50
Goleta Slough	South	1.67	2.00	3.00	2.00	NA	2.00	2.13
Ventura River	South	2.33	2.00	2.00	2.00	NA	2.00	2.07
Malibu Lagoon	South	2.00	1.50	3.00	2.00	NA	3.00	2.30
Bolsa Chica	South	NA	2.50	3.00	2.00	NA	2.00	2.38
Newport Bay	South	1.67	2.50	3.00	3.00	NA	3.00	2.63
Batiquitos Lagoon	South	2.00	2.50	3.00	2.00	NA	3.00	2.50

Figure 3. Statewide map of EMPA sites and their final score categories for Emergent Vascular Plant Support.

Functional Analysis 2: Sea Level Rise Amelioration and Resiliency

The estuary function for Sea Level Rise Amelioration has been defined as: *Capacity to absorb and protect adjacent uplands from 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 dissipating energy, accreting sediment and providing space for habitat migration.*

Indicators used to Assess this Function Include:

- General habitat condition (CRAM)
- Marshplain vegetation community
- Marshplain elevation and inundation
- Sediment accretion
- Level 1 indicators
  - Adjacent land use
  - Marshplain topography-DEM
  - Marshplain migration potential

This function has been given four condition statements to help analyze the ability of an estuary to adapt with sea level rise. Because good condition vegetation communities are critical to sea level rise resiliency, some analyses of condition statements for Sea Level Rise Resiliency are similar or identical to those of the Emergent Vascular Plant Functional Analysis. Each condition statement was analyzed separately and the resulting scores were then averaged to give each estuary an overall score for the function.

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

Justification of Condition Statement:

The overall CRAM index score, as well as the individual physical and biotic attribute scores, are relevant when evaluating an estuary's resilience to sea level rise. Specifically, the 'Physical Structure' attribute consists of two metrics - structural patch richness and topographic complexity. Structural patch richness is the number of different obvious types of physical surfaces or features that may provide habitat for aquatic, wetland, or riparian species. Patches can include: abundant wrackline or organic debris, pools or depression in channels, shellfish beds, submerged vegetation, algal mats, etc. Topographic complexity refers to the micro- and macro-topographic relief and variety of elevations within a wetland due to physical features and elevation gradients that affect moisture gradients or that influence the path of flowing water. Higher physical attribute scores indicate complex topography, intact sediment deposition processes, and a variety of elevation zones which allow wetlands to accrete sediment to combat sea level rise. Physical complexity also allows for the distribution of floodwaters which reduces the impact of high tides and storm surge.

The biotic attribute score consists of three metrics - plant community composition, horizontal interspersion, and vertical biotic structure. Plant community composition measures the number of plant layers based on height, the number of dominant plant species within each layer, and the number of dominant invasive plants. Horizontal interspersion refers to the variety and interspersion of plant "zones." Plant zones are obvious multi-species associations (in some cases zones may be plant monocultures; for instance, pickleweed) that remain relatively constant in makeup. The vertical component of biotic structure consists of the interspersion and complexity of plant layers. For estuarine wetlands this metric is assessed as the amount of living vegetation, entrained litter, or detritus across the marshplain and the amount of space beneath it. Having complex vegetation structure helps trap sediment, maintain elevation, and reduce erosion that could be caused by sea level rise. Diverse vegetation also allows for habitat migration, ensuring species can shift landward as water levels increase.

Main Findings:

The first indicator statement of general habitat condition combines three elements of CRAM (overall CRAM score, physical attribute score, biotic attribute score). A high average score for these elements indicates that the general habitat condition of the estuary is appropriate for supporting vegetation, which helps ameliorate sea level rise. The larger marshplain estuaries as well as the less urban estuaries score highest for this indicator.

Level of Confidence in Findings:

Our level of confidence in these findings is high. The California Rapid Assessment Method has been extensively tested and validated since 2005. This is a reliable tool to assess habitat condition.

Recommendations to Enhance Confidence:

Next steps include ensuring that locations for CRAM evaluations align with monitoring stations for estuaries that were previously scored and conducting CRAM surveys for all estuaries in the project (e.g., Bolsa Chica, Morro Bay, Bolinas Lagoon, Drakes Estero). Additionally, each station should be surveyed every 2-3 years to ensure that accurate data is being used in these analyses.

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

Justification of Condition Statement:

Vegetation, particularly in the upper marsh, helps trap sediments brought in by tidal movements, river flows, and storm surges. Roots of marsh plants bind the soil together, reducing erosion and preventing sediment from being washed away. Over time, these plants help build up the elevation of the marsh, creating a natural barrier against rising sea levels. In addition, vegetation contributes to soil stabilization. The organic matter produced by marsh plants helps increase the soil's ability to retain water, reduce compaction, and maintain structural integrity. These properties allow the marsh to better withstand sea level rise and maintain its elevation over time.

Main Findings:

Marshplain vegetation cover (total vegetation relative to non-vegetated cover) in middle and high marsh elevations was relatively consistent across all estuaries with most receiving a score of 3. The ability of plant cover to trap sediment effectively depends on several factors, such as the type of plants, the specific environment, and the sediment characteristics. But generally, a score of 2 or 3 indicates greater than 30% overall cover, which should be enough to trap and stabilize sediments.

Level of Confidence in Findings:

Our level of confidence in these findings is high.

Recommendations to Enhance Confidence:

Potential ways to improve our confidence would be to include more vegetation transects per station, or to sample vegetation in both seasons. Currently these transects are only being sampled in the Fall season. Intercalibration for our team on percent vegetated cover estimates would also improve the accuracy of these findings. Additionally, we would like to include manipulatively testing how cover thresholds relate to sedimentation rates.

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.

Justification of Condition Statement:

The estuary's capacity for habitat migration directly enhances its function for Sea Level Rise Amelioration by ensuring the persistence of critical habitat zones as water levels rise. As sea level rise alters the marine-freshwater-terrestrial interface, the ability of tidal marshes and associated plant communities to migrate landward is essential for maintaining their role in dissipating wave energy, reducing erosion, and stabilizing sediment. Without physical barriers to migration, the estuary can facilitate the natural transition of marsh habitats upslope, allowing emergent vegetation to establish in newly suitable areas. This process preserves the geomorphic integrity of the estuarine system, sustaining its capacity to buffer adjacent uplands from the impacts of rising sea levels and storm surge.

Additionally, the availability of migration space strengthens the estuary's long-term resilience by promoting sediment accretion and habitat continuity across changing environmental conditions. As marshes shift landward, they continue to trap sediment and organic matter, building elevation capital that helps mitigate inundation risks. This dynamic response supports the persistence of critical ecological functions such as carbon sequestration, water filtration, and biodiversity maintenance, all of which contribute to the estuary's ability to absorb sea level rise impacts. By providing the necessary space for habitat migration, the estuary ensures the ongoing protection of adjacent uplands and maintains its role as a natural buffer against coastal change, reinforcing ecosystem stability and resilience under future climate scenarios.

The marshplain migration condition was interpreted using a combination of DEMs and land cover data to characterize the potential migration area available for the marshplain to move into and the future habitat proportions under 1.2 ft of sea level rise. Ideally, an estuary is surrounded by natural or open land cover with sufficient space and comparable elevation zones in order to accommodate rising sea levels.

Main Findings:

Upland migration allows key wetland habitats to move inland, maintaining their function and structure. If the composition of the surrounding landscape is open, the northern California estuaries are presumed to be able to migrate inland thus increasing their resilience while central and southern California estuaries are more limited due to urbanization of surrounding landscape. When elevation zones are taken into account, central and southern California sites are better suited to maintain marsh habitats without being consumed by water when migrating landward. When all surrounding conditions are considered together, northern and more remote central sites perform the best.

Level of Confidence in Findings:
Our level of confidence in these findings is medium.

Recommendations to Enhance Confidence:
In order to enhance our confidence in our findings, we should make sure that we are using the most recent, high resolution LiDAR data to determine the elevation in and around the estuary footprint. Higher resolution topographic mapping within the estuary to refine our marsh elevation zones.

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

Justification of Condition Statement:
Determining longer-term sediment accretion rates over time can provide valuable insights into the dynamics of sediment accumulation, which is important for understanding the resilience of coastal ecosystems, especially in the face of SLR. Combining these metrics with other data helps determine if estuaries are keeping pace with projected SLR.

This condition statement will use marshplain accretion rate estimated from the deployment of feldspar plots (Figure 4) and sediment grain size analysis to estimate the sediment quantity and quality available to support marshplain accretion. Accretion rates will be compared to the current sea level rise rate estimated by OPC. If accretion rates match or exceed the current rate of sea level rise, that would indicate higher resiliency. Because accretion rates require several years between marker deployment and first sampling, this analysis has not yet been performed.

Figure 4. Ross Clark deploying feldspar on the Moro Cojo Slough marshplain in 2021.

Main Findings:

Data from prior studies (e.g. Thorne et al. 2024) indicate that marshes located in larger watersheds with fluvial inputs would have the largest elevation gains, thereby having a greater potential to keep pace with SLR, while marshes located in small urban estuaries would have the smallest. The EMPA estuaries have feldspar plots deployed at sampling stations to track accretion over time, and ideally some of these could be paired with existing sediment elevation tables (SETs) to determine vulnerability to SLR. This analysis will be completed in subsequent reports.

Level of Confidence in Findings:

NA

Recommendations to Enhance Confidence:

NA

Summary of Results for Sea Level Rise Amelioration and Resiliency

The Sea Level Rise Amelioration function was scored in this report without including scores for sediment accretion. The Sea Level Rise Amelioration function-based assessment resulted in a score for each estuary ranging from 1 to 3 (Table 6, Figure 5) In general, northern California estuaries scored higher than central and southern estuaries, with the highest score for Ten Mile and Big River and the lowest scoring for Newport Bay.

Table 6. SLR Amelioration and Resiliency function scoring for each condition statement for all 16 estuaries. Scores are grouped into tertiles: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good).

Estuary	Region	General habitat condition	Marsh vegetation distribution	Marsh plain resiliency: Sufficient upland migration area			Marsh plain resiliency: Composition of future areas	Sediment accretion rates	Final Score
		High CRAM Index, physical, and biotic attribute scores	*Vegetation cover*	*Buffer land cover*	*Perimeter land cover*	*Perimeter contiguity*	*Habitat distribution*	*Sediment supply*	
Ten Mile River	North	3.00	3.00	3.00	3.00	2.00	3.00	NA	2.83
Big River	North	3.00	3.00	3.00	3.00	3.00	2.00	NA	2.83
Navarro River	North	2.33	2.00	3.00	3.00	2.00	1.00	NA	2.22
Drakes Estero	North	NA	3.00	3.00	3.00	2.00	1.00	NA	2.40
Bolinas Lagoon	North	NA	3.00	3.00	2.00	NA	1.00	NA	2.25
Pajaro River	Central	2.00	3.00	3.00	3.00	1.00	2.50	NA	2.42
Moro Cojo Slough	Central	1.33	3.00	3.00	3.00	1.00	2.50	NA	2.31
Carmel River	Central	3.00	3.00	2.00	3.00	3.00	2.50	NA	2.75
Arroyo de la Cruz	Central	2.67	2.00	3.00	3.00	3.00	3.00	NA	2.78
Morro Bay	Central	NA	3.00	2.00	3.00	3.00	1.00	NA	2.40
Goleta Slough	South	1.67	3.00	1.00	2.00	NA	3.00	NA	2.13
Ventura River	South	2.33	2.00	1.00	2.00	NA	3.00	NA	2.07
Malibu Lagoon	South	2.00	3.00	1.00	1.00	NA	2.50	NA	1.90
Bolsa Chica	South	NA	3.00	1.00	1.00	NA	2.00	NA	1.75
Newport Bay	South	1.67	3.00	1.00	1.00	NA	1.00	NA	1.53
Batiquitos Lagoon	South	2.00	3.00	1.00	1.00	NA	1.00	NA	1.60

Figure 5. Statewide map of EMPA sites and their final score categories for Sea Level Rise Amelioration and Resiliency.

Functional Analysis 3: Nekton Habitat Provision

The estuary function for Nekton Habitat Provision has been defined as: *Support for a variety of resident and transitory fishes and crustaceans by providing appropriate water quality, habitat diversity and food sources.*

Indicators used to assessment of this function include:

- Water quality (DO, temp, salinity, etc.)
- General community composition (eDNA)
- Benthic infauna community (small and large)
- SAV distribution
- Fish community
- Mobile invertebrate community
- Macroalgae distribution
- General habitat condition (CRAM)
- Level 1 indicators
    - Habitat mapping

Six condition statements have been drafted to help direct data analysis to quantify how well the estuary is performing in supporting nekton habitat. Each condition statement was evaluated separately.

Below we provide initial results for each condition statement when possible. This function analysis is still under development as many of the condition statements require greater than five years of data to make definitive inferences. We outline the initial narratives around each condition statement and provide next steps when possible.

Condition Indicator 1: The estuary does not experience extended periods of hypoxia, high water temperatures, or extreme salinity that significantly exceeds or impedes physiological limits (indicator: water quality).

Justification of Condition Statement:

The use of estuaries by nekton 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).

Specifically, water temperature is connected to nekton physiology as nekton species typically have an optimal temperature range for growth, reproduction, and overall survival. Most nekton prefer estuarine waters that are not too warm or cold, with temperatures often ranging between 15-25°C (depending on species). Some species, such as juvenile fish, may prefer the relatively stable temperatures of estuaries over the more variable conditions of open marine waters. Estuaries can serve as thermal refuges, where nekton seek shelter from extreme temperatures in surrounding areas. Finally, temperature affects how and when nekton might move into estuaries seasonally because species follow temperature cues for spawning or feeding.

Next, dissolved oxygen affects nekton communities because organisms generally require a certain concentration of dissolved oxygen for respiration. Low DO levels (hypoxia) can stress organisms and drive them away from areas with poor oxygen conditions. When DO levels drop too low, especially in poorly flushed or eutrophic estuaries, areas of hypoxia can form, causing nekton to relocate to more oxygen-rich areas within or outside estuaries.

Finally, as seen in the EMPA estuary type groupings, estuaries are characterized by their salinity, which is related to mouth status, river flow, and stratification. Most estuarine species are adapted to tolerate variable salinities. However, some species have more specific salinity requirements, thus community composition varies with salinity regime and salinity at the time of sampling. Dramatic shifts in salinity due to heavy rainfall or drought can disrupt nekton use of estuaries, pushing them either upstream into fresher water or downstream into more saline conditions. This movement is usually dependent on their tolerance to salinity and their need for certain estuarine resources (e.g., food, shelter).

In summary, nekton seek estuary waters in which these environmental factors are within a given range (e.g., steelhead use of Russian River and comparable estuaries; Boughton et al 2017). Temperature, DO, and salinity work together to shape the distribution, behavior, and health of nekton. Estuaries provide essential habitats for many species, but shifts in any of these parameters can push nekton into or out of these vital ecosystems.

Main Findings:
While we cannot score this condition statement at present, we identified and quantified daily, threshold, and event metrics that will be used in future scoring and assessment (see Appendix F: Additional SOP Results. When consistent cross-site time series are available, we will proceed to score EMPA sites in relation to nekton habitat. At that time, we will also develop a more profound interpretation of these metrics in terms of nekton health.

We derived three types of metrics to evaluate each estuary. A metric is a quantifiable measurement of a specific unit or process. We can use these metrics to compare within and among systems.

1. *Daily metrics* - These metrics are used to summarize water quality conditions for each day. They give an overview of daily variability (e.g., mean, min, max, range) of the parameters (temperature, salinity, DO) and their distribution (10th, 50th, and 90th percentiles).

2. *Threshold metrics* - These metrics count how many days or observations fall below or above a specified threshold. Thresholds can be determined by the physiological limits of estuarine species. Metrics can quantify how frequently water conditions fall outside specific ranges. For example, we can quantify the number of days DO falls below 1 mg/L, 2 mg/L, and 3 mg/L.

3. *Event metrics* - Event metrics are designed to capture episodic phenomena, such as hypoxia or temperature spikes. These metrics help monitor discrete events, their frequency, and their impact. For example, we can quantify the number of consecutive hours DO falls below 2 mg/L.

Overall, in most cases where data are available, abiotic conditions are within expected ranges across the EMPA sites. In southern CA, it is most likely that an estuary will exceed temperature thresholds as compared to central and north regions (due to a latitudinal effect). Event-driven changes in temperature, DO, and salinity occur regularly within the temporarily closed estuaries and have corresponding effects on fish communities.

Level of Confidence in Findings:

Our level of confidence in these findings is low. Over the last few years, many steps have been implemented to better standardize data collection, data QA/QC, and data analysis with these large time-series datasets. However, due to the current resources, water quality data has been collected inconsistently and data are not concurrent in different systems. Due to these inconsistencies in data collection, we used a subset of the water quality data in this report to illustrate how California estuaries are extremely dynamic with varying water quality conditions. At this time, we cannot provide statistical summaries or provide management guidance about these systems. In order 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).

Recommendations to Enhance Confidence:

The essence of this condition statement is to track how often and for how long water quality conditions in these estuary sites exceed physiological threshold for fish. By defining metrics (as above), we are able to quantify how often the EMPA sites are exceeding these limits. However, different species may exhibit different physiological limits. We recommend the consistent collection of water quality data over the next several years to begin to link water quality conditions with physiological thresholds.

Condition Indicator 2: The benthic infauna community composition is representative of the estuary type and salinity regime (indicator: benthic infauna).

Justification of Condition Statement:

Benthic infauna are a critical food source for many nekton species, including juvenile fish and larger predatory species. Therefore, it is important to have systems that have representative communities. A diverse community of benthic infauna contributes to overall ecosystem diversity, which supports a wide range of nekton species with varying ecological needs. The complex relationships between benthic infauna and nekton promote resilience in estuarine ecosystems, enabling them to recover from disturbances.

Main Findings:

An assessment of both intertidal and subtidal infaunal cores indicates that infauna across a range of taxonomic and functional groups are present in most estuaries. When numbers are low, it is likely related to sampling locations, grain size, or potentially inlet status. In order to quantitatively demonstrate those drivers, increased sampling with increased funding would be needed. Due to fewer samples being analyzed for benthic infauna compared to fish, the analysis combines data from different regions. However, no significant differences were found between regions in terms of abundance, species richness, or community composition ($p > 0.05$ in all cases).

Numerous studies in southern California and other regions have observed that overlying vegetation cover and sediment properties can affect infaunal macrofaunal assemblages. Typically, more disturbed or lower plant cover or early restoration marshes have a lower proportion of oligochaetes and a higher proportion of insect larvae as compared to the assemblage in more mature marshes (e.g. Whitcraft and Levin 2007, Talley and Levin 1999, Moseman et al. 2004). Thus, species richness, taxonomic grouping, and feeding type groupings can be used to infer habitat condition (with consideration of estuary type).

Additionally, the implications of a highly invaded invertebrate community in estuaries are significant, as invasive species can profoundly alter the structure, function, and biodiversity of these ecosystems. Estuaries are particularly vulnerable to invertebrate invasions due to their dynamic nature as an ecotone, which often provides ideal conditions for non-native species to establish themselves. The presence of invasive invertebrates can have both direct and indirect effects on native species, trophic processes, ecosystem processes, and overall ecosystem health. However, few management actions exist for many of the smaller, cryptic or widely distributed invertebrates. Yet, it is useful to establish a baseline of invasive presence with a watch for known ecosystem engineers or particularly harmful invasive species.

Level of Confidence in Findings:

Our level of confidence in these findings is medium to low. However, due to the current resources and the larger core sizes originally taken in Fall 2023, not all invertebrate cores from each estuary have been processed in time for this report. Future confidence in scores will be increased as these remaining cores are processed. Due to the low sample size processed for this report, we only had two estuaries represented in this report to illustrate how California estuaries vary in terms of invertebrate communities. At this time, we cannot provide statistical summaries or provide management guidance about these systems.

Recommendations to Enhance Confidence:

One commonly used example of a benthic assessment index is the multivariate AZTI Marine Biotic Index (M-AMBI). M-AMBI is a multi-metric index that takes into account the AZTI Marine Biotic Index (AMBI), species richness, and the Shannon diversity index of macrobenthic communities in order to calculate an ecological quality ratio between 0 and 1, with 1 indicating the best ecological status (Muxika, Borja, & Bald, 2007). AMBI is a biotic index that calculates the biotic coefficient (BC) based on the proportional abundance of species belonging to one of five ecological groups (EG) based on their sensitivity/tolerance to environmental stress (A. Borja, Franco, & Pérez, 2000). M-AMBI has been found to remove the salinity bias often associated with AMBI in which low salinity systems have relatively low abundance and species richness (A. Borja & Muxika, 2004). Studies typically use ecological group classification based on local expertise on the US west coast because the accuracy of AMBI is improved when using tolerance values tailored to a local region (Gillett et al., 2015).

As more data is collected, we can apply the M-AMBI to understand the condition of the benthic community. However, more studies will have to be conducted to understand the connection between benthic condition and nekton habitat, as well as to validate the M-AMBI in intertidal environments. Mouth status (opening and closing events) are natural disturbance events that the index should capture, however in these scenarios the signal in condition may not be necessarily related only to the listing pollutant but rather the mouth status. More validation exercises need to be completed to understand how the M-AMBI can be applied to both temporarily closed systems and the use of M-AMBI between intertidal and subtidal habitats.

Condition Indicator 3: The native fish and crustacean community composition is representative of the estuary type, and salinity and temperature regime (indicator: fish).

Justification of Condition Statement:

The composition of native fish and crustacean communities are critical indicators to an estuary supporting nekton habitat. The overall plan for evaluating this indicator is to develop an evaluation framework similar to the Biological Condition Gradient model (BCG) (USEPA 2016). The BCG is a conceptual, scientific framework developed to interpret response in biological communities to anthropogenic stressors. It combines the best professional judgement of scientists with quantitative models to develop scorable decision rules that apply within various types or the locations of the ecosystems.

To begin to evaluate and understand representativeness, we took a multi-tier approach to start to outline a method for scoring this indicator. The first step, completed in this report, is to present community composition (both presence/absence) and abundance by species to understand the data collected. Next steps, completed in this report, include using multivariate statistical techniques to associate this community composition with potential environmental correlates (including salinity, temperature, dissolved oxygen, SAV presence, inlet status, etc.). A preliminary list of "expected" estuarine fish taxa was developed for each region (south, central, north) (Appendix D: Fish Species Regional Lists). For demonstration purposes in this report, this expected list was compared to the community composition of fish caught in Fall 2023. Final steps, not completed in this report, include convening an expert panel with taxonomists, fish experts, and BCG practitioners. The panel will evaluate proposed regional expected fish lists, calibrate the conceptual BCG with data for specific estuaries, and develop quantitative decision rules for assigning sites to BCG levels for that system using a combination of expert elicitation and consensus.

Main Findings:

Fish occur in relatively high abundances in all systems and are highly variable with location and likely across seasons (seasonal comparisons need to be completed in future reports). Southern CA estuaries are more highly invaded than central and northern estuaries, potentially correlated with urbanization. Overall, despite seining and traps being point-in-time capture methods, the community composition of dominant fish within the estuaries appears to match expected estuarine fish communities. However, these methods miss rare, endangered, migratory, sensitive, and highly mobile fish groups due to the nature of sampling. If research questions or funding dictated, these methods and scoring could be scaled up or increased in frequency to answer such questions.

Level of Confidence in Findings:

Our level of confidence in these findings is medium. Although we believe the approach is the correct one, we need to incorporate data across multiple seasons and years.

Recommendations to Enhance Confidence:

In this report, we took a multi-tier approach to start to outline a method for scoring this indicator, but we did not assign a score for this indicator as additional data (e.g. SAV distribution) needs to be collected. The next step to realize scoring is to convene an expert panel with taxonomists, fish experts, and BCG practitioners. The overall goal of this panel will be to develop quantitative decision rules for assigning sites to BCG levels for that system using a combination of expert elicitation and consensus. By developing a BCG, we can then use an index to score this condition statement.

Condition Indicator 4: The extent and distribution of ephemeral macroalgae is low enough to allow for native fish and crustacean communities (indicator: macroalgae).

Justification of Condition Statement:
High cover of ephemeral macroalgae within an estuary can be indicative of impairment to aquatic life. Therefore, condition statement 4 assesses the extent of both intertidal and floating subtidal macroalgae. We evaluate the average percent cover of macroalgae across intertidal transects and subtidal visual estimates.

Main Findings:
None of our sites in the timeframe of this report (Fall 2023) exceeded the threshold of 70% floating or intertidal macroalgae cover that indicates ecosystem impairment. However, it should be noted that the ideal time for surveys of macroalgae is summer and that inlet status, which also changes regularly and in seasons, affects macroalgae blooms.

Level of Confidence in Findings:
Our level of confidence in these findings is medium. Although we believe the approach is the correct one, we need to incorporate data across multiple seasons and years.

Recommendations to Enhance Confidence:
To improve confidence in these results, macroalgae should be surveyed across multiple time points throughout the year. Ideal surveys should be completed in the summer and percent cover should be evaluated alongside macroalgae biomass. Regression curves could be created to crosswalk macroalgae cover and biomass.

Condition Indicator 5: The extent and distribution of SAV is representative of the estuary type (indicator: SAV).

Justification of Condition Statement:
Submerged Aquatic Vegetation (SAV) provides an important role in the ecology of coastal systems, 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 that serve as temporary refuge from predators, enhance carbon and nitrogen cycling, and serve as a productivity hot spot for commercially and societally important fauna, as well as protected species like sea turtles. Due the diversity of estuaries along the coast of California, some systems are expected to consist of expansive eelgrass beds, while other systems may have more ephemeral eelgrass or widgeon grass (Ruppia sp.) beds. However, the extent and distribution of these SAV beds is not well known or mapped across the coast. We must invest in consistent monitoring of SAV beds to understand how nekton habitat may vary with SAV extent, distribution, and health.

Main Findings:

While recognized as an incredibly important component of nekton habitat, SAV surveys were not in the scope of this work in this timeframe. Preliminary scores were generated for this indicator using estimates from seining work, and these scores indicate that sites that are perennially open tend to have more eelgrass, which is likely to structure fish communities.

Level of Confidence in Findings:

Our level of confidence in these findings is low. In subsequent reports, we hope to better incorporate SAV monitoring data in evaluating nekton habitat. In the interim, we evaluated the proportion of fish seines that were pulled near SAV beds, as well as estimating the proportion of sampling stations with known SAV in the fall 2023 post-hoc. There is sampling bias in the location of fish seines, as well as bias in regional field leads using Best Professional Judgement (BPJ) to estimate SAV. This is why it is critical to incorporate SAV into monitoring while in the field, rather than post-hoc estimates.

Recommendations to Enhance Confidence:

Though the EMPA program realizes the importance of tracking SAV extent and distribution through time, extensive resources are needed to implement a complete monitoring program. There are regional efforts that could be leveraged to connect EMPA programmatic data with SAV monitoring data:

1. Southern California Bight Regional Monitoring Program
2. Morro Bay NEP
3. Elkhorn Slough NERR
4. EPA-funded southern California SAV monitoring group
5. NPS eelgrass monitoring in Drakes Estero

Although the EMPA program collaborates with many of these programs, there are limitations to using this data:

1. Temporal variation - SAV surveys do not always align with the same season and year when EMPA data is collected.
2. Spatial variation - SAV surveys do not always align with the EMPA station locations within the estuaries. This makes it difficult to link EMPA monitoring data with SAV bed presence.
3. Species diversity - Most monitoring programs only monitor eelgrass or Zostera sp. However, widgeon grass or Ruppia sp. is present in many estuaries and is a critical habitat for many nekton species.

We must invest in consistent monitoring and mapping of SAV beds to understand how nekton habitat may vary with SAV extent, distribution, and health.

Condition Indicator 6: There is high habitat complexity and interspersion across the estuary as defined by a variety of physical habitat types (indicator: level 1-CRAM).

Justification of Condition Statement:

High habitat complexity and interspersion across the estuary can provide a variety of physical habitats for nekton species. To measure this, we leveraged the existing rapid assessment methods, CRAM. The California Rapid Assessment Method (CRAM) is a tool for assessing the condition of wetlands and streams at scales ranging from individual projects to watersheds, regions, and statewide. CRAM, alone or with other assessment methods, can be used to assess current conditions, understand potential factors impacting wetland/stream condition, evaluate alternative project sites and designs, and assess project performance.

Specifically, we pulled CRAM scores from the estuarine and bar built estuarine modules for the attribute 'Physical Structure’. This attribute consists of two metrics - structural patch richness and topographic complexity. Structural patch richness is the number of different obvious types of physical surfaces or features that may provide habitat for aquatic, wetland, or riparian species. Patches can include: abundant wrackline or organic debris, pools or depression in channels, shellfish beds, submerged vegetation, algal mats, etc. Topographic complexity refers to the micro- and macro-topographic relief and variety of elevations within a wetland due to physical features and elevation gradients that affect moisture gradients or that influence the path of flowing water.

Main Findings:
For fish using the marshplain, as well as for vegetation contributing to microhabitat, habitat complexity is a key metric that we were able to score. Generally, these scores correlate with the size and intact slope of the marshplain. Larger and more intact estuaries scored higher than those with limited size, highly urbanized watersheds, and/or fragmented landscapes.

Level of Confidence in Findings:
Our level of confidence in these findings is high. The California Rapid Assessment Method has been extensively tested and validated since 2005. This is a reliable tool to assess habitat condition.

Recommendations to Enhance Confidence:
Next steps include ensuring that locations for CRAM evaluations align with monitoring stations for estuaries that were previously scored and conducting CRAM surveys for all estuaries in the project (e.g., Bolsa Chica, Morro Bay, Bolinas Lagoon, Drakes Estero). Additionally, each station should be surveyed every 2-3 years to ensure that accurate data is being used in these analyses.

Summary of Results for Nekton Habitat

Overall, due to missing data and the need for additional framework development, the nekton habitat function is not scored in this report. Future steps of developing a nekton BCG, better supporting water parameter measuring, and increasing SAV mapping efforts will enable this function to be scored effectively (Table 7).

Table 7. Due to missing data and the need for additional framework development, the Nekton Habitat function is not scored in this report. We only provide the scores for the three condition statements that were able to be scored.

Estuary	Water Quality	Benthic Infauna	Fish and Inverts	Macroalgae	SAV	Habitat Complexity	Compiled Score
Ten Mile River	NA	NA	NA	3	2	2.3	NA
Big River	NA	NA	NA	3	3	2.8	NA
Navarro River	NA	NA	NA	3	2.5	1.5	NA
Drakes Estero	NA	NA	NA	3	2	NA	NA
Bolinas Lagoon	NA	NA	NA	3	1	NA	NA
Pajaro River	NA	NA	NA	2.5	1	1.5	NA
Moro Cojo Slough	NA	NA	NA	NA	1	1.0	NA
Carmel River	NA	NA	NA	3	1	2.7	NA
Arroyo de la Cruz	NA	NA	NA	2.5	1	2.0	NA
Morro Bay	NA	NA	NA	2.5	2	NA	NA
Goleta Slough	NA	NA	NA	3	1.5	1.5	NA
Ventura River	NA	NA	NA	3	1	2.2	NA
Malibu Lagoon	NA	NA	NA	3	2.5	1.7	NA
Bolsa Chica	NA	NA	NA	3	3	NA	NA
Newport Bay	NA	NA	NA	2.5	2	2.0	NA
Batiquitos Lagoon	NA	NA	NA	3	3	1.3	NA

Functional Analysis 4: Secondary Production

The estuary function for Secondary Production has been defined as: *Transformation of allochthonous and autochthonous organic matter into meiofauna and macrofauna, which in turn are consumed by the resident nekton of the estuary or are exported out to the nearshore coastal zone.*

Indicators used to Assess this Function Include:

- Water quality (DO, temp, salinity, etc.)
- Sediment nutrient concentration (TOC/TN)
- General community composition (eDNA)
- Benthic infauna community (small and large)
- SAV distribution
- Marshplain vegetation community
- Level 1 indicators
    - Habitat mapping

Six condition statements have been drafted to help direct data analysis to quantify how well the estuary is performing in supporting Secondary Production. Each condition statement was evaluated separately.

Below we provide initial results for each condition statement when possible. This function analysis is still under development as many of the condition statements require greater than five years of data to make definitive inferences. We outline the initial narratives around each condition statement and provide next steps when possible.

Condition Indicator 1: The estuary does not experience periods of extended hypoxia, high water temperatures, or extreme salinity that significantly exceeds or impedes physiological limits of organisms responsible for organic matter transformation (indicator: water quality).

Justification of Condition Statement:

Tracking and measuring general water quality conditions of an estuary is extremely important in understanding how a particular system may support secondary production. The transformation of allochthonous (external) and autochthonous (local) organic matter in estuaries (key in secondary production) is closely tied to key environmental factors such as temperature, dissolved oxygen (DO), and salinity. These factors influence microbial, invertebrate, and biochemical processes that break down organic matter, affecting nutrient cycling and secondary production in estuarine ecosystems.

First, water temperature plays an important role in the rate of microbial decomposition and enzymatic activity. Warmer temperatures typically increase the metabolic rates of microorganisms (bacteria, fungi, archaea), accelerating the breakdown of both allochthonous and autochthonous organic matter. Higher temperatures can also speed up the mineralization process, turning organic matter into inorganic nutrients (e.g., ammonium, phosphate, nitrate) more quickly. This affects nutrient cycling, which is critical for primary productivity in the ecosystem. Conversely, excessive heat can stress organisms and reduce biodiversity if temperature thresholds are exceeded.

The presence of dissolved oxygen is essential for aerobic decomposition, where bacteria break down organic matter with oxygen. Aerobic decomposition is generally more efficient at converting organic carbon into inorganic nutrients compared to anaerobic decomposition (which occurs in low oxygen conditions). Connecting to dissolved oxygen, increases in temperature can also lead to higher microbial growth and decomposition rates, potentially reducing the availability of oxygen in the system (depending on the level of organic matter being decomposed). When oxygen levels are low (hypoxic conditions), anaerobic microbes take over the decomposition process, slowing nutrient cycling and also producing gases like methane and hydrogen sulfide, which can be harmful to many estuarine organisms.

Finally, salinity has the most direct influence of these factors on microbial community structure. Certain microbes thrive at specific salinity levels, and salinity stress can alter microbial composition, which in turn affects the efficiency of organic matter breakdown. Post-organic matter breakdown, salinity also influences the solubility and movement of nutrients through the system, which can affect the microbial decomposition process and the availability of nutrients for primary producers like phytoplankton or benthic algae. The transformation of organic matter in estuaries is optimized when salinity levels are within a particular range for the dominant microbial groups. Extreme salinity fluctuations (either very low or very high) can reduce microbial activity, slowing down decomposition rates and limiting nutrient recycling. Finally, salinity also affects the growth and distribution of primary producers, which influences the amount of autochthonous organic matter available for transformation by decomposers.

Changes to all of these abiotic factors can directly impact secondary production by affecting the availability of nutrients required by organisms further up the food chain. Metrics and analyses will be similar to Nekton Habitat (as described above), as many of the same metrics will inform secondary production.

Main Findings:
In most cases where data are available, abiotic conditions are within expected ranges within the EMPA estuaries. Unlike with the nekton function, fewer published ranges exist for decomposing communities. However, in southern CA, it is most likely that an estuary will exceed temperature thresholds as compared to central and north regions (due to a latitudinal effect). Event-driven changes in temperature, DO and salinity occur regularly and have corresponding effects on decomposer communities.

Level of Confidence in Findings:
Our level of confidence in these findings is low. Over the last few years, many steps have been implemented to better standardize data collection, data QA/QC, and data analysis with these large time-series datasets. However, due to the current resources, water quality data has been collected inconsistently and data are not concurrent in different systems. Due to these inconsistencies in data collection, we used a subset of the water quality data in this report to illustrate how California estuaries are extremely dynamic with varying water quality conditions. At this time, we cannot provide statistical summaries or provide management guidance about these systems. In order 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).

Recommendations to enhance confidence:
The essence of this condition statement is to track how often and for how water quality conditions influence microbial, invertebrate, and biochemical processes that break down organic matter, affecting

nutrient cycling and secondary production in estuarine ecosystems. We recommend the consistent collection of water quality data over the next several years to begin to link water quality conditions with physiological thresholds.

Condition Indicator 2: The estuary supports high vegetation cover in the upper marsh elevation habitats (e.g., the mid and high marsh zones; indicator: vegetation).

Justification of Condition Statement:

The presence, types, and distribution of primary producers influences the amount and quality of autochthonous organic matter available for transformation by decomposers. In addition, the presence of vegetation for microhabitat creation (E.g. shaded, cooler habitat) also influences the community composition of decomposers. Thus, extensive high vegetation cover can support the transformation of allochthonous and autochthonous organic matter into fauna, which in turn can be consumed by the resident nekton of the estuary.

Main Findings:

High vegetation cover in the upper marsh was present for all but three of the surveyed estuaries (one in each region). This likely indicates the presence of sufficient autochthonous organic material from plants as well as microhabitats that facilitate aerobic (thus faster) biogeochemical cycling and breakdown of all organic matter.

Level of Confidence in Findings:

Our level of confidence in these findings is high. Local experts are able to accurately identify plant species on the ground.

Recommendations to Enhance Confidence:

Potential ways to improve our confidence would be to include more vegetation transects per station, or to sample vegetation in both seasons. Currently these transects are only being sampled in the Fall season. Another option would be to randomly select a number of additional vegetation plots throughout the estuary to sample rather than whole transects. Additionally, more research could be conducted to directly connect vegetation cover with the transformation of allochthonous and autochthonous organic matter and quantify the amount of matter.

Condition Indicator 3: The benthic infauna community composition is representative of the estuary type and salinity regime and contains habitat-appropriate composition of feeding types (indicator: benthic infauna).

Justification of Condition Statement:

Benthic infauna are both key to the breakdown of organic material as well as serve a critical food source for many nekton species, therefore it’s important to have systems that have representative communities. Marsh decomposer communities include diverse groups of invertebrates, fungi and bacteria that often work synergistically to break down complex carbon substrates such as lignocellulose under both aerobic and anaerobic conditions. Structural differences in macrofaunal communities between natural and created systems have been shown to translate to higher trophic levels by altering foraging patterns of nekton.

Main Findings:

Benthic infauna (while data are sparse) indicate that infauna across a range of taxonomic and functional groups are present in high abundances in most estuaries. When abundance or functional diversity are low, it is likely related to sampling locations, grain size, or potentially inlet status. In order to quantitatively demonstrate those drivers, increased sampling with increased funding would be needed.

Level of Confidence in Findings:

Our level of confidence in these findings is medium to low. However, due to the current resources and the larger core sizes originally taken in Fall 2023, not all invertebrate cores from each estuary have been processed in time for this report. Future confidence in scores will be increased as these remaining cores are processed. Due to the low sample size processed for this report, we only had two estuaries represented in this report to illustrate how California estuaries vary in terms of invertebrate communities. At this time, we cannot provide statistical summaries or provide management guidance about these systems.

Recommendations to Enhance Confidence:

Confidence in benthic infauna scoring can be increased through several strategies, including higher replication sampling strategies, accurate identification methods, and enhanced data analysis technique development. This framework has already been modified for the next sampling time period by collecting higher replicates of smaller cores. In addition, further core processing as well as more fine scale taxonomic identification are planned, which will increase confidence. One suggestion moving forward might be to divide the sampling zone into different strata based on habitat types or environmental gradients (e.g., sediment type, inlet status) to ensure a more comprehensive assessment using a similar number of cores. Finally, similar to recommendations around nekton scoring, next steps include using experts to modify existing invertebrate indices to apply to these estuarine systems. We will also strive to incorporate environmental data (e.g., sediment characteristics, water quality, temperature) into analyses to assess how abiotic factors influence benthic infauna and inform management.

Condition Indicator 4: There is high habitat complexity and interspersion across the estuary as defined by a variety of physical habitat types (indicator: level 1-CRAM).

Justification of Condition Statement:

High habitat complexity and interspersion across the estuary can provide a variety of physical habitats for nekton 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. Scores will be derived following the same process described above.

Main Findings:

Habitat complexity is a key metric that we were able to score. Generally, these scores correlate with the size and intact slope of the marshplain. Larger and more intact estuaries scored higher than those with limited size, highly urbanized watersheds, and/or fragmented landscapes. Similar to high vegetation cover, a diversity of habitats supports sufficient organic material as well as microhabitats that facilitate aerobic (thus faster) biogeochemical cycling and breakdown of all organic matter.

Level of Confidence in Findings:

Our level of confidence in these findings is high. The California Rapid Assessment Method has been extensively tested and validated since 2005. This is a reliable tool to assess habitat condition.

Recommendations to Enhance Confidence:

Next steps include ensuring that locations for CRAM evaluations align with monitoring stations for estuaries that were previously scored and conducting CRAM surveys for all estuaries in the project (e.g., Bolsa Chica, Morro Bay, Bolinas Lagoon, Drakes Estero). Additionally, each station should be surveyed every 2-3 years to ensure that accurate data is being used in these analyses.

Condition Indicator 5: The extent and distribution of SAV is representative of the estuary type (indicator: SAV).

Justification of Condition Statement:

Submerged Aquatic Vegetation (SAV) provides an important role in the ecology of coastal systems, as it provides unique structure and enhancement of biogeochemical processes. SAV can serve as temporary refuge from predators, enhance carbon and nitrogen cycling, and serve as a productivity hot spot for commercially and societally important fauna, as well as protected species like sea turtles. SAV provides critical habitat for meiofauna and macrofauna. As mentioned above, we don't have robust enough data to begin evaluating this condition statement and hope to do so in subsequent reports.

Main Findings:

Presence of SAV within the estuaries is indicative of another organic matter source, a habitat for many organisms, and contributor to nutrient cycling. SAV surveys were not in the scope of this work in this timeframe. Preliminary scores were generated for this indicator using estimates from seining work, and these scores indicate that sites that are perennially open tend to have more eelgrass, which is likely to influence secondary production and reduce eutrophication.

Level of Confidence in Findings:

Similar to Nekton Habitat, our level of confidence in these findings is low. In subsequent reports, we hope to better incorporate SAV monitoring data in evaluating Secondary Production.

Recommendations to Enhance Confidence:

Though the EMPA program realizes the importance of tracking SAV extent and distribution through time, extensive resources are needed to implement a complete monitoring program. We must invest in consistent monitoring and mapping of SAV beds to understand how nekton habitat may vary with SAV extent, distribution, and health.

Condition Indicator 6: Sediment nutrient ranges are indicative of optimal benthic infauna productivity (indicator: sediment nutrients).

Justification of Condition Statement:

Benthic infauna productivity is directly tied to secondary production. One way to evaluate an optimal benthic infauna community is to evaluate whether or not sediment nutrients (TOC: Total Organic Carbon and TN: Total Nitrogen) are in ranges consistent with optimal benthic infauna communities. In southern

California, there are established thresholds of sediment organic matter concentrations in muddy sediments associated with changes in macrobenthic community composition (Walker et al. 2022). Therefore, sediment nutrient thresholds can be used to determine the probability of the systems having biological integrity (Table 8). These numeric thresholds have only been validated in southern California and are only appropriate for samples dominated by mud (<60% sand).

Table 8. Different TOC or TN thresholds (mg/g) that are predictive of a 0.8, 0.7, and 0.6 probability of having a benthic community in good condition given that amount of TOC or TN (Walker et al. 2022).

Parameter	Sediment Type	Probability		
		0.6	0.7	0.8
TN	Mud	3.68	2.58	1.23
TOC	Mud	28.96	22.9	15.51

Main Findings:
While sediment nutrient ranges indicative of optimal benthic productivity were only validated for southern CA subtidal areas based on published tools, most estuaries in southern California demonstrated limited impairment. Next steps include validation for a larger latitudinal range of estuaries as well as the intertidal elevation.

Level of Confidence in Findings:
Our level of confidence in these findings is medium. Although most systems in southern California demonstrated limited impairment, nutrient thresholds were derived based on subtidal benthic infauna samples. Next steps include validation for a larger latitudinal range of estuaries, as well as the intertidal elevation.

Recommendations to Enhance Confidence:
At this time, no scores were assigned to this condition statement indicator due to lack of validation across the California coast and low sample size. We recommend increased sampling in order to conduct regression analyses to validate nutrient thresholds across the state of California.

Summary of Results for Secondary Production

A summary of results for Secondary production are shown in Table 9. Overall, due to missing data or the need for additional framework development, the secondary production function is not scored in this report. Future steps including validation of sediment nutrient ranges for other estuaries, better supporting water parameter measuring, and increasing SAV mapping efforts will enable this function to be scored effectively.

Table 9. Due to missing data and the need for additional framework development, the Secondary Production function is not scored in this report. We only provide the scores for the three condition statements that were able to be scored.

Estuary	Water Quality	Vegetation Cover	Benthic Infauna	Habitat Complexity	SAV	Sediment Nutrients	Compiled Score
Ten Mile River	NA	3	NA	2.3	2	NA	NA
Big River	NA	3	NA	2.8	3	NA	NA
Navarro River	NA	2	NA	1.5	2.5	NA	NA
Drakes Estero	NA	3	NA	NA	2	NA	NA
Bolinas Lagoon	NA	3	NA	NA	1	NA	NA
Pajaro River	NA	3	NA	1.5	1	NA	NA
Moro Cojo Slough	NA	3	NA	1.0	1	NA	NA
Carmel River	NA	3	NA	2.7	1	NA	NA
Arroyo de la Cruz	NA	2	NA	2.0	1	NA	NA
Morro Bay	NA	3	NA	NA	2	NA	NA
Goleta Slough	NA	3	NA	1.5	1.5	NA	NA
Ventura River	NA	2	NA	2.2	1	NA	NA
Malibu Lagoon	NA	3	NA	1.7	2.5	NA	NA
Bolsa Chica	NA	3	NA	NA	3	NA	NA
Newport Bay	NA	3	NA	2.0	2	NA	NA
Batiquitos Lagoon	NA	3	NA	1.3	3	NA	NA

Outreach and Engagement

North Coast Outreach and Engagement

Recognizing that estuarine monitoring along the North Coast, particularly north of Mendocino County, has been underrepresented within the statewide EMPA Monitoring Program, focused outreach activities were undertaken and the information gathered provides insights on opportunities and next steps. The EMPA team outreach effort for the North Coast region was motivated by the following goals: 1) raise awareness towards greater use and expansion of EMPA Monitoring Program standard monitoring procedures (SOPs) and contribution to the statewide effort, 2) explore collaboration opportunities to fund monitoring coordination and expanded estuarine monitoring aligned with the state-wide effort, and 3) identify potential coordination partners.

Beginning in the fall of 2023, outreach planning, led by the San Francisco Estuary Institute and in collaboration with the EMPA team, involved initial conversations with key partners, the development of a contact log, and establishment of a process for outreach. In the spring of 2024, an outreach email and interest survey were sent out to 35 identified individuals. The team received 16 responses and then subsequently met with 11 people as part of two informational sessions offered on May 29th and 30th, 2024, with two follow-up conversations. Participants included representatives from state and local agencies, Tribes, academia, non-profits, and land trusts. Based on these conversations, the team documented current North Coast monitoring, identified interests in potential adoption of EMPA Monitoring Program SOPs, and explored partnership and coordination capacity. The discussion also brought forward additional challenges and opportunities. The team then provided a set of potential near-term activities, which are intended to support priorities going forward. Overall, this outreach effort demonstrated broad and strong interest in the program, documented challenges around funding and capacity, and identified potential next steps for increasing engagement with the EMPA Monitoring Program and capacity-building and coordination entity opportunities. The activities and outcomes of the effort were documented in a brief memo, “Outreach and Engagement to Build Capacity for Estuarine Monitoring in the North Coast of California” (Appendix E: Outreach and Engagement to Build Capacity for Estuarine Monitoring in the North Coast of California).

Presentations

A key part of building a standardized statewide estuary monitoring program involves sharing the framework with the greater estuary monitoring community to gain interest and adoption. A concerted effort was made to share the Estuary MPA Monitoring Framework via conferences, work groups and local symposiums. In 2023 and 2024, presentations were given at 12 conferences and local workgroup meetings and symposiums.

- American Fisheries Society Conference. March, 2023. Brooke Fulkerson. A Framework for Condition Assessment and Monitoring of Estuary MPAs in California.
- California Estuarine Monitoring Workshop in Tiburon, CA. August, 2023.
- Coastal and Estuarine Research Federation Conference. November, 2023. Kevin O’Connor, Ross Clark, Jan Walker, Eric Stein, Christine Whitcraft, Brent Hughes, John Largier, David Jacobs, and

Christina Toms. Monitoring for management: Evaluating ecosystem function in California estuaries.

- Coastal and Estuarine Research Federation Conference. November, 2023. Ross Clark, Kevin O'Connor, Jan Walker. Monitoring for management: A modular, ecosystem function-based assessment framework to assess estuarine condition.
- California State Parks Estuary Workgroup. December, 2023. Kevin O'Connor, Ross Clark, Jan Walker, Eric Stein, Christine Whitcraft, Brent Hughes, John Largier, David Jacobs, and Christina Toms. Monitoring for management: Evaluating ecosystem function in California estuaries
- Central Coast Water Board TMDL Roundtable. February 2024. Ross Clark, Kevin O'Connor, Jan Walker, Eric Stein. Monitoring for management: A modular, ecosystem function-based assessment framework to assess estuarine condition
- North Santa Monica Bay State of the Watershed 2024 (Malibu). April 25, 2024. Christine Whitcraft. Monitoring for management: Evaluating ecosystem function in California estuaries.
- EMPA connection to Waterboard Programs. May 2024. Ross Clark, Kevin O'Connor, Jan Walker, Eric Stein. EMPA Monitoring Program: A modular, ecosystem function-based assessment framework to assess estuarine condition.
- UCSC Wetlands Science Symposium. June 2024. Jan Walker. Monitoring for management: Leveraging regional efforts to assess estuarine condition.
- UCSC Wetlands Science Symposium. June 2024. Ross Clark, Kevin O'Connor, Jess Turner. Linking Estuarine Condition Assessments, Marsh Plain Dynamics and Sediment Carbon Sequestration
- Environmental Management Symposium. August 2024. Christine Whitcraft. Invited plenary. Monitoring for Management: A Modular, Ecosystem Function-based Assessment Framework for Estuaries
- Western Society of Naturalists Conference. November 2024. M. Abrecht, D.K. Jacobs. eDNA fish faunal analysis of estuarine marine protected areas in California

Website Updates

Over the last three years, the EMPA program has expanded to include new partners and estuaries. To increase transparency among groups, we improved our EMPA landing page and website[16] to include:

1. Data Download - The first component highlighted on the website is the new data download tool[17]. This query tool allows all users to download available data by region, estuary type, MPA status, individual estuary, year, or SOP.

[16] https://empa.sccwrp.org

[17] https://nexus.sccwrp.org/empadataquery/

2. Project Information - We have included both the EMPA project information, as well as any other information on projects using the EMPA framework to collect and upload data into the EMPA portal. Each website card hosts relevant scopes of work and published datasets.
3. Monitoring Resources - All EMPA monitoring resources are available for download, including SOPs and field data sheets.
4. Data Upload Infrastructure - The bulk of the website hosts the data infrastructure to allow users to submit data into the EMPA portal. This includes the data templates and relevant data schemas or descriptions (look up lists, column descriptions, etc.). The website also hosts the data submission tool[18].
5. Metadata - Due to the expansion of the program and the ability to accept data from other projects, an extensive effort has been made to catalog all the appropriate project metadata. Metadata is available when data is downloaded.

[18] https://checker.sccwrp.org/empachecker/

Lessons Learned and Recommendations to Improve the EMPA Monitoring Framework Over Time

The EMPA Monitoring Framework describes a consistent, comprehensive approach to statewide estuarine monitoring. The EMPA team has worked to refine and enhance the EMPA assessment framework, field protocols, and data analysis approaches. The framework is intended to be modified and expanded over time as information needs shift, new monitoring programs and partners come online, and monitoring methods are iteratively improved. After each field season, team members from each regional team meet to discuss sampling protocols and challenges, and document method improvements. Below are a number of lessons learned and recommendations to improve the EMPA monitoring framework over the next few years, as resources allow.

Commitment to long-term Mapping and Monitoring

1) **The EMPA program collects baseline information across a broad spectrum of functions. To further understand why a system may be performing poorly, more extensive follow-up assessments should be conducted.**

The EMPA program was designed to collect baseline information to assess key functions in an estuary within a 3-day sampling campaign, twice a year. The data collected are able to broadly describe the overall condition and functions of the system. However, to further understand shifts in and drivers of condition and function, more extensive follow-up assessments are often necessary. For example, if a system scores low for secondary production, additional monitoring (such as supplemental indicators and/or increased sampling replication) may need to be added to understand the cause of a low score. The California Estuary Monitoring Workgroup and partner estuary managers can help the EMPA team identify thresholds and triggers for supplemental monitoring.

2) **Long-term time-series water level and water quality data are fundamental to estuarine assessment, and investments in the collection and management of these data should be prioritized.**

Hydrology and water quality are fundamental drivers of estuarine extent, condition, and functions, especially in California which experiences tremendous intra- and inter-annual variability in rainfall, runoff, and temperatures. This is among the many reasons why the EMPA monitoring framework emphasizes time series collection of water level and water quality data. However, continuous time series monitoring of these indicators is expensive and requires significant data management infrastructure, which is beyond the capabilities of most managers and NGOs. The EMPA program currently only monitors water levels and water quality for one month twice a year, and while this cost-effective approach helps managers broadly characterize estuarine hydrology and water quality, it can miss short-term/extreme events that exert significant and lasting influences on estuarine conditions.

To fully capture the status, trends, and inherent dynamism of these systems, and identify management interventions that can support long-term estuarine health and resilience, significant investment is necessary to improve water level and water quality data collection at EMPA sites over longer time periods (>5 years). Relatively few estuaries in California support long-term water level/water quality monitoring, so this expansion would represent a significant advance in statewide tracking of estuarine function. Effective and high-quality data collection requires, at a minimum, monthly download, intercalibration, and maintenance of data loggers. Efficient data storage requires the infrastructure for large data management and query, as well as personnel hours for comprehensive quality assurance/quality control. Thankfully, effective procedures for data collection and management are well-established by federal partners, including NOAA/NERRs, USGS, and the NEPs.

3) **The state and its partners should fund consistent statewide remote sensing and mapping that tracks the abundance, distribution, and condition of estuarine resources.**

Consistent with the USEPA's three-tiered approach to wetland monitoring and the state's Wetland and Riparian Area Monitoring Plan (WRAMP), the EMPA framework is most useful and powerful where it can leverage Level 1 (remote sensing and mapping data), Level 2 (rapid assessment), and Level 3 (quantitative field assessment) data. Timely and effective management of estuarine resources at local, regional and statewide scales requires up-to-date and comprehensive data describing the abundance, distribution, and condition of estuaries and their contributing watersheds. Key estuarine attributes/indicators that can be remotely sensed and mapped include elevations, hydrology, and vegetation. Level 1 data collected at routine intervals are key to detecting change, identifying trends, prioritizing management actions, and serving as inputs to models and assessment tools, such as those that can anticipate the impact of sea level rise and changes in watershed hydrology on estuaries. They also provide important landscape-scale context for the analysis and interpretation of site-scale data. Historically, mapping of estuarine resources in California has occurred irregularly and in a piecemeal manner, making it difficult to achieve these objectives. To remedy this situation, we recommend the OPC and its partners develop a program to routinely and comprehensively map coastal habitats statewide. Such a program could leverage OPC investments in mapping coastal wetlands, beaches, and watersheds[19], automated habitat mapping protocols developed by the SF Estuary WRMP[20], state LiDAR efforts[21], and other existing efforts. Recent interest by OPC in funding regular collection of LiDAR data along the coast is an encouraging step in this direction.

Remote sensing approaches that utilize satellite data may be especially helpful in monitoring the enormous geography of the California coast. In 2021, the EMPA team collaborated with NASA-JPL to build a Google Earth Engine-based tool which can be used to assess and classify estuaries along the California coast. This interactive, cost effective, user-friendly tool uses maps and time series satellite data to quantify various water quality metrics including temperature, chlorophyll concentrations, and mouth condition (degree of opening/closure) over time. Unfortunately, this tool is still not available to the public due to prolonged NASA review, but alternative satellite-based approach (Inlet Tracker, Heimhumber et al. 2021) may be equally suitable for the EMPA framework. Recently, team members have also been meeting with scientists from Geoscience Australia to understand how their DEA Intertidal[22] product can support more comprehensive mapping of hard-to-survey intertidal mudflat habitats.

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[19] https://www.sfei.org/projects/coastal-wetlands-beaches-and-watersheds-inventory
[20] https://www.sfei.org/projects/baylands-habitat-map-2020
[21] https://www.arcgis.com/apps/View/index.html?appid=9204adf2fd1546379b845d163ef2544a
[22] https://www.ga.gov.au/scientific-topics/dea/dea-data-and-products/dea-intertidal

Finally, drone-based assessment techniques can allow for temporal flexibility and cost-effective repeat photogrammetry, affording a significant advancement in other remote sensing approaches for coastal mapping, habitat monitoring, and environmental management. Drone surveys provide on-demand remote sensing at low cost and with reduced human risk. Drones are currently being used by the Morro Bay NEP and in San Diego Bay to monitor SAV beds, and approach that should be expanded to other EMPA sites where SAV conservation and enhancement is a management priority.

Ensuring Support for Training and Enhancement of Protocols

4) **Team intercalibration is critical for consistent, high quality data collection across regions and partners.**

Due to COVID protocols in 2021, we were unable to host an EMPA team intercalibration to review monitoring protocols and procedures in the field. Even though we held virtual team trainings, SOPS were interpreted and implemented slightly differently across regional teams. In 2023, we held our first EMPA team intercalibration at San Elijo Lagoon in southern California. This intercalibration allowed us to review all 15 SOPS together and perform them as a group in an estuarine environment. We were able to clear up discrepancies across regions and better understand how each region faces different topographic, hydrologic, site access, and other challenges. Due to this intercalibration exercise, we were able to clarify our SOPS and collect higher quality data. Moving forward, we suggest implementing yearly intercalibrations to increase data collection consistency, support team collaboration, and learn and grow as a program.

5) **SOPS may have to be adjusted based on mouth state (open vs closed), especially for systems with extreme inundation.**

A number of the EMPA bar-built estuary sites can become inundated early in the fall season (typically when early rains encounter a closed inlet condition but do not breach) which inhibits station access and data collection. In previous seasons, teams have acted accordingly to collect the data they can, given the higher water levels, but this results in a much lower data yield at affected sites for the fall season. One method of addressing this challenge is to compensate for missed SOPs in fall by executing them instead during the spring sampling season. An alternative strategy would be modifying SOPs so that data can be collected at stations flooded by higher water levels in the fall.

6) **eDNA is an effective tool to track species composition over time, however method improvement is still ongoing.**

Over the last few seasons of eDNA collection, the EMPA team has learned multiple lessons spanning sample collection through analysis. Results can be found in Appendix F: Additional SOP Results. Efficient eDNA water collection and filtering in the field is still proving challenging. Estuarine water can be extremely turbid, often resulting in long water filtration times and clogged filters that aren't ideal for processing in the field. Freezing and transporting water samples for lab filtration has proved effective thus far, however it can be costly to overnight frozen water bottles. Other alternatives, including pre-processing of samples using filters with larger pore sizes, may be suitable for particular sampling purposes. Selection of sampling stations may also vary with project goals. For example, the addition of upstream eDNA stations may support recovery of freshwater taxa or investigation of spatial variation within a system. Regarding analysis, examining data at the sequence level proved essential, allowing for greater confidence in taxonomic assignments as well as the detection of genetic diversity within species of management interest, like steelhead trout. This process also highlighted the significance of primer selection in eDNA monitoring, as metabarcoding primers differ in their ability to detect or resolve certain groups and thus differ in their ability to answer specific scientific or management questions. Following this, project goals should guide decisions on which primer, or potentially suite of primers, should be employed in monitoring protocols.

Exploring new Partnerships to Enhance Data Collection

7) **Birds and charismatic megafauna are critical ecological indicators for habitat quality and outcomes of management interest for program partners, and could be considered as additional indicators in the EMPA framework.**

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. Proper management of estuarine habitat is especially important for special-status species, whose low numbers may be most impacted by poor foraging and reproductive opportunities. EMPA program partners such as CDFW, USFWS, Joint Ventures, and NGOs often have specific targets for the recovery of these species, and dedicate considerable resources to recovery efforts. 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. Numerous estuaries within the EMPA monitoring network are known for their bird and wildlife populations. For example, Drakes Estero, one of the least visited EMPA sites, has a wide diversity of megafauna utilizing the estuary that includes river otters, coyote, cattle, tule elk, California sea lions, harbor seals, and the occasional sea otter (see Silliman et al. 2018; Fig. 1).

Despite the importance of birds and wildlife as indicators of estuarine health, there are several challenges to integrating monitoring of these species into the EMPA framework. Different bird species and guilds often require different monitoring SOPs (e.g. point counts, transects, playback, etc.) during different seasons (breeding, nonbreeding) to accurately capture status and trends of bird abundance and community composition over time. The same is true of wildlife monitoring, which can include coordinated distance monitoring (observing from a far for extended periods of time), wildlife camera trapping, scat analysis, eDNA, tagging/relocating, and modelling (Tinker et al. 2017, Sanchez 2021, Hughes et al. 2024). Estuaries that are frequented by humans (boaters, hunters, recreators, etc.) may alter how and when birds and other wildlife use estuarine habitats, which can complicate detections. It can be challenging to draw conclusions from site-specific data about the status and trends of species that utilize a broad spectrum of habitats throughout their life cycle, such as migratory shorebirds/waterfowl and generalists such as deer and coyotes.

To begin address these challenges, we recommend the following to consider how birds and megafauna may be integrated into the EMPA framework:

Birds. Appendix G: Bird Monitoring SOP describes an SOP for visual bird monitoring that could be piloted during future EMPA monitoring rounds if resources allow. The program could also leverage partnerships with local groups to incorporate ongoing surveys and databases like eBird. In many cases, local observers have detailed knowledge of their environment and bird populations and are at sites more frequently than the monitoring teams, which can enhance the quality and accuracy of the data collected. Additionally, by involving a wide variety of participants, data can be cross-checked and verified, increasing its reliability. One of the most well-known examples of participatory science in bird monitoring is the Christmas Bird Count by the National Audubon Society. Every year, thousands of volunteers participate in this event, contributing valuable data on bird populations, which helps track the health of bird species over time. These participatory science surveys can play key roles in monitoring birds, especially in large-scale and long-term studies that would otherwise be difficult to achieve with limited professional resources. Overall, monitoring bird populations in estuaries allows us to better understand environmental health and to implement effective conservation and management strategies.

Megafauna. Appendix H: Megafauna SOP describes an SOP for visual megafauna monitoring that could be implemented during future EMPA monitoring rounds, again if resources allow. This SOP was first piloted by the EMPA team in spring 2024 along the North Coast. Results can be found in Appendix F: Additional SOP Results. This protocol does not include humans (or their domesticated animals), which requires its own protocols (Note: EMPA is capturing indicators of human use, including monitoring for trash and microplastics – see SOP 15).

8) **The EMPA program should develop community science SOPs to expand outreach efforts and leverage public interest and participation in monitoring.**

To engage the public and local, regional, and state agencies, we recommend establishing community science programs that allow the public to participate in data collection, and expand the spatial and temporal scale of data collection efforts. We recommend establishing photo monitoring locations at each of the selected estuaries (capturing mouth conditions, marsh plain water elevations, and/or other key indicators) that encourage the public to upload photos to an online, interactive portal. This crowd-sourced data can then be used to track changes in estuary features on multiple time scales. CoastSnap[23] is one example of a program that serves as a template for this approach, by using crowd-sourced photographs to quantify change in beach and dune characteristics over time. We also recommend developing community data collection SOPs that can supplement data collected by the EMPA program. Volunteer-specific SOPs would allow local partners to utilize community volunteers to collect data more frequently and at more locations.

Enhancing Outreach and Communication

9) **The EMPA monitoring program should collaborate with managers and the California Estuary Monitoring Workgroup to develop interpretive frameworks for data that can be communicated via easy-to-understand estuarine report cards and dashboards.**

Early phases of the EMPA monitoring program have focused on identifying key functions and indicators of interest, developing SOPs and data management infrastructure, field testing of monitoring approaches,

[23] https://siocpg.ucsd.edu/projects/coastsnap/

and data analysis/synthesis to primarily address the information needs of OPC and CDFW. As time passes and the program matures, it should expand to include interpretive frameworks for data that can support decision-making by a broader range of program partners. Key outputs of these frameworks are report cards and dashboards that allow complex quantitative and qualitative data to be synthesized into simpler metrics that can be shared with broader audiences (including the general public).

To develop its initial monitoring blueprint in 2020, the EMPA team asked members of the program's Management Advisory Committee to identify key management questions that they hoped would be answered at least in part by the program (Table 10).

Table 10. Key management questions identified by the Management Advisory Committee.

Assessing baseline conditions and subsequent trends of key indicators	**Assessing factors that affect conditions**	**Developing information to support**
▪ Habitat abundance and distribution ▪ Habitat condition ▪ Abundance and distribution of native, culturally important, and special-status species ▪ Abundance and distribution of invasive species	▪ EMPA designation and protection level ▪ Recreation and consumptive human uses ▪ Upstream water diversions ▪ Watershed urbanization and agriculture ▪ Climate change impacts (e.g., temperature, sea level rise, ocean acidification, freshwater and sediment inputs	▪ Nature-based climate change adaptation ▪ Mouth/inlet management ▪ Habitat restoration, enhancement, and adaptive management ▪ Inland/upslope migration of habitats ▪ Infrastructure realignment
Identifying appropriate reference or comparator locations for estuaries		
Assessing how EMPAs support offshore ecological communities		

The team also developed a preliminary crosswalk between these questions and the monitoring indicators that would help answer them. This crosswalk should be refined with input from managers and the California Estuary Monitoring Workgroup to form the foundation of a broader interpretive framework. This framework would describe how EMPA data can be analyzed and interpreted to address specific management and monitoring questions that are a high priority for managers. It would describe how Level 1-2-3 data could be integrated to assess how estuaries respond to climate change and management actions across different spatial and temporal scales. This framework should describe a potential ongoing role for the CEMW in advising how program data should be applied to decision-making.

This framework should also describe strategies for information reporting to diverse audiences (managers, technical staff, the general public, etc.). A priority request from the MAC early in EMPA monitoring program development was to identify scoring criteria that would help evaluate the overall condition of estuaries and efficacy of MPAs. We recommend working with the CEMW to develop a report card for estuaries that can provide management recommendations for stressor amelioration, restoration actions, and adaptive management.

Finally, over the course of the next three years, the EMPA team will develop an automated dashboard to help convert existing and ongoing state and regional monitoring data into actionable information that can help agencies evaluate wetland health and condition and inform management decisions. At this time, the main goal of the dashboard is to automate the ecosystem function scoring calculations to generate real-time assessment information. We will host the assessment information and tools within a public-facing interactive dashboard hosted on the EMPA website.

10) The EMPA program should leverage partner regional monitoring efforts and related data sets to help answer management questions.

We recommend continued efforts to crosswalk the EMPA monitoring program with other regional programs. Examples include:

- The EMPA framework recognizes the importance of SAV to numerous estuarine functions. However, monitoring the health and distribution of SAV in estuaries is time-consuming and beyond the scope of what can be monitored in a 3-day sampling timeframe. As a result, the Program must partner with other monitoring groups that are already conducting this work. Programs that currently monitor SAV include those at the Morro Bay National Estuary Program, Elkhorn Slough NERR, and Southern California Regional Monitoring Program.
- The San Onofre Nuclear Generating Station (SONGS) Mitigation Monitoring Program at the University of California, Santa Barbara monitors a variety of indicators at several southern California estuaries (San Dieguito Lagoon, Point Mugu, Tijuana Estuary, Carpinteria).
- Monitoring programs at the Elkhorn Slough and Tijuana River National Estuarine Research Reserves collect data on multiple biotic and abiotic parameters.
- There are many upcoming estuary monitoring projects in the North Coast region, including at Redwood Creek and Elk River. Partnering with these efforts would help achieve the goals of the EMPA program’s North Coast Strategy (SFEI 2024).

11) Program participants should prioritize the long-term collection of a subset of indicators to address key management questions.

The EMPA framework includes 15 SOPs and 9 priority functions, and was intended to provide a “menu” of monitoring options so that program participants can select those that best meet their specific information needs and align with institutional capacity. Implementing all of these SOPs and monitoring all functions requires a great deal of time and effort that is beyond what most program participants can consistently sustain. We therefore recommend that EMPA partners work with the California Estuary Monitoring Workgroup (CEMW) to identify a subset of indicators/SOPs that address key functions of statewide management importance. This would allow managers to prioritize a subset of indicators/SOPs in years when available resources are lean, help broaden the spatial coverage and institutional diversity of program participants, and reduce the risk that sudden changes in funding and staff resources will lead to gaps in key datasets. The list in Table 11 below from the Southern California Wetlands Recovery Project, could be a useful starting point for the CEMW.

Table 11. Subset of EMPA Monitoring Program SOPs selected by the Southern California Wetlands Recovery Project as their core indicator list.

Indicator	Method
Habitat & Elevation	Menu of options: High resolution aerial imagery of habitat types
Marsh Vegetation	Transect surveys used for ground truthing aerial imagery. Vegetation composition, invasive species tracking
Water Quality	Continuous sampling
	Discrete sampling
Hydrology	Water level sensor
Rapid Assessment	CRAM
Fish	Menu of options
Invertebrates- macrofauna	Targeted checklist of key species
Eutrophication	Sediment grab

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Appendix A: Inventory and Characterization of Studied Sites

The 16 selected sites represent a range of estuary types, sizes, and levels of protection in California (Table A- 1).

Four MPAs were selected on the north coast region including two lagoonal (Ten Mile and Navarro River), one riverine (Big River) and one embayment (Drakes Estero) estuarine systems. Bolinas Lagoon, selected as the fifth northern California estuary, is a reference site and classified as an embayment.

Along the central coast region, three MPAs were selected. Two are classified as embayments (Moro Cojo Slough and Morro Bay), while the third is lagoonal (Arroyo de la Cruz). The two reference sites (Pajaro and Carmel) are classified as lagoonal estuaries.

A similar combination of estuary types was selected for the south coast, including two embayment estuaries (Upper Newport Bay and Batiquitos Lagoon), and one lagoonal estuary (Goleta Slough). Two reference sites (Malibu Lagoon and Ventura) are classified as lagoonal estuaries. In 2023, Bolsa Chica (embayment) was added for monitoring.

All estuary images provided below were obtained from the California Coastal Records Project[24], unless otherwise noted.

[24] www.californiacoastline.org

Table A- 1. Name, location, size and other pertinent information on the sixteen selected EMPA monitoring sites.

Estuary Name	Latitude	Longitude	MPA Name	Estuary Size (acres)	Estuary Classification (CMECS)	Region of State	Adjacent or within State or National Park?	Adjacent to offshore MPA? (within 3 miles)
Ten Mile River	39.55368	-123.76719	Ten Mile Estuary SMCA	212	Lagoonal Estuary	North Coast	Yes, MacKerricher SP	Yes, Ten Mile Beach SMCA, Ten Mile SMR
Big River	39.30197	-123.79277	Big River Estuary SMCA	314	Riverine Estuary	North Coast	Yes, Mendocino Headlands SP	No
Navarro River	39.19173	-123.76139	Navarro River Estuary SMCA	185	Lagoonal Estuary	North Coast	Yes, Navarro River Redwoods SP	No
Drakes Estero	38.03079	-122.93373	Drakes Estero SMCA, Estero de Limantour SMR	2,692	Embayment/Bay	North Coast	Yes, Point Reyes National Seashore	Yes, Point Reyes SMR
Bolinas Lagoon	37.91790	-122.67944	N/A	1,261	Embayment/Bay	North Coast	Yes, Golden Gate National Recreation Area	No
Pajaro River	36.84549	-121.80534	N/A	793	Lagoonal Estuary	Central Coast	Yes, Zmudowski SB	No
Moro Cojo Slough	36.79578	-121.78270	Moro Cojo Slough SMR	975	Embayment/Bay	Central Coast	No	No
Carmel River y	36.53703	-121.92670	N/A	93	Lagoonal Estuary	Central Coast	Yes, Carmel River SB	Yes, Carmel Bay SMCA, Point Lobos SMR
Arroyo de la Cruz	35.70998	-121.31025	Piedras Blancas SMR	23	Lagoonal Estuary	Central Coast	Yes, Hearst San Simeon SP	Yes, Piedras Blancas SMR
Morro Bay	35.36654	-120.86563	Morro Bay SMR, Morro Bay SMRMA	2,586	Embayment/Bay	Central Coast	Yes - Morro Bay SP, Montana de Oro SP	No
Goleta Slough	34.41717	-119.82404	Goleta Slough SMCA (No-Take)	325	Lagoonal Estuary	South Coast	No	Yes, Campus Point SMCA
Ventura River	34.27601	-119.30806	N/A	38	Lagoonal Estuary	South Coast	Yes, Emma Wood SB	No
Malibu Creek	34.03258	-118.68058	N/A	34	Lagoonal Estuary	South Coast	Yes, Malibu Lagoon SB	No
Bolsa Chica	33.682540	-118.03669	Bolsa Chica Basin SMCA (No Take)	1,300	Embayment/Bay	South Coast	Yes, Bolsa Chica SB	No
Newport Bay	33.62807	-117.88822	Upper Newport Bay SMCA	1,760	Embayment/Bay	South Coast	Yes, Upper Newport Bay Nature Preserve	Yes, Crystal Cove SMCA
Batiquitos Lagoon	33.08760	-117.3106	Batiquitos Lagoon SMCA	538	Embayment/Bay	South Coast	No	Yes, Swami's SMCA

Ten Mile River (MPA) – Lagoonal

Site Tag: NC-TEN

Ten Mile River estuary is located in northern Mendocino County in California, 220 km north of Golden Gate Bridge. The estuary is about 0.85 square kilometers in size. The watershed drains approximately 310 square kilometers, with elevations ranging from sea level to 977 meters. Annual rainfall average varies from 40 inches on the coast to 51 inches inland. Ten Mile is categorized as lagoonal and it is an intermittently closed estuary characterized by mouth closures during low-flow conditions.

Salinity varies from fresh water during river flow events to near-ocean values during summer high tide when the mouth is open. Water temperature in the estuary is low, rising a little in the fall. Dissolved oxygen levels remained close to saturation values during sampling events.

Big River (MPA) – Riverine

Site Tag: NC-BIGR

Big River estuary is located in Mendocino County, California, 200 km north of Golden Gate Bridge. The estuary is about 1.27 square kilometers in size. The watershed is approximately 470 square kilometers, and the annual rainfall average varies from 40 inches at the coast to 50 inches inland. It is classified as a riverine estuary and is typically open to the sea.

Salinity fluctuates as seawater flows in on the flood tide and out again on the ebb tide, with low-tide near-surface salinities dropping. Dissolved oxygen levels remained close to saturation during the fall observation period.

Navarro River (MPA) – Lagoonal

Site Tag: NC-NAV

Navarro River is located in Mendocino County, California, 185 km north of Golden Gate Bridge. The estuary covers an area of about 0.75 square kilometers. The watershed encompasses about 815 square kilometers and is divided into five major drainage basins. Yearly rainfall average in the watershed is about 40 inches. The estuary is lagoonal, with the river mouth closing intermittently when waves build up the beach berm, typically during summer when river flow is low.

During periods of mouth closure in both spring and fall, the water level rises in the lagoon – and in spring the water temperature also increases markedly. Bottom salinities may be low during flow events but tend to be high during periods of low flow and closure when the water column stratifies. Dissolved oxygen levels fluctuate significantly, associated with bloom events and stratification related to mouth closures.

Drakes Estero (MPA) – Embayment

Site Tag: NC-DRA

Drakes Estero and Estero de Limantour are interconnected embayments in Marin County, California, 45 kilometers north of Golden Gate Bridge. The watershed is very small (about 31.7 square kilometers) and the estuary area is large (10.9 square kilometers during the highest tidal levels). Average rainfall is 37 inches per year.

The waters in Drakes Estero and Estero de Limantour are close to seawater throughout the year, except immediately after rain events. Hypersalinity may develop at inner sites in late summer. Water temperature is close to ocean temperatures in winter but increases through spring, and waters are persistently warmer at inner sites in summer and fall. Temperatures also show intra-seasonal fluctuations associated with the spring-neap cycle and secondary influences of upwelling outside the mouth. Dissolved oxygen levels are close to saturation but vary markedly between day and night, associated with the diurnal cycle in photosynthesis (and secondary influence of tides).

Bolinas Lagoon (non-MPA reference) – Embayment

Site Tag: NC-BOL

Bolinas Lagoon was chosen as the non-MPA reference site along the north coast. It is an embayment located in Marin County, California, 18 kilometers north of Golden Gate Bridge. The estuary area is about 5.1 square kilometers and like Drakes Estero it has a small watershed (43.3 square kilometers). The average annual rainfall is 41 inches.

Most of the year, salinities are close to seawater values. Seawater temperatures are influenced by San Francisco Bay outflow and only occasionally exhibits low values characteristic of upwelled waters. Large fluctuations in temperature are tidally driven and enhanced by diurnal warming. Dissolved oxygen levels are generally close to saturation.

Pajaro River (non-MPA reference) – Lagoonal

Site Tag: CC-PAJ

The Pajaro River estuary is an intermittently closed estuary in Central California with its mouth opening to Monterey Bay, 24 kilometers southeast of Santa Cruz. The estuary area is about 3.2 square kilometers and the 3,400 square kilometer watershed extends into four counties. Yearly rainfall averages in the watershed vary from 16 inches at the coast to 40 inches inland.

Water levels of the Pajaro River estuary vary seasonally and with changes in mouth conditions. Spring tidal inflows maintain cool temperatures, but as the mouth closes in summer, water temperatures increase significantly, salinity decreases, and oxygen levels drop with periods of near-bottom hypoxia, likely associated with stratification.

Moro Cojo Slough (MPA) – Embayment

Site Tag: CC-MCS

Moro Cojo Slough is an embayment located in Monterey County California, approximately 28km southeast of the city of Santa Cruz and with its mouth opening to Monterey Bay. The estuary area is 3.95 square kilometers, and the watershed area is small (44 square kilometers). The average rainfall is 20 inches per year.

The water level in Moro Cojo Slough varies little due to a tide gate structure at the harbor. The muted tidal conditions support spring-neap cycles and water chemistry is influenced by offshore upwelling. The muted tidal exchange leads to periods of hypersalinity throughout the summer. Water temperature and dissolved oxygen concentrations exhibit strong day-night cycles associated with the shallow water and high organic content of soils within the Moro Cojo Slough.

Carmel River (non-MPA reference) – Lagoonal

Site Tag: CC-CAR

The Carmel River estuary is in Central California, 52 kilometers south of Santa Cruz. The estuary area is 0.38 square kilometers, draining a watershed of 660 square kilometers with elevations that rise up to 1,479 meters. The average yearly rainfall is 18.2 inches.

Carmel River estuary is a perched lagoon, where the closed mouth conditions support water levels that are frequently above ocean high tide levels. When the mouth is open, the lagoon will drain but water elevations within the lagoon remain above the ocean low tide due to the beach sand bar. During prolonged closures, the lagoon becomes completely fresh, with periodic wave overwash leading to high salinity subsurface water during closures resulting in persistent high salinities hypoxic near-bottom conditions. Oxygen levels are close to saturation.

Arroyo de la Cruz (MPA) – Lagoonal

Site Tag: CC-ADLC

Arroyo de la Cruz is a lagoonal estuary in Central California, 175 kilometers southeast of Santa Cruz. The estuary area is about 0.09 square kilometers. The watershed covers 208 square kilometers, with elevations from sea level to 1085 meters. The average yearly rainfall varies from 19 inches at the coast to 42 inches inland.

The muted tidal range due to a frequent beach bar leads to frequent perched conditions within the lagoon. Bottom waters are fresh for much of the year, with occasional intrusions of seawater that increase salinity for a week following mid-summer king tides events. Estuarine waters warm seasonally, with periodic wave overwashing events leading to periods with cooler high oxygen conditions.

Morro Bay (MPA) – Embayment

Site Tag: CC-MOR

Morro Bay is in San Luis Obispo County in Central California, 210 kilometers south of Santa Cruz. The estuary area is 10.5 square kilometers, and the watershed covers 188.6 square kilometers. The average yearly rainfall varies from 16 inches at the coast to 35 inches inland. Water chemistry instrumentation are maintained by the Central and Northern California Ocean Observing System (CeNCOOS) on a pier near the mouth of the Bay as well as at a site in the inner bay. Salinities at the mouth remain near seawater values with coldest water observed at high tides during active upwelling outside the Bay. With low river inflow, salinities in the inner bay frequently remain high. Salinities can drop briefly following rain events. Dissolved oxygen in the inner Bay exhibits strong day-night fluctuations and can drop below 50% saturation at night on occasion.

Goleta Slough (MPA) – Lagoonal

Site Tag: SC-GOL

Goleta Slough is an intermittently closed estuary near Santa Barbara in Southern California, about 153 kilometers northwest of Los Angeles. The estuary area is 1.31 square kilometers and receives seasonal inflow from a watershed comprising seven creeks and draining an area of 117 square kilometers. Average rainfall is 18 inches per year.

When the mouth is open, water levels rise and fall tidally, driving fluctuations in temperature and salinity. During closure events, near-bottom dissolved oxygen can drop to zero, consistent with strong stratification of salt water at depth. When the mouth is open, dissolved oxygen concentrations and water temperature fluctuates with the tides.

Ventura River (non-MPA reference) – Lagoonal

Site Tag: SC-VEN

The Ventura River estuary in Southern California is 102 km northwest of Los Angeles. The estuary area is about 0.15 square kilometers. The 585 square-kilometer watershed includes elevations from sea level to 1836 meters. The average yearly rainfall across the watershed ranges from 16.9 inches at the coast to 23.9 inches inland.

Water levels are frequently muted and perched in spring and summer when the mouth is closed. Water levels rise during king tides at the end of June and July due to wave over wash. During these periods near-bottom salinity increases markedly, before dropping again as freshwater discharge flushes high-salinity water during neap tides. When the mouth is open, salinity rises and estuary temperatures drops. Dissolved oxygen levels are commonly saturated, there are marked hypoxic events and brief anoxia that are likely associated with stratification episodes related to changing salinities.

Malibu Lagoon (non-MPA reference) – Lagoonal

Site Tag: SC-MAL

Malibu Creek estuary, known as Malibu Lagoon, is an intermittently closed estuary in Southern California with its mouth at the north end of Santa Monica Bay, about 43 kilometers west of Los Angeles. The estuary area is about 0.14 square kilometers. The watershed encompasses 282 square kilometers and is one of the largest watersheds draining into Santa Monica Bay. Average yearly rainfall is 20 inches.

Water level data show periods of closure in summer and periods of river flow and lowered salinities in winter. Sheltered from the influence of upwelling, lagoon temperatures are higher than in estuaries in central and northern California.

Bolsa Chica (MPA) – Embayment Site Tag: SC-BOL

As one of the last remaining wetland ecosystems in Southern California, Bolsa Chica is an artificial and permanently open embayment, located in Huntington Beach 64 kilometers southeast of Los Angeles. The Bolsa Chica Wetlands form the largest saltwater marsh south of Point Conception, with an area of approximately 5.26 square kilometers and a watershed spanning 78 square kilometers. The region receives an average yearly rainfall of 12 inches.

Water level data shows that Bolsa Chica is fully tidal. Year round, salt water enters the wetlands through Anaheim Bay in Seal Beach and a tidal inlet near the south end of the estuary resulting in salinity levels similar to the ocean. During the rainy season, fresh water from the Wintersburg Flood Control Channel flows into the wetlands, creating brackish conditions.

Newport Bay (MPA) – Embayment

Site Tag: SC-NEW

Newport Bay is a permanently open embayment in Southern California, located 60 kilometers southeast of Los Angeles. The estuary area is about 7.12 square kilometers. The watershed is 400 square kilometers, and includes a population of about 640,000 people. The average yearly rainfall is 12 inches.

Sensors measuring depth, temperature, conductivity (salinity), and dissolved oxygen were deployed 0.25 meters above the bottom at one location in the inner estuary.

Water level data show that the Bay is fully tidal. The bay is large enough that waters are retained in the Bay long enough to warm to a seasonal maximum in July-August. However, there is a clear spring-neap cycle in temperature associated with the bay-ocean exchange rate. Comprised almost entirely of seawater, Bay salinities remain high, with only occasional drops in salinity following rain events. Near-bottom dissolved oxygen shows persistent hypoxia near-bottom at the measurement site.

Batiquitos Lagoon (MPA) – Embayment

Site Tag: SC-BAT

Batiquitos Lagoon is a permanently open embayment in San Diego County, 140 kilometers southeast of Los Angeles. The mouth of Batiquitos Lagoon has been armored in a way that it is always open. The estuary area is 2.18 square kilometers and the surrounding watershed is 223 square kilometers. The average rainfall in the area varies from 7 to 15 inches per year.

One site in the estuary was chosen for deployment of near-bottom depth, temperature, conductivity (salinity) and dissolved oxygen sensors.

As in Newport Bay and Drakes Estero, water level data show that the estuary is fully tidal. While the bay also warms up seasonally, the estuary is smaller with cooler waters – water temperatures do not exhibit a spring-neap cycle. Salinity remains near seawater levels most of the year.

Appendix B: Modifications to Stations in 2023

Outlined below in Figure B-1 through Figure B-4 are station changes made to the North Coast sites Bolinas Lagoon, Drakes Estero, Big River, and Ten Mile River. Site maps show the station location changes within each site, and the descriptions below elaborate how and why changes were made.

Bolinas Lagoon

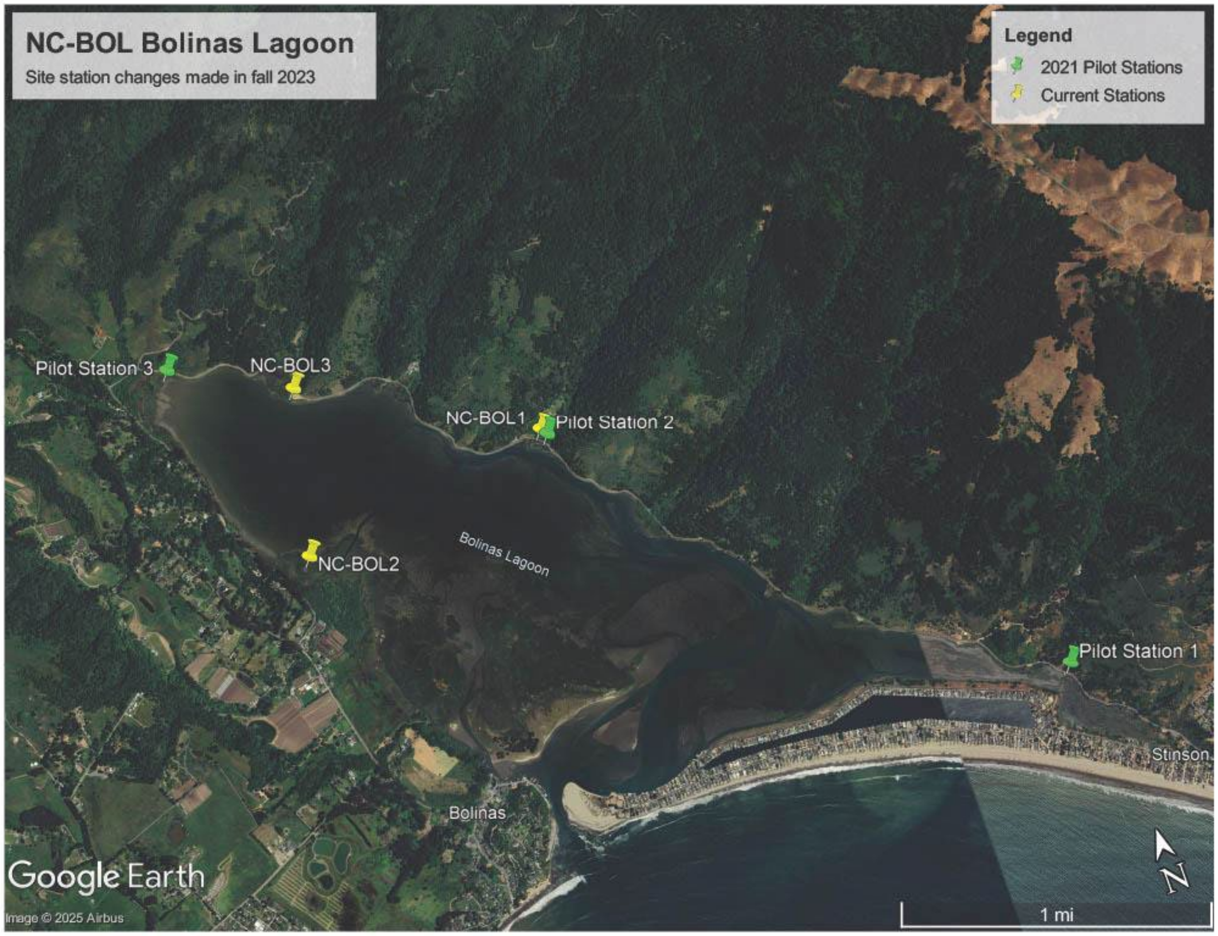


Figure B-1. Changes to stations in Bolinas Lagoon between 2021 and 2023

In Bolinas Lagoon, stations were chosen that reflect the different aspects of the lagoon, including shallow backwaters that shift to large open mudflats at low tide (Stations 2 & 3), as well as deep intertidal channels (Station 1) that generate swift tidal currents and supply ocean water to the rest of the system. Stations were also changed to accommodate the North Coast team's ability to safely and effectively execute beach seines as Bolinas can be a challenging environment for fishing due to excessive clay deposits from the surrounding watershed.

Drakes Estero

Figure B-2. *Changes to stations at Drakes Estero between 2021 and 2023*

An additional two stations were added to Drakes Estero to capture the entirety of this vast estuary and the varying communities that occur between its mouth and backwaters. In 2021, Schooner Bay was split into two stations, of which now have been collapsed into the current station 3. Additionally, the team also added Bull Point as station 2 and Limantour Beach as station 1. Data collected from each of these locations reflects different biotic and abiotic trends occurring within Drakes Estero's large bay-like system.

Big River

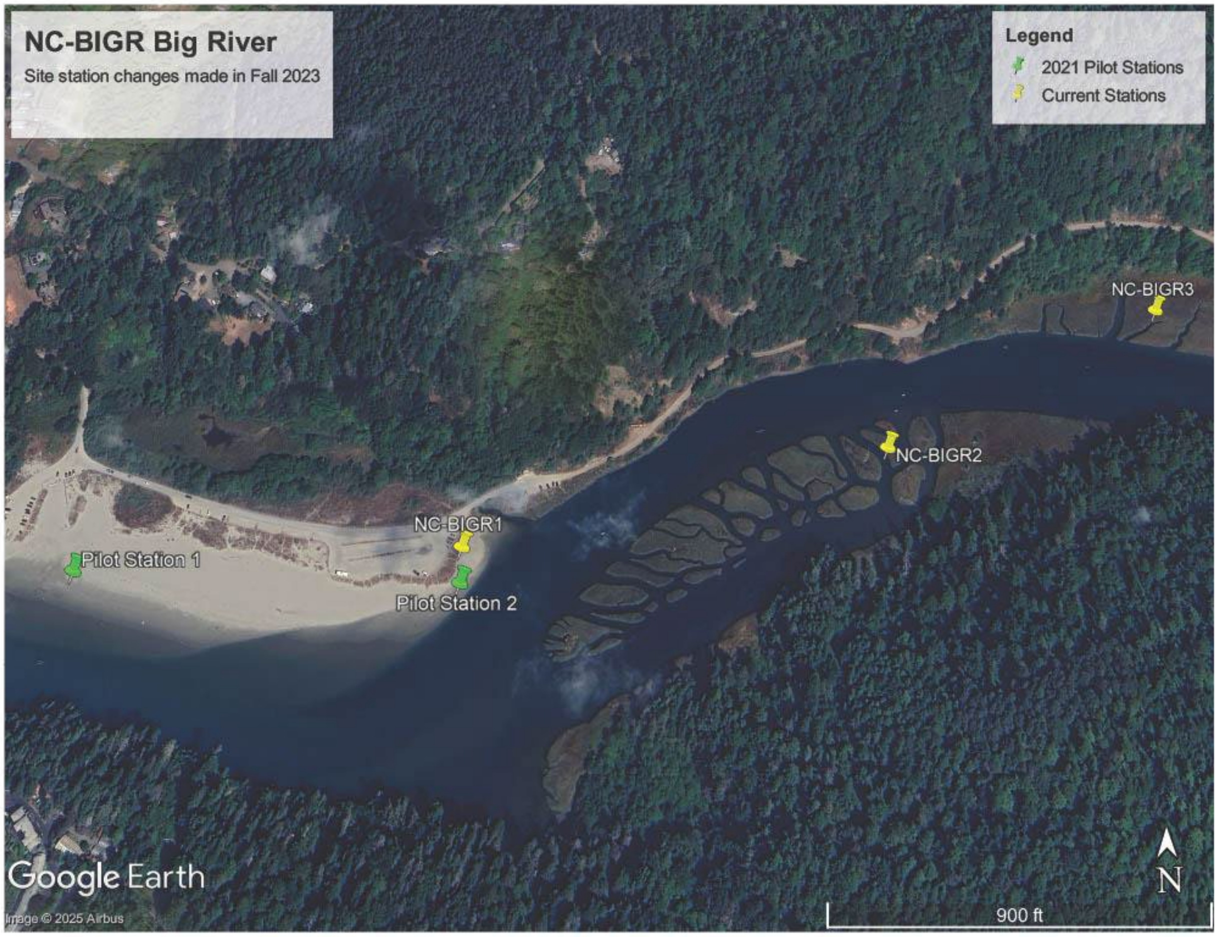


Figure B-3. Changes to stations at Big Lagoon between 2021 and 2023

In Big River, the sampling scheme was pushed further inland to shift from a predominately marine-oriented environment at the mouth to the estuarine aspects of the ecosystem found a great distance upstream due to its heavy tidal influence. Initially, the two pilot stations at Big River were chosen by the mouth due to limited marsh accessibility. However, the team improved their access to marshes with inflatable kayaks. As a result, the original station 1 was dropped at the mouth of Big River, the original station 2 became station 1, and stations 2 and 3 were implemented further upstream. The North Coast team is now able to sample a larger breadth of Big River that captures the far reach of the ocean's tides and its influence on the surrounding environment's biotic and abiotic features.

Ten Mile River

***Figure B-4**. Changes to stations at Ten Mile River between 2021 and 2023*

Similarly to Big River, the sampling scheme of Ten Mile River was also pushed further upstream to capture the estuarine aspects of the system found further inland. Access to Ten Mile's stations involve seeking permission to enter private property and strategic timing with the status of the river's mouth as it is a bar-built estuary that is annually closed. When closed in the fall, Ten Mile River becomes heavily inundated, rendering stations 2 and 3 inaccessible and unconducive for data collection. Given the circumstances of this system, 3 stations close to its mouth were originally chosen for accessibility. The sampling scheme has now shifted to the removal of pilot stations 1 and 2 as they were too marine in nature, changing pilot station 3 to the current station 1, and implementing stations 2 and 3 further upstream to assess the ocean's tidal influence on the ecosystem's biotic and abiotic aspects.

Appendix C: Data Analysis Methods

Functional Analysis 1: Support of Emergent Vascular Plant Communities

Below we describe the methods to score each condition statement and provide the results when possible.

Condition Indicator 1: Assessments of the marshplain using the California Rapid Assessment Method (CRAM) show high values for the Index score, along with the Physical, and Biotic attribute scores.

The statewide estuary CRAM Index scores were plotted (N = 284) as a cumulative frequency distribution (CFD) plot and then the CRAM scores for 12 of the 16 EMPA estuaries were plotted along the curve as points based on their most recent average CRAM score (Figure C-1). Four of the estuaries do not have CRAM scores within this time frame. This process was repeated for the estuary physical (Figure C- 2) and biotic attribute scores (Figure C- 3). For scoring this condition statement, the CFD was divided equally into three condition tertiles. Each estuary score was plotted along the CFD for all California estuaries. Scores between the 67-100%, 34-66%, and 0-33% were given a score of 3, 2, or 1, respectively.

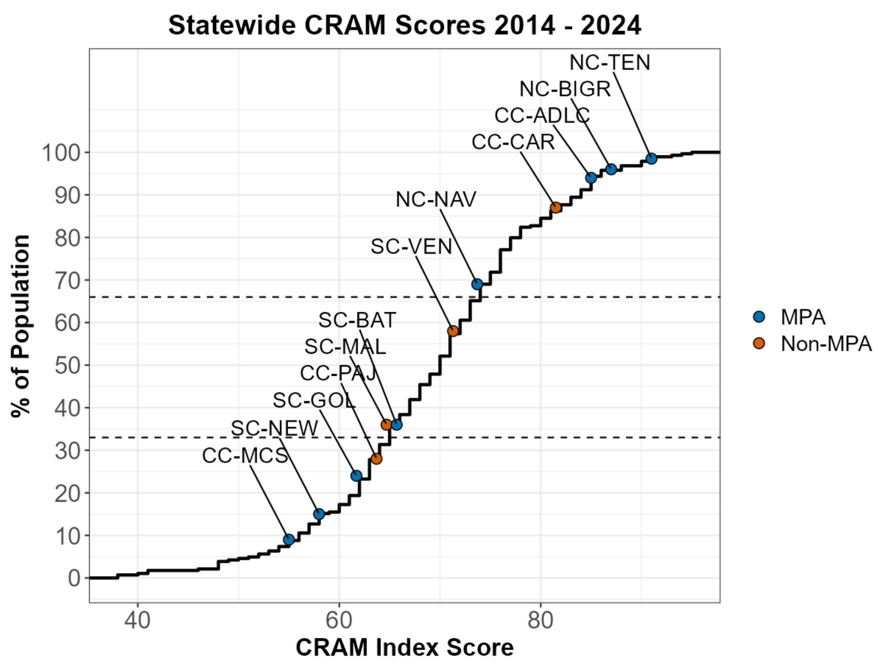


Figure C-1. Cumulative frequency distribution plot of statewide estuary CRAM Index score data from 2014-2024 with 12 EMPA estuaries plotted on the line.

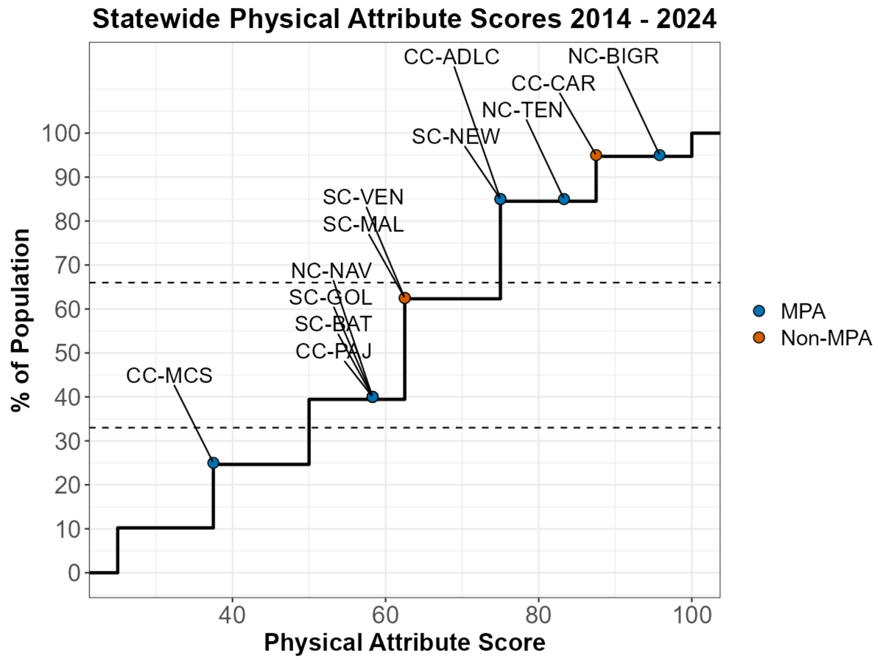


Figure C- 2. Cumulative frequency distribution plot of statewide estuary CRAM Physical Attribute score data from 2014-2024 with 12 EMPA estuaries plotted on the line.

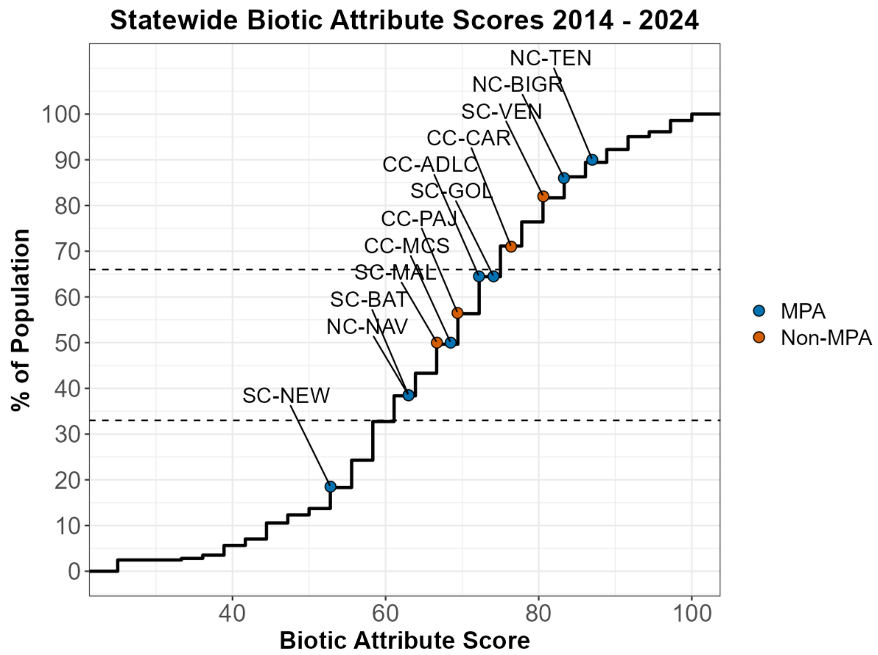


Figure C- 3. Cumulative frequency distribution plot of statewide estuary CRAM Biotic Attribute score data from 2014-2024 with 12 EMPA estuaries plotted on the line.

The General Habitat Condition Score for each estuary is the average of the CRAM index and two attribute binned scores as assigned by this analysis process. Results are shown in Table C- 1.

In general, larger and/or more remote estuaries (Ten Mile, Big River, Carmel) scored higher than estuaries that are managed open and/or in close proximity to stressors (Moro Cojo Slough, Goleta Slough, Newport Bay). Additionally, north coast estuaries overall scored higher than central and south coast estuaries, most likely due to increased stressors, adjacent development (urban and agriculture), and mouth management.

Table C- 1. Condition Indicator 1: High California Rapid Assessment Method (CRAM) condition scores.

Estuary	Region	CRAM	Biotic	Physical	Final
Ten Mile River	North	3	3	3	3.00
Big River	North	3	3	3	3.00
Navarro River	North	3	2	2	2.33
Drakes Estero	North	NA	NA	NA	NA
Bolinas Lagoon	North	NA	NA	NA	NA
Pajaro River	Central	2	2	2	2.00
Moro Cojo Slough	Central	1	2	1	1.33
Carmel River	Central	3	3	3	3.00
Arroyo de la Cruz	Central	3	2	3	2.67
Morro Bay	Central	NA	NA	NA	NA
Goleta Slough	South	1	2	2	1.67
Ventura River	South	2	3	2	2.33
Malibu Creek	South	2	2	2	2.00
Bolsa Chica	South	NA	NA	NA	NA
Newport Bay	South	1	1	3	1.67
Batiquitos Lagoon	South	2	2	2	2.00

Condition Indicator 2: The marshplain vegetation is dominated by native species and robust cover.

To estimate Marsh Vegetation Distribution condition, data were evaluated within two categories (subindex) that were then combined for a final condition indicator score. For this analysis, plant communities in high performing estuaries have a high percentage of native plant species (subindex 1) and dense vegetation cover in higher marsh elevation habitats (mid and high marsh) (subindex 2). Vegetation cover data for the fall 2023 sampling event for all estuaries was evaluated to standardize the timeframe when data were collected. By standardizing data, we can decrease variability in the data due to the temporal differences and increase our ability to detect a difference in condition.

The marshplain vegetation community shows a high percentage of native plant species relative to total cover (Subindex 1)

To evaluate native plant cover, two metrics were characterized: Relative Invasive Abundance and Invasive Plant Ecological Severity. This sub-index takes into account both the presence of invasive species, as well as the severity of the invasive plant.

Relative Invasive Abundance Metric: Percent cover data from the 2023 EMPA sampling event were used to plot the relative abundance of native, non-native, and invasive plants at each estuary (Figure C- 4). O'Loughlin et al. (2021) notes that above 20-30% cover of invasive species, native plant species richness and abundance start to decrease. Using guidance by O'Loughlin et al. (2021), the condition tertiles were set at 10% and 20% invasive and non-native plant cover. Estuaries that were found to have a combined invasive and non-native cover below 10%, 10-20%, or above 20% were given scores of 3, 2, or 1, respectively for the Relative Invasive Abundance metric.

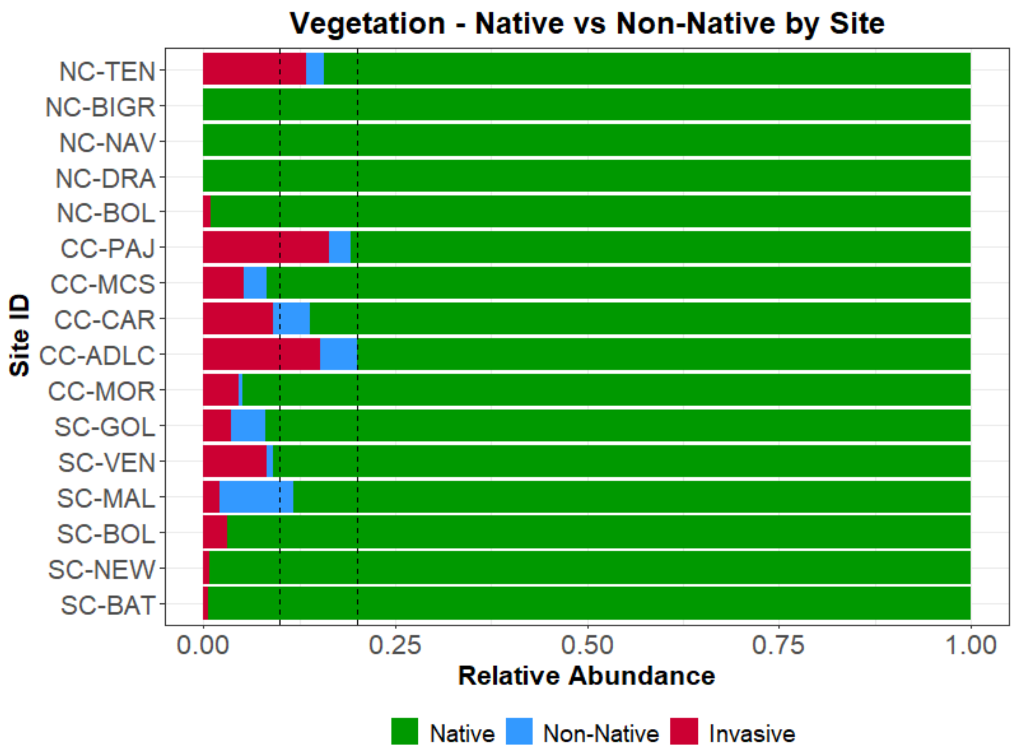


Figure C- 4. Plot of abundance of native, non-native, and invasive plants at each estuary. Relative Invasive abundance metric cores of 3, 2, and 1 were given to estuaries that had combined invasive and non-native cover below 10%, 10-20%, or above 20%, respectively.

Invasive Plant Ecological Severity Metric: A table of all invasive plants found at each estuary was generated and classified according to the California Invasive Plant Council (Cal-IPC)[1] rating levels. The ecological severity of each invasive species was determined (limited, moderate, or high) and each estuary was scored based on the greatest ecological severity of species found there (Table C- 2). Estuaries with

[1] https://www.cal-ipc.org/plants/inventory/

“high severity” rated species received a score of 1, estuaries with invasive species classified as moderate or limited received a score of 2, and estuaries with no documented invasive species received a 3.

Table C- 2. Table of all invasive plants present in each estuary according to the California Invasive Plant Council (Cal-IPC) color coded by ecological severity of each species.

Site ID	Scientific Name	Common Name	Status	Cal IPC Rating	Total Invasive Species	Score
NC-TEN	*Festuca perennis*	Rye grass	Invasive	Moderate	1	2
NC-BOL	*Carduus pycnocephalus*	Italian thistle	Invasive	Moderate	1	2
CC-PAJ	*Raphanus sativus*	Radish	Invasive	Limited	8	1
	Conium maculatum	Poison hemlock	Invasive	Moderate		
	Ammophila arenaria	European beachgrass	Invasive	High		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
	Dittrichia graveolens	Stinkwort	Invasive	Moderate		
	Cakile maritima	European sea rocket	Invasive	Limited		
	Brassica nigra	Black mustard	Invasive	Moderate		
CC-MCS	*Picris echioides*	Bristly oxtongue	Invasive	Limited	9	2
	Geranium dissectum	Cutleaf geranium	Invasive	Limited		
	Festuca perennis	Rye grass	Invasive	Moderate		
	Avena fatua	Wild oat	Invasive	Moderate		
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
	Brassica nigra	Black mustard	Invasive	Moderate		
	Conium maculatum	Poison hemlock	Invasive	Moderate		
	Rumex crispus	Curly dock	Invasive	Limited		
	Bromus diandrus	Ripgut grass	Invasive	Moderate		
CC-CAR	*Rumex crispus*	Curly dock	Invasive	Limited	6	1
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
	Geranium dissectum	Cutleaf geranium	Invasive	Limited		
	Carpobrotus edulis	Iceplant	Invasive	High		
	Cakile maritima	European sea rocket	Invasive	Limited		
CC-ADLC	*Arundo donax*	Giant reed	Invasive	High	6	1
	Foeniculum vulgare	Fennel	Invasive	Moderate		
	Hydrilla verticillata	Hydrilla	Invasive	High		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
	Raphanus sativus	Radish	Invasive	Limited		
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
CC-MOR	*Atriplex semibaccata*	Australian saltbush	Invasive	Moderate	6	1
	Carpobrotus edulis	Iceplant	Invasive	High		
	Cakile maritima	European sea rocket	Invasive	Limited		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
	Brassica nigra	Black mustard	Invasive	Moderate		

Site ID	Scientific Name	Common Name	Status	Cal IPC Rating	Total Invasive Species	Score
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
SC-GOL	*Polypogon monspeliensis*	Rabbit's foot grass	Invasive	Limited	3	1
	Carpobrotus edulis	Iceplant	Invasive	High		
	Cakile maritima	European sea rocket	Invasive	Limited		
SC-VEN	*Cakile maritima*	European sea rocket	Invasive	Limited	9	1
	Carpobrotus edulis	Iceplant	Invasive	High		
	Nicotiana glauco	Tobacco plant	Invasive	Moderate		
	Arundo donax	Giant reed	Invasive	High		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
	Cotula coronopifolia	Brass buttons	Invasive	Limited		
	Ricinus communis	Castor bean	Invasive	Limited		
	Brassica nigra	Black mustard	Invasive	Moderate		
	Rumex crispus	Curly dock	Invasive	Limited		
SC-MAL	*Atriplex semibaccata*	Australian saltbush	Invasive	Moderate	3	1
	Bromus rubens	Red brome	Invasive	High		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
SC-BOL	*Mesembryanthemum crystallinum*	Crystalline iceplant	Invasive	Moderate	3	2
	Mesembryanthemum nodiflorum	Slender-leaved iceplant	Invasive	Limited		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
SC-NEW	*Limonium ramosissimum*	Algerian sea lavender	Invasive	Limited	1	2
SC-BAT	*Polypogon monspeliensis*	Rabbit's foot grass	Invasive	Limited	2	2
	Bromus diandrus	Ripgut grass	Invasive	Moderate		

Native Plant Cover Subindex score was determined for each estuary by calculating the average of the Relative Invasive Abundance Metric and Invasive Plant Ecological Severity Metric (Table C- 3).

Table C- 3. Native Plant Species Cover (Subindex 1) score for each estuary.

Estuary	Region	Abundance	Invasive Severity	Subindex 1 Score
Ten Mile River	North	2	2	2
Big River	North	3	3	3
Navarro River	North	3	3	3
Drakes Estero	North	3	3	3
Bolinas Lagoon	North	3	2	2.5
Pajaro River	Central	1	1	1
Moro Cojo Slough	Central	2	2	2
Carmel River	Central	2	1	1.5
Arroyo de la Cruz	Central	1	1	1
Morro Bay	Central	3	1	2
Goleta Slough	South	3	1	2
Ventura River	South	3	1	2
Malibu Creek	South	2	1	1.5
Bolsa Chica	South	3	2	2.5
Newport Bay	South	3	2	2.5
Batiquitos Lagoon	South	3	2	2.5

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

To evaluate high vegetation cover, one metric was characterized: vegetated cover. This sub-index takes into account the vegetated percent cover in the marshplain.

Vegetated Cover Metric: Percent cover of vegetated and non-vegetated marshplain was collected for every quadrat along the vegetation transects and the percentages for mid and high marsh habitats were plotted for all 16 estuaries (Figure C- 5). Low marsh was excluded from this analysis because low marsh habitat will naturally have a high percent of non-vegetated marshplain. The condition tertiles were set at 33% and 66% percent cover. Estuaries that had vegetated cover of 0-33%, 34-66%, or 67-100% received a score of 1, 2, or 3, respectively (Table C- 4).

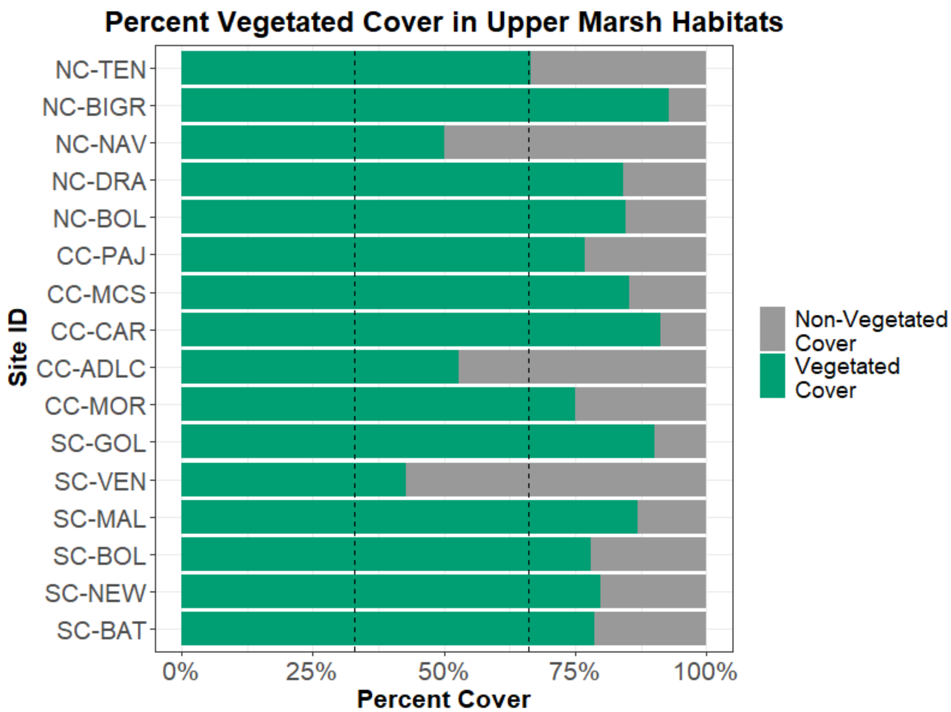


Figure C- 5. Plot of percent cover of vegetated and non-vegetated cover at each estuary. Vegetated cover metric scores of 1, 2, and 3 were given to estuaries that had 0-33%, 34-66%, or 67-100% vegetated cover, respectively.

Table C- 4. Vegetation Cover (Subindex 2) score for each estuary.

Estuary	Region	Subindex 2 Score
Ten Mile River	North	3
Big River	North	3
Navarro River	North	2
Drakes Estero	North	3
Bolinas Lagoon	North	3
Pajaro River	Central	3
Moro Cojo Slough	Central	3
Carmel River	Central	3
Arroyo de la Cruz	Central	2
Morro Bay	Central	3
Goleta Slough	South	3
Ventura River	South	2
Malibu Creek	South	3
Bolsa Chica	South	3
Newport Bay	South	3
Batiquitos Lagoon	South	3

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

To estimate marshplain topographic variability needed to support a diverse plant community, GIS data of the marshplain were analyzed to quantify the relative amount of marshplain topographic variability (levels of ruggedness).

The footprint boundaries for each estuary were downloaded as shapefiles from the Pacific Marine & Estuarine Fish Habitat Partnership (PMEP) database[2] and mapped in ArcGIS Pro. A digital elevation model (DEM) was downloaded from the NOAA Digital Coast Data Access Viewer[3], (the same DEM NOAA uses for their sea level rise projections), mapped in ArcGIS Pro (Esri 2024), and clipped to the estuary footprint (Figure C- 6). The Terrain Ruggedness Index tool[4] in the Arc Hydro toolbox in ArcGIS Pro was used to calculate the ruggedness index of each estuary. Esri provides bins of elevation values used to estimate change in elevation, classified as ruggedness. Due to the planar nature of marshplains relative to all landforms (mountains, hills, valleys) the EMPA estuaries ruggedness scores all fell in the smallest bin (0-80 m) of the Ruggedness Index tool. New bins were created by dividing the EMPA estuary values into thirds. The largest values (21-25), indicating higher topographic variability, received a condition score of 3, middle values (15-20) received a score of 2, and lower values (10-14) received a score of 1 (Table C- 5).

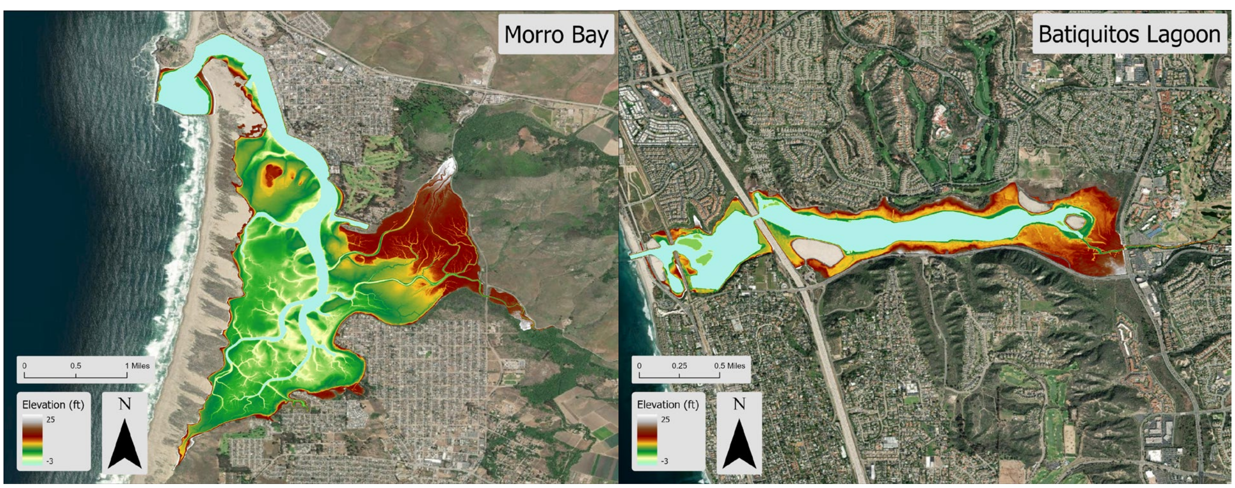


Figure C- 6. Example DEMs that were analyzed using the Terrain Ruggedness Index tool in the Arc Hydro toolbox in ArcGIS Pro to calculate the ruggedness index of each estuary.

[2] https://www.pacificfishhabitat.org/data/
[3] https://coast.noaa.gov/dataviewer/#/
[4] https://hub.arcgis.com/content/28360713391948af9303c0aeabb45afd/about

Table C- 5. GIS-based ruggedness scores for each estuary. The largest values (21-25, received a condition score of 3, middle values (15-20) received a score of 2, and lower values (10-14) received a score of 1.

Estuary	Region	Ruggedness	Score
Ten Mile River	North	23	3
Big River	North	25	3
Navarro River	North	21	3
Drakes Estero	North	25	3
Bolinas Lagoon	North	17	2
Pajaro River	Central	16	2
Moro Cojo Slough	Central	14	1
Carmel River	Central	21	3
Arroyo de la Cruz	Central	16	2
Morro Bay	Central	15	2
Goleta Slough	South	17	2
Ventura River	South	17	2
Malibu Creek	South	12	2
Bolsa Chica	South	16	2
Newport Bay	South	21	3
Batiquitos Lagoon	South	16	2

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

Using water depth loggers deployed at a number of estuaries, our goal is to create a time series of water elevation data to document marshplain flooding events. Currently we do not have water level data that has been linked to an elevation datum needed to complete our analysis for all 16 estuaries. Figure C- 7 demonstrates the potential analysis for this indicator. Water level data was plotted as a time series with three different marshplain elevation levels based on the mouth state along with the duration of inundation. Our analysis will look similar, but rather than using mouth state we would be using the elevation zones defined by the quadrats in the vegetation transects. Once water elevation data are georeferenced to a vertical datum for all the estuaries, a relative inundation analysis will be possible.

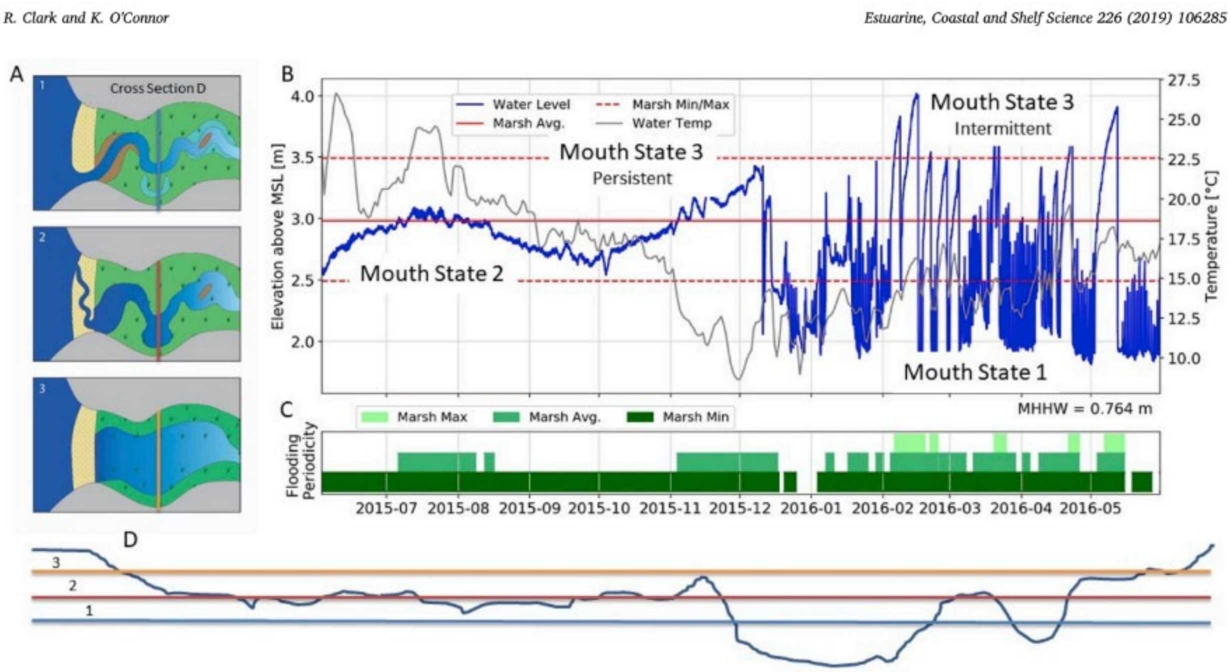


Figure C- 7. *Example of potential summary figure that will be created for all 16 estuaries showing a combination of water elevation, temperature, and three marshplain surfaces being inundated at different times.*

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

Each vegetation quadrat that was sampled contained the name and percent cover of species found within the sampled area (see SOP). The species were considered as a group and compared to the California Native Plant Society Manual of California Vegetation (CNPS 2024) to determine the alliances most appropriate for that quadrat. The highest number of alliances observed at one site was five. Estuaries that had 1, 2, or more than 2 alliances present were scored as a 1, 2, or 3, respectively (Table C- 6).

Table C- 6. Condition score for each estuary based on the number of plant alliances present.

Estuary	Region	Alliances	Score
Ten Mile River	North	1	1
Big River	North	1	1
Navarro River	North	1	1
Drakes Estero	North	1	1
Bolinas Lagoon	North	2	2
Pajaro River	Central	5	3
Moro Cojo Slough	Central	3	3
Carmel River	Central	2	2
Arroyo de la Cruz	Central	1	1
Morro Bay	Central	3	3
Goleta Slough	South	2	2
Ventura River	South	2	2
Malibu Creek	South	3	3
Bolsa Chica	South	2	2
Newport Bay	South	3	3
Batiquitos Lagoon	South	4	3

Functional Analysis 2: Sea Level Rise Amelioration and Resiliency

Below we describe the methods to score each condition statement and provide the results when possible.

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

For this Condition analysis the CRAM Index scores were plotted as a cumulative frequency distribution plot and then 12 of the 16 monitoring sites for this project were plotted along the curve as points based on their most recent average CRAM score (Figure C-1, Figure C- 2, Figure C- 3). Results are shown in Table C- 1.

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

As completed for Vascular Plant Functional Assessment, Vegetation Cover Condition was interpreted using data to characterize Native Abundance and Vegetated marshplain (Figure C- 4). Results are shown in Table C- 4.

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.

The marshplain migration condition was interpreted using data to characterize the potential migration area available for the marshplain to move into and the future habitat proportions under 1.2 ft of sea level rise. Ideally, an estuary is surrounded by natural or open land cover with sufficient space and comparable elevation zones in order to accommodate rising sea levels.

The area surrounding the estuary has sufficient upland migration area to respond to SLR (Subindex 1).

A buffer zone refers to the areas of land or vegetation that surround or protect the estuarine ecosystem from external pressures, including the effects of rising sea levels. The more extensive and intact these buffer zones are, the better they can mitigate the impacts of sea level rise, coastal erosion, and storm surges.

In ArcGIS Pro, following the methods described by Lowe et al. 2021, we created a 500 m buffer around each wetland footprint using the Buffer tool and overlaid the National Land Cover Dataset (NLCD) (Dewitz 2023). We clipped the land cover layer to the 500 m buffer, reclassified the land cover classes into three new ones: open, developed, and agricultural land cover (Figure C- 8), and calculated the percentage of each new cover class. For scoring purposes, we combined the open and agriculture classes under the assumption that wetlands could potentially migrate into agricultural land. If a buffer had a combined open and agriculture percent cover of 0-33%, 34-66%, or 67-100% it received a 1, 2, or 3, respectively. Results are shown in Table C- 7.

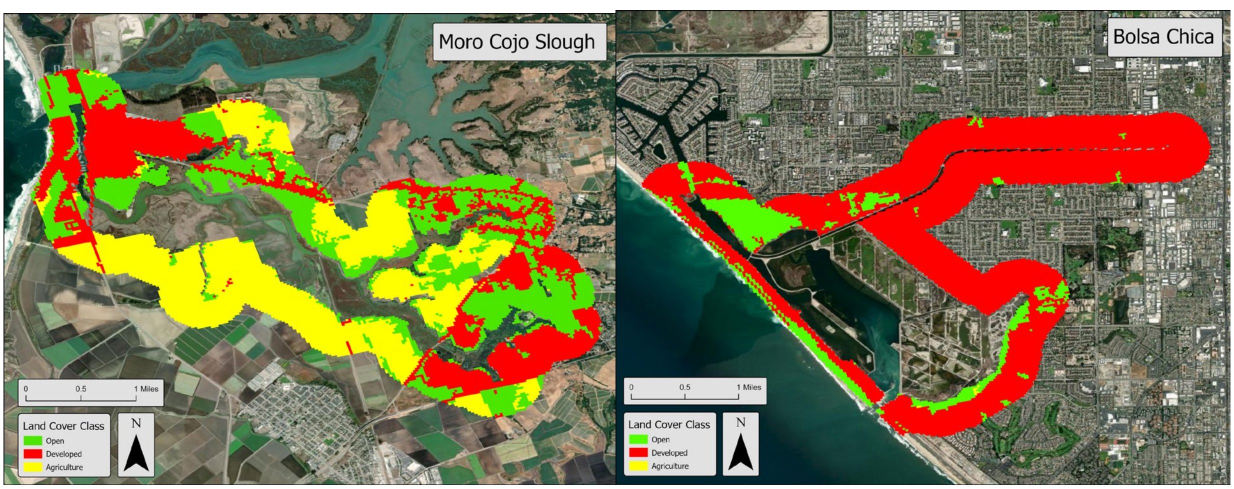


Figure C- 8. *Example outputs for determining the transition zone and associated land use in each estuary. The NLCD land cover layer was clipped to the 500 m buffer and reclassified into three new groups: open, developed, and agricultural land cover.*

Table C- 7. Percent cover of each land cover type within each 500 m buffer and the corresponding score.

Estuary Name	Region	Landcover Type			Score
		Open	Developed	Ag	
Ten Mile River	North	80	17	3	3
Big River	North	89	11	0	3
Navarro River	North	87	13	0	3
Drakes Estero	North	98	2	0	3
Bolinas Lagoon	North	74	26	0	3
Pajaro River	Central	26	19	55	1
Moro Cojo Slough	Central	35	29	36	2
Carmel River	Central	29	66	5	1
Arroyo de la Cruz	Central	94	6	0	3
Morro Bay	Central	62	38	0	2
Goleta Slough	South	17	80	3	1
Ventura River	South	20	74	6	1
Malibu Creek	South	15	82	3	1
Bolsa Chica	South	26	74	0	1
Newport Bay	South	13	87	0	1
Batiquitos Lagoon	South	16	84	0	1

We created another 30 m buffer around each wetland footprint representing the immediate wetland perimeter, clipped the NLCD layer, and reclassified it into two new cover classes: developed and open, which included agricultural land (Figure C- 9). The width of 30 m was chosen in order to capture the NLCD raster around the whole wetland due to the 30 x 30 m resolution of the raster. A smaller boundary could be used if a higher resolution raster is available. Following methodology in Lowe et al. 2021, we determined if at least 40% of the wetland perimeter was open land cover. That report justified using 40% as the cutoff because for all the wetlands considered by the Southern California Wetlands Recovery Project, where 40% was the average proportion of the existing wetland perimeter that was undeveloped and could potentially become a transition zone. For this EMPA program, since the southern sites have the most surrounding development, we used that as our cutoff as well. If an estuary had a perimeter that contained 40-100%, 20-39%, or 0-19% open cover it received a score of 3, 2, or 1, respectively. Results are shown in Table C- 8

Figure C- 9. Example outputs for determining the land use of the immediate wetland perimeter. The NLCD land cover layer was clipped to the 30 m buffer and reclassified into two new groups: open and developed cover.

Table C- 8. Percent cover of each land cover type within each 30 m buffer and the corresponding score.

Estuary Name	Region	Landcover Type		Score
		Open + Ag	Developed	
Ten Mile River	North	61	39	3
Big River	North	76	24	3
Navarro River	North	51	49	3
Drakes Estero	North	97	3	3
Bolinas Lagoon	North	24	76	2
Pajaro River	Central	84	16	3
Moro Cojo Slough	Central	79	21	3
Carmel River	Central	43	57	3
Arroyo de la Cruz	Central	97	3	3
Morro Bay	Central	59	41	3
Goleta Slough	South	34	66	2
Ventura River	South	35	65	2
Malibu Creek	South	19	81	1
Bolsa Chica	South	18	82	1
Newport Bay	South	18	82	1
Batiquitos Lagoon	South	12	88	1

If a wetland did have a combined percent cover of at least 40%, a separate analysis was done to determine the level of contiguity of those land covers. The perimeter layer with the two classes was put into the Raster Calculator tool to select for only open cover areas. This new layer was used in the Region Group tool, then the Zonal Statistics as Table tool to calculate the area and percent cover for each of the patches of open cover. Scoring was based on the largest patch of contiguous open cover along the 30 m perimeter. If the largest patch of contiguous open cover was 50-100%, 25-49%, or 0-24% of the initial open cover percentage, an estuary received a score of 3, 2, or 1, respectively. Results are shown in Table C- 9.

Table C- 9. Scoring table for contiguous open cover.

Estuary Name	Region	# Open Patches	Percent Largest Contiguous Patch	Area of Largest Contiguous Patch (sq m)	Score
Ten Mile River	North	24	37	92,348	2
Big River	North	31	66	333,975	3
Navarro River	North	40	33	82,568	2
Drakes Estero	North	15	49	843,815	2
Bolinas Lagoon	North	NA	NA	NA	NA
Pajaro River	Central	41	23	305,491	1
Moro Cojo Slough	Central	38	20	178,381	1
Carmel River	Central	20	50	49,590	3
Arroyo de la Cruz	Central	2	77	57,617	3
Morro Bay	Central	49	68	408,766	3
Goleta Slough	South	NA	NA	NA	NA
Ventura River	South	NA	NA	NA	NA
Malibu Creek	South	NA	NA	NA	NA
Bolsa Chica	South	NA	NA	NA	NA
Newport Bay	South	NA	NA	NA	NA
Batiquitos Lagoon	South	NA	NA	NA	NA

The surrounding landscape elevation allows for marsh migration such that the estuary will contain less than 50% open water after 1.2 ft of sea level rise (Subindex 2)

As estuaries face SLR and increased inundation, the associated marsh elevation zones could naturally migrate inland or adjust in elevation. The less land that is developed around the estuary, the more flexible the ecosystem is in adapting to changes in sea level. Thus, the composition of marsh elevation zones in the future could remain similar to what it is now.

The NOAA DEMs used in the vegetation function analysis were reclassified into four marsh elevation zones, using the “habitat zone”[5] notated in the quadrats along the vegetation transects (Figure C-10).

[5] See SOP 11 for list of habitat zone definitions.

The four marsh elevation zones being represented were water, low marsh, mid marsh, and high marsh. The number of pixels were calculated in each class to determine their relative abundance in the current estuary footprint. We repeated this process for the wetland footprint plus the 500 m buffer (Figure C-11). Using the marsh elevation zones determined in the footprint from the vegetation transects, we added 1.2 ft to the upper limit of each of the zones to simulate potential wetland migration under OPC's high SLR estimate. We took this layer and the reclassified land cover raster and used the Raster Calculator tool to eliminate the parts of the land that were developed to get a more accurate estimate of the potential land available for wetland migration under the 1.2 ft SLR scenario (Figure C- 12). We plotted these marsh elevation zone estimates side by side to determine what wetland habitats would be lost or gained (Figure C-13, Figure C-14, Figure C-15).

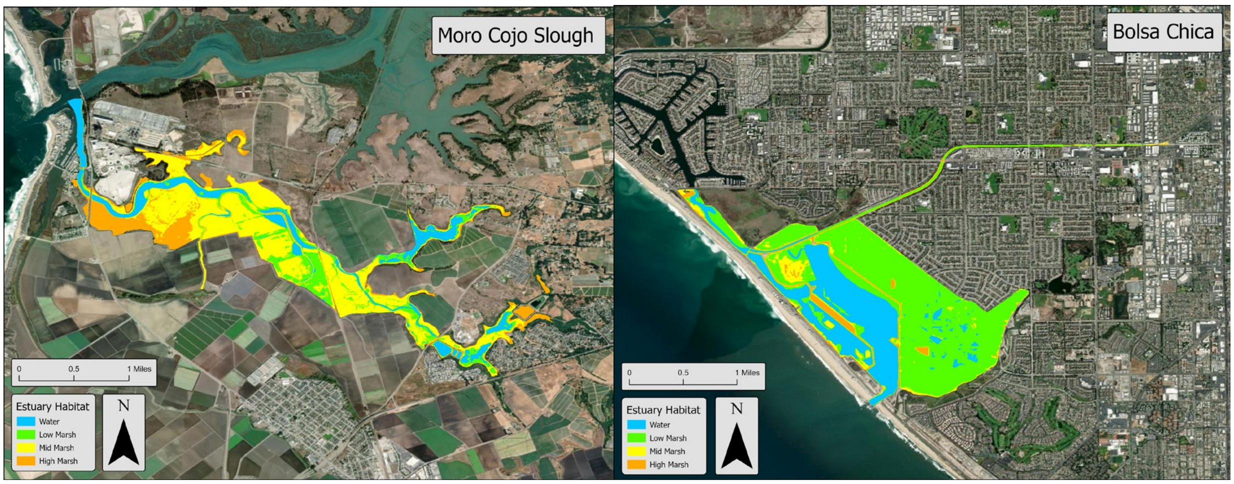


Figure C-10. Example outputs of delineated marsh elevation zones using habitat designations in vegetation quadrats.

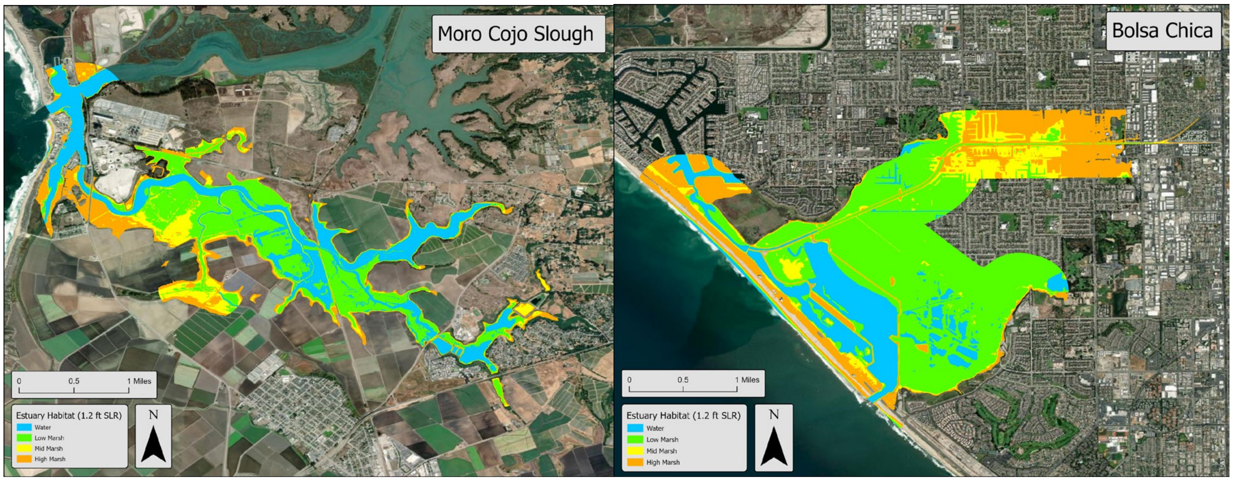


Figure C-11. Example outputs of delineated marsh elevation zones using habitat designations in vegetation quadrats and adding 1.2 ft to view potential wetland migration.

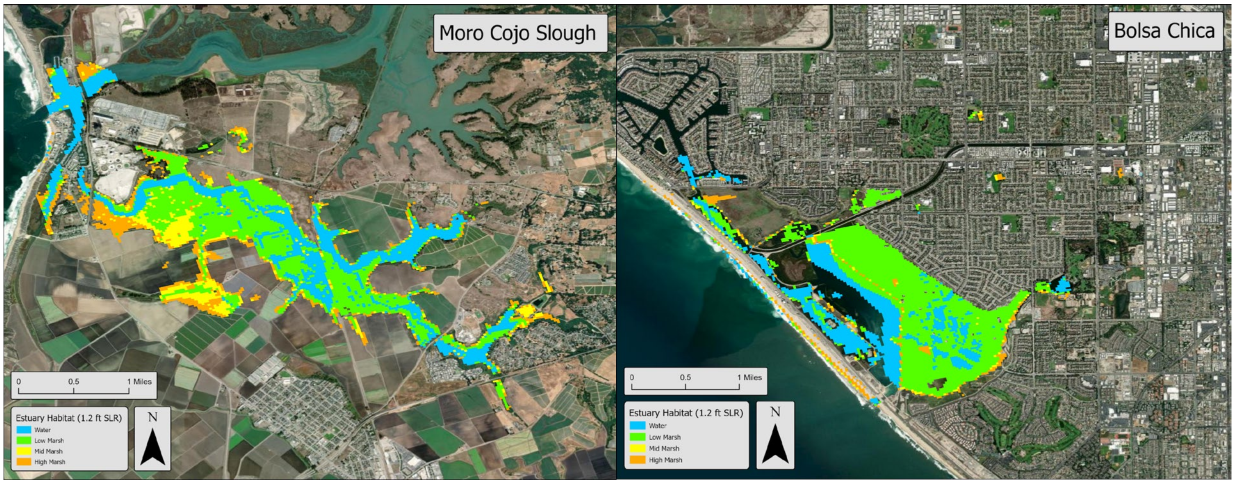


Figure C- 12. *Example outputs of delineated marsh elevation zones using habitat designations in vegetation quadrats and adding 1.2 ft to view potential wetland migration but excluding developed land cover areas.*

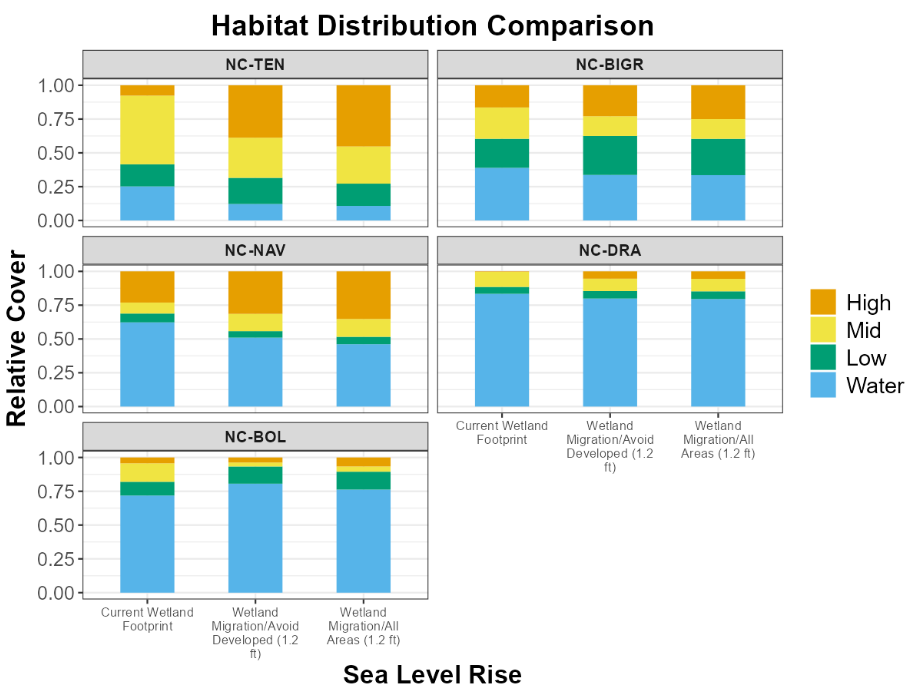


Figure C-13. *Relative cover of the current wetland footprints in the North Coast (column 1), wetland migration with 1.2 ft of SLR excluding all developed areas (column 2), and wetland migration with 1.2 ft of SLR including all land cover classes (column 3)*

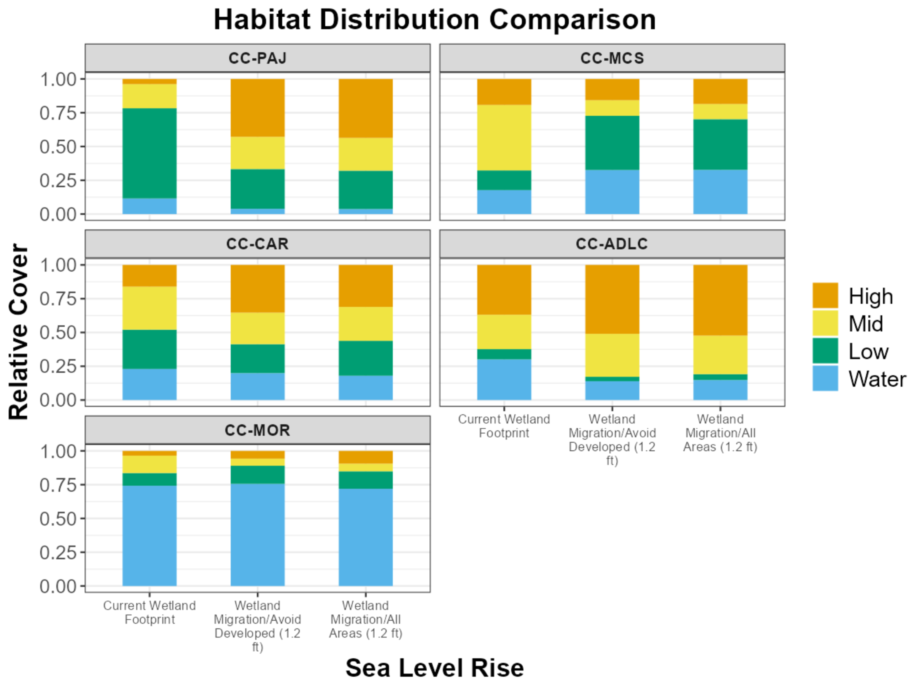


Figure C-14. *Relative cover of the current wetland footprints in the Central Coast (column 1), wetland migration with 1.2 ft of SLR excluding all developed areas (column 2), and wetland migration with 1.2 ft of SLR including all land cover classes (column 3).*

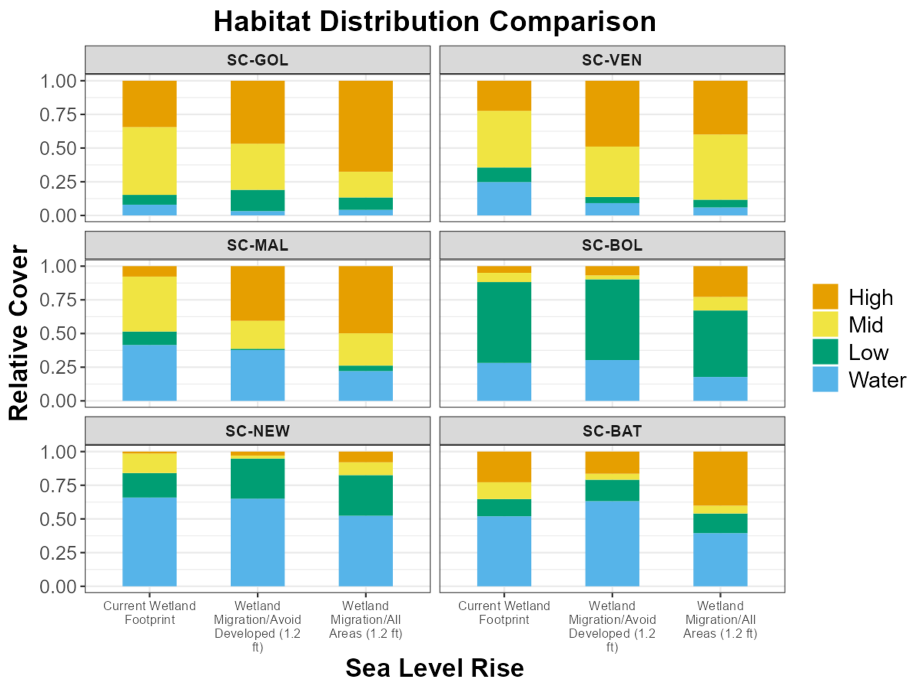


Figure C-15. *Relative cover of the current wetland footprints in the South Coast (column 1), wetland migration with 1.2 ft of SLR excluding all developed areas (column 2), and wetland migration with 1.2 ft of SLR including all land cover classes (column 3)*

Current and future wetland areas excluding developed areas (central column for each estuary in Figures 15, 16, 17) were given a score for this analysis. If a site had 50% or more water cover, it received a 1. If it had 50% or more combined water and low marsh cover it received a 2. If it had less than 50% combined water and low marsh cover it received a 3 for both the current and future scenarios. Results are shown in Table C- 10.

Table C- 10. Scores for the composition of current and future marsh elevation zones for each estuary.

Estuary Name	Region	Current Wetland Extent Score	Future Wetland Extent Score (1.2 ft SLR)	Score
Ten Mile River	North	3	3	3
Big River	North	2	2	2
Navarro River	North	1	1	1
Drakes Estero	North	1	1	1
Bolinas Lagoon	North	1	1	1
Pajaro River	Central	2	3	2.5
Moro Cojo Slough	Central	3	2	2.5
Carmel River	Central	2	3	2.5
Arroyo de la Cruz	Central	3	3	3
Morro Bay	Central	1	1	1
Goleta Slough	South	3	3	3
Ventura River	South	3	3	3
Malibu Creek	South	2	3	2.5
Bolsa Chica	South	2	2	2
Newport Bay	South	1	1	1
Batiquitos Lagoon	South	1	1	1

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

Determining longer-term sediment accretion rates over time can provide valuable insights into the dynamics of sediment accumulation, which is important for understanding the resilience of coastal ecosystems, especially in the face of SLR. Combining these metrics with other data helps determine if estuaries are keeping pace with projected SLR.

This condition statement will use marshplain accretion rate estimated from the deployment of feldspar plots (Figure C- 16) and sediment grain size analysis to estimate the sediment quantity and quality available to support marshplain accretion. Accretion rates will be compared to the current sea level rise rate estimated by OPC. If accretion rates match or exceed the current rate of sea level rise, that would indicate higher resiliency. Because accretion rates require several years between marker deployment and first sampling, this analysis has not yet been performed.

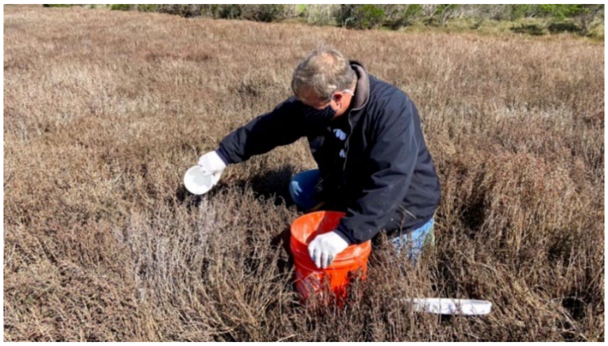


Figure C- 16. Ross Clark deploying feldspar on the Moro Cojo Slough marshplain in 2021.

Functional Analysis 3: Nekton Habitat Provision

Below we describe the methods to evaluate each condition statement and provide initial results when possible. This function analysis is still under development as many of the condition statements require greater than five years of data to make definitive inferences. We outline the initial narratives around each condition statement and provide next steps when possible.

Condition Indicator 1: The estuary does not experience extended periods of hypoxia, high water temperatures, or extreme salinity that significantly exceeds or impedes physiological limits (indicator: water quality).

Metrics

Over the last few years, many steps have been implemented to better standardize data collection, data QA/QC, and data analysis with these large time-series datasets. However, due to the current resources, water quality data has been collected inconsistently and data are not concurrent in different systems.

Due to these inconsistencies in data collection, we use a subset of the water quality data in this report to illustrate how California estuaries are extremely dynamic with varying water quality conditions. At this time, we cannot provide statistical summaries or provide management guidance about these systems. In order 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).

To begin to evaluate condition statement 1, we derived three types of metrics to evaluate each estuary. A metric is a quantifiable measurement of a specific unit or process. We can use these metrics to compare within and among systems.

1. Daily metrics - These metrics are used to summarize water quality conditions for each day. They give an overview of daily variability (e.g., mean, min, max, range) of the parameters (temperature, salinity, DO) and their distribution (10th, 50th, and 90th percentiles).
2. Threshold metrics - These metrics count how many days or observations fall below or above a specified threshold. Thresholds can be determined by the physiological limits of estuarine

species. Metrics can quantify how frequently water conditions fall outside specific ranges. For example, we can quantify the number of days DO falls below 1 mg/L, 2 mg/L, and 3 mg/L.

3. Event metrics - Event metrics are designed to capture episodic phenomena, such as hypoxia or temperature spikes. These metrics help monitor discrete events, their frequency, and their impact. For example, we can quantify the number of consecutive hours DO falls below 2 mg/L.

For each parameter (temperature, salinity, oxygen), we compared a subset of the metrics within each region and across seasons. As data are not necessarily concurrent, we used all the available data in the EMPA portal (ranging from 2021 to 2024) and grouped the data into spring and fall seasons. We illustrate the data as a series of matrices that compare the data using quartiles, grouping the data into 25% intervals (Figure C-17, Figure C-18, Figure C-19).

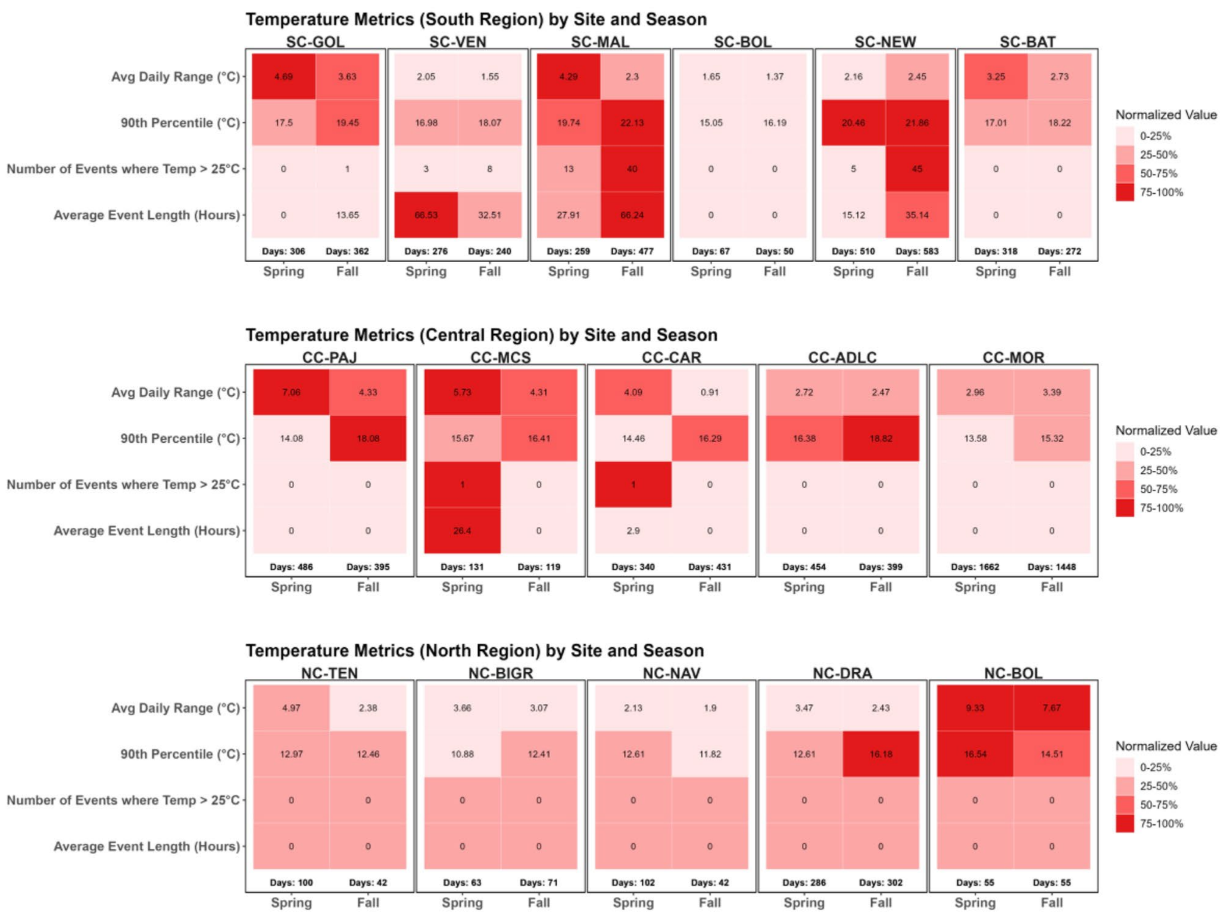


Figure C-17. *Temperature metrics (avg. daily range, 90th percentile, number of events where temp > 25, and average event length) for the south, central, and north regions. Each matrix is divided by site and season (spring and fall). Values within boxes are the values corresponding to the metric and colors represent the quartile. For each season, the number of days with available data are listed.*

Figure C-18. *Salinity metrics (90th percentile, avg. daily range, number of low salinity events (<10 ppt) and high salinity events (>35 ppt), and average low and high event length) for the south, central, and north regions. Each matrix is divided by site and season (spring and fall). Values within boxes are the values corresponding to the metric and colors represent the quartile. For each season, the number of days with available data are listed.*

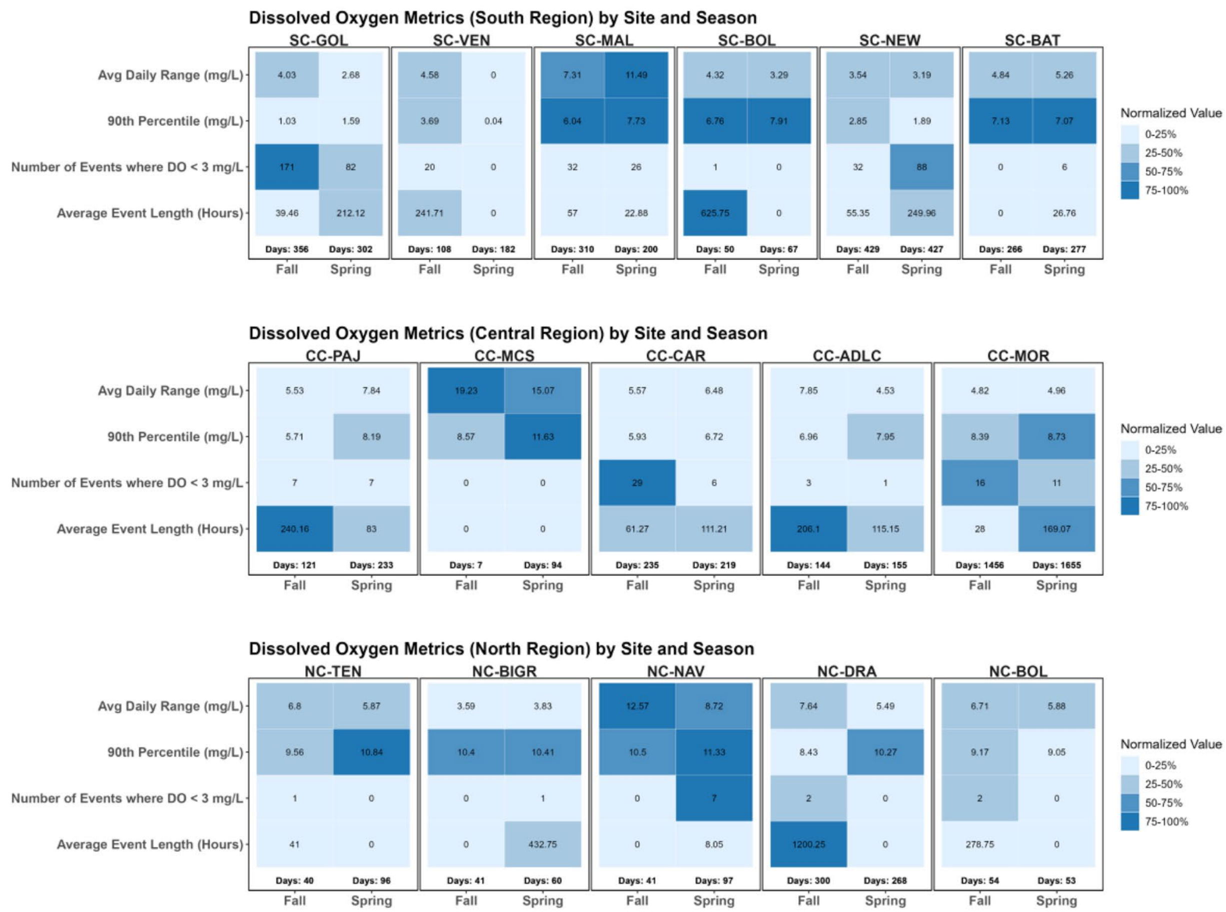


Figure C-19. DO metrics (avg. daily range, 90th percentile, number of events where DO < 3 mg/L, and average event length) for the south, central, and north regions. Each matrix is divided by site and season (spring and fall). Values within boxes are the values corresponding to the metric and colors represent the quartile. For each season, the number of days with available data are listed.

To further explore the threshold metrics, we also compared the amount of time each estuary spent above or below specific thresholds. Thresholds were derived from the literature to identify common critical temperature and DO thresholds of estuarine fish (e.g., bay pipefish, California anchovy, California killifish, California halibut, and topsmelt). We illustrate the amount of time each estuary spent below these thresholds as a series of stacked bar plots (Figure C-20, Figure C- 21, Figure C-22). While we use all the available data in the EMPA portal (ranging from 2021 to 2024) due to inconsistencies in site dates, this is undesirable as year and season are conflated and this will be avoided in future analyses. These graphics are presented as a demonstration of analyses that will be done in the future with more robust datasets. In subsequent reports, we recommend examining the data across consistent time ranges and seasons.

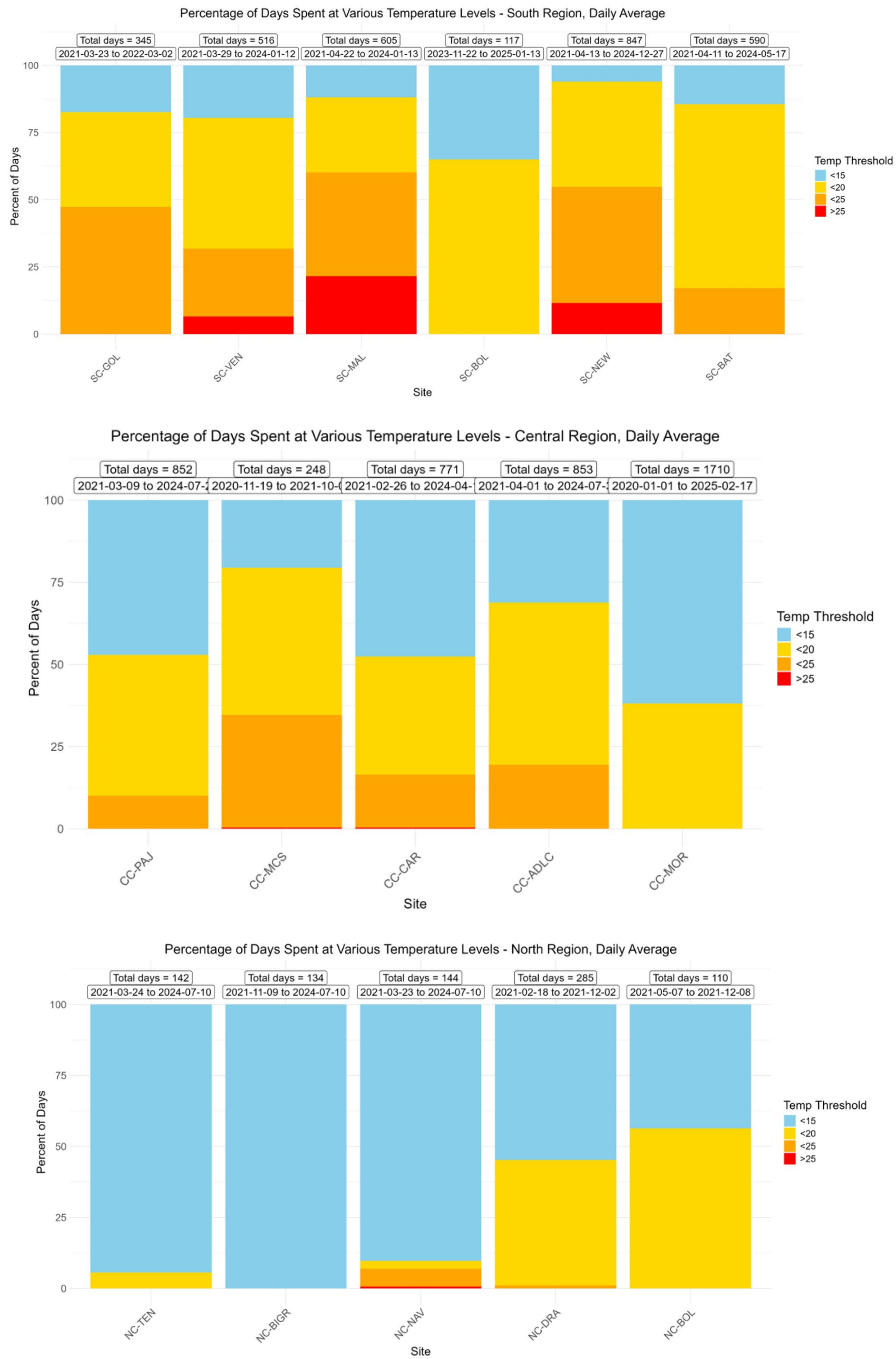


Figure C-20. Percent of days each site spent at various temperature thresholds levels for each region. Color represents the temperature threshold. Above each box, the amount of available data in days and the time range of the availability is listed.

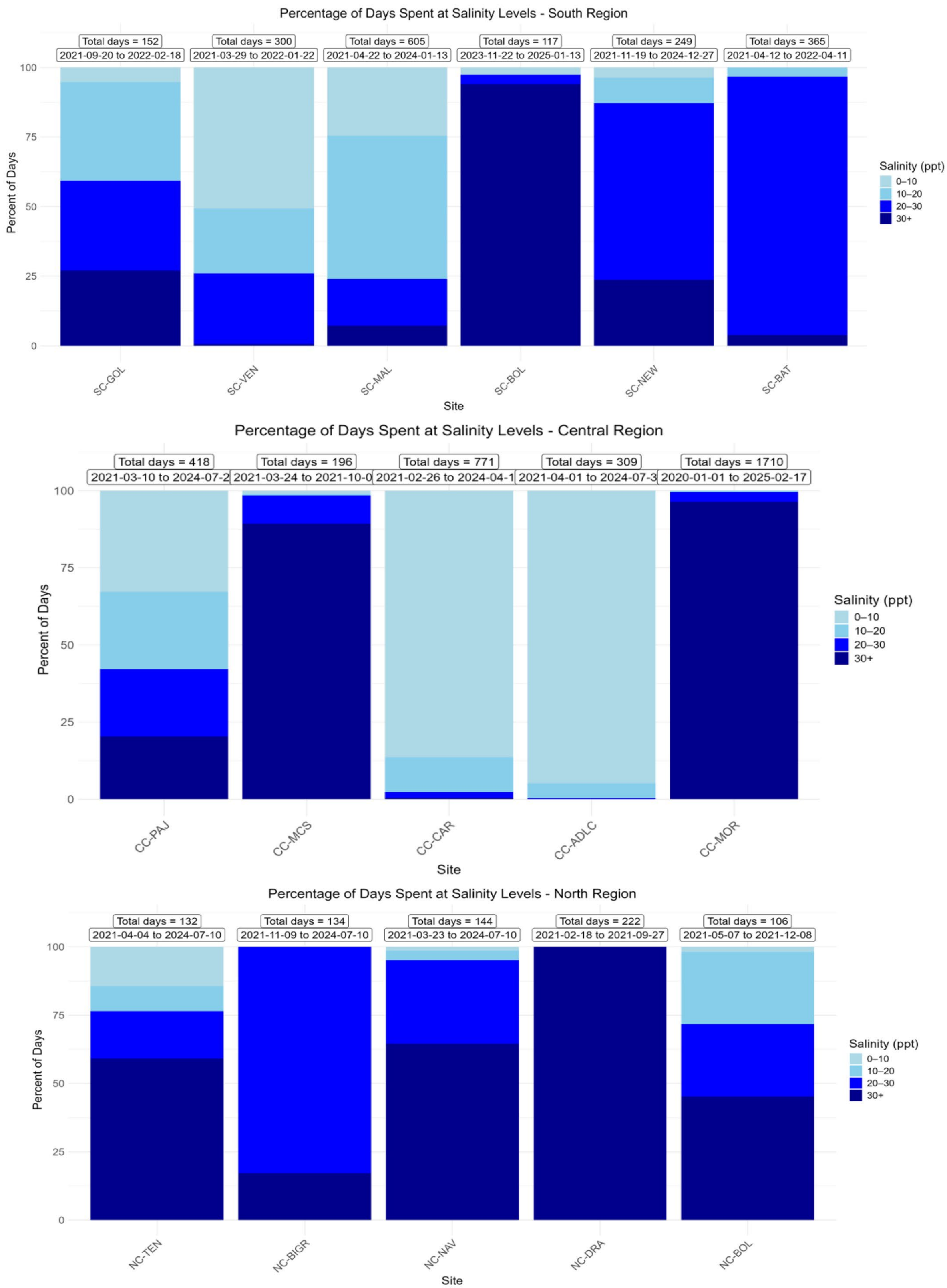


Figure C- 21. Percent of days each site spent at various salinity levels for each region. Color represents the salinity level. Above each box, the amount of available data in days and the time range of the availability is listed.

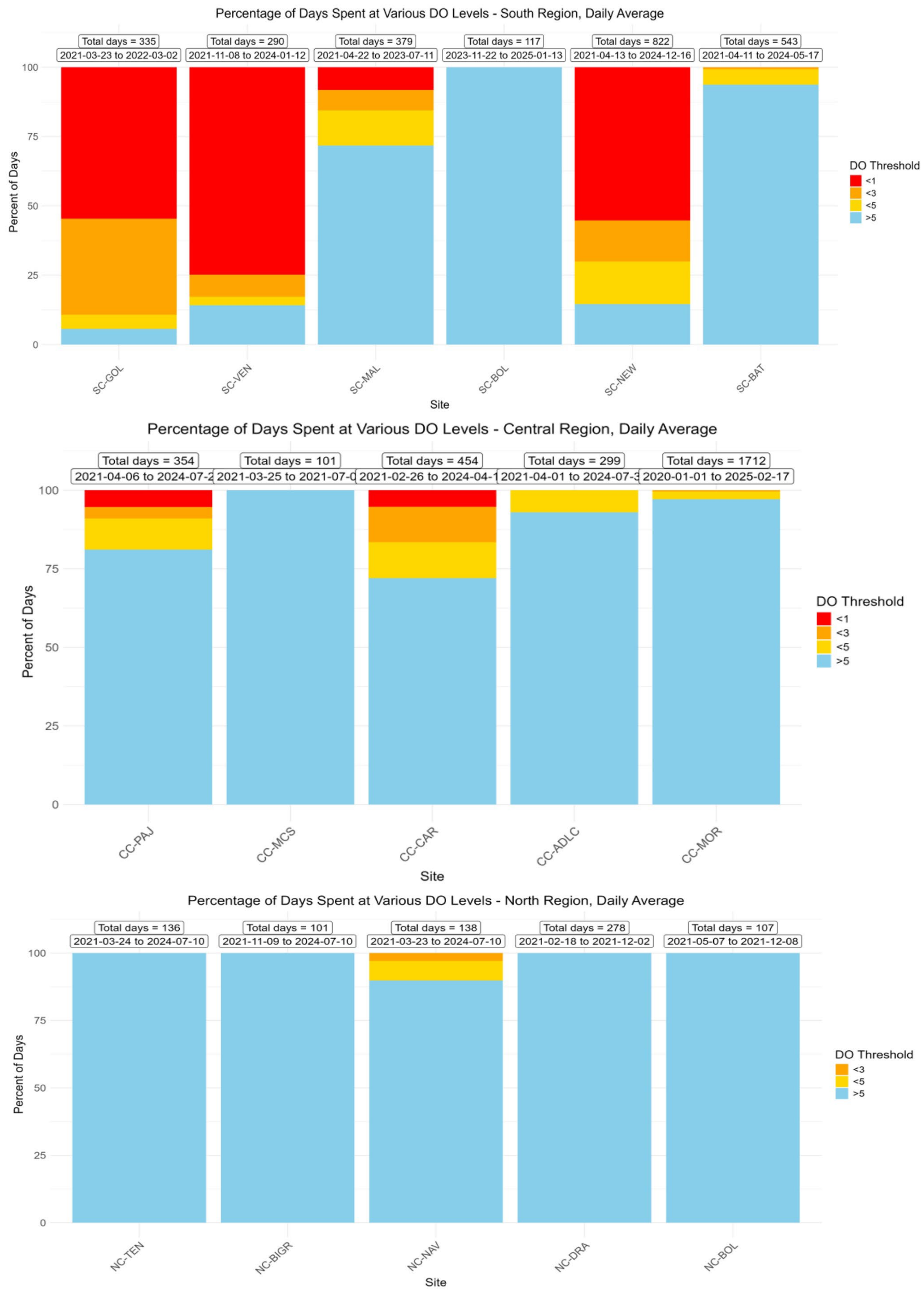


Figure C-22. *Percent of days each site spent at various DO thresholds for each region. Color represents the DO threshold. Above each box, the amount of available data in days and the time range of the availability is listed.*

Physiological limits

The essence of this condition statement is to track how often and for how long water quality conditions in these estuary sites exceed physiological threshold for fish. By defining metrics (as above), we are able to quantify how often the EMPA sites are exceeding these limits. However, different species may exhibit different physiological limits. Therefore, we also examined how the limits of specific fish of interest might be exceeded within specific systems. For example, in Figure C- 23, we illustrate how temperature can vary within Newport Bay and how this variation can sometimes exceed thresholds for some fish, but not all. These types of graphics can help managers understand what systems might not support target fish species.

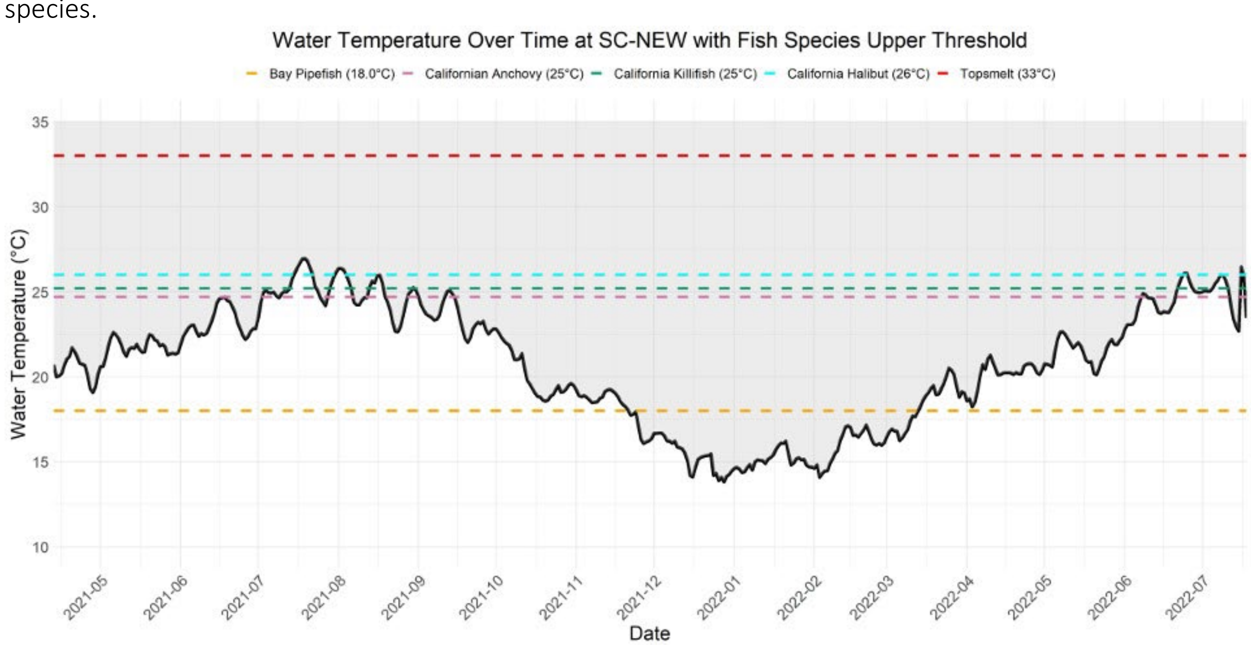


Figure C- 23. Daily average water temperature (black line) from May 2021 to July 2022 in Newport Bay (SC-NEW). Horizontal dashed-lines illustrate the upper temperature thresholds for five estuarine fish.

Time series data

An important consideration when evaluating estuary water quality data is the typical dynamics of a given system. Conditions may go beyond physiological conditions, either as brief but severe adverse conditions (acute effects) or as prolonged but less severe conditions (chronic effects). While biotic consequences may be observed, estuarine systems are extremely dynamic and naturally experience periods of low DO, variable salinities, and high temperatures. These "extreme events" can be ecologically important, promoting habitat diversity and thus biodiversity or promoting desirable trophic outcomes. Using data collected to-date, we have illustrated time series and metrics that we will use in future assessments related to the physiological limits of typical estuarine fish. For a closer look across all systems, see Appendix F: Additional SOP Results.

Scoring

While we cannot score this condition statement at present, we have identified and quantified daily, threshold, and event metrics that will be used in future scoring and assessment. When consistent cross-site time series are available, we will proceed to score EMPA sites in relation to nekton habitat. At that time, we will also develop a more profound interpretation of these metrics in terms of nekton health.

Condition Indicator 2: The benthic infauna community composition is representative of the estuary type and salinity regime (indicator: benthic infauna).

For the nekton function, both intertidal and subtidal infaunal cores were evaluated or scored. Subtidal habitats are most accessible for fish foraging, but many fish species also access the intertidal marshplain during higher tides. Results are shown in Figure C- 24 through Figure C- 33.

Because fewer samples were analyzed for benthic infauna as compared to fish, the analysis is combined across regions. Potentially limited by sample size, no statistical differences exist between regions in abundance, species richness, or community composition (p> 0.05 in all cases). Also, it should be noted that taxonomic identification was done and is presented as "morphospecies". Morphospecies is defined as a group of organisms classified based on their observable physical characteristics (morphology), like size, shape, and coloration, but lower identification was not possible due to life history stage (e.g. fly larvae) or expertise (e.g. oligochaetes).

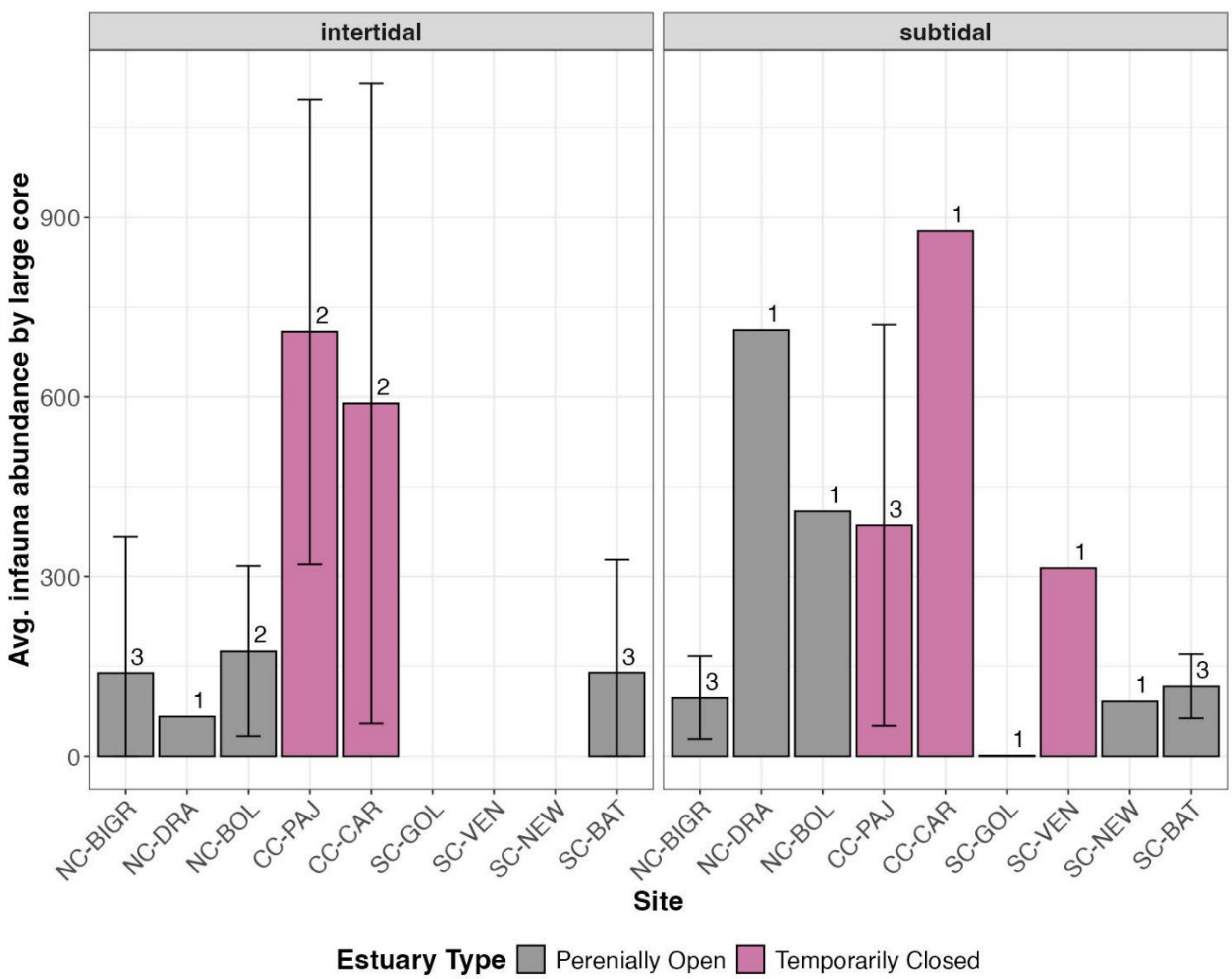


Figure C- 24. Average infauna abundance per large core (10cm x 10cm, 785 cm^3) in the intertidal and subtidal zone. Grey boxes represent sites that are perennially open and pink boxes represent sites that are temporarily closed. Numbers above bars are the total number of cores.

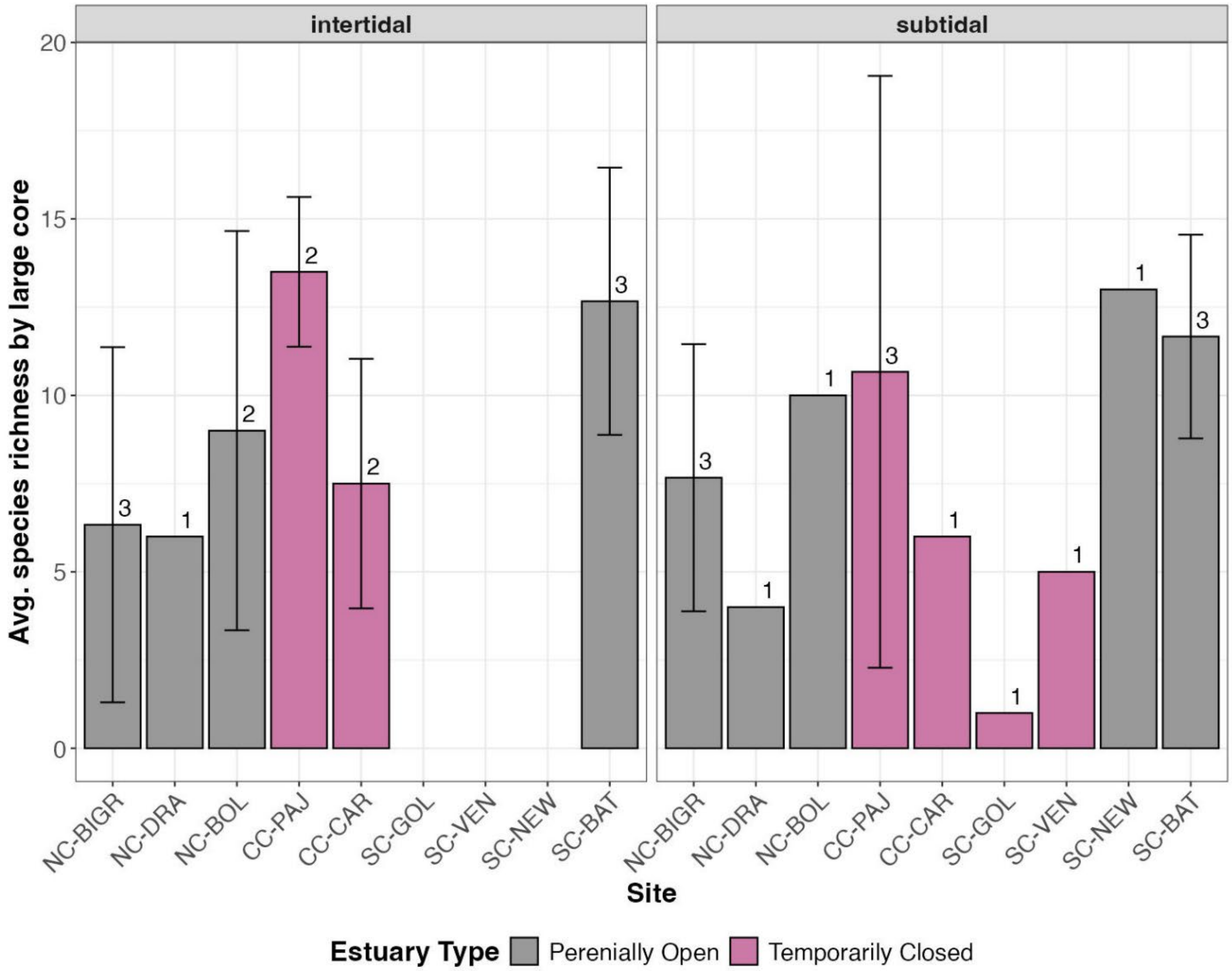


Figure C- 25. Average infauna species richness per large core (10cm x 10cm, 785 cm^3) in the intertidal and subtidal zone. Grey boxes represent sites that are perennially open and pink boxes represent sites that are temporarily closed. Numbers above bars are the total number of cores.

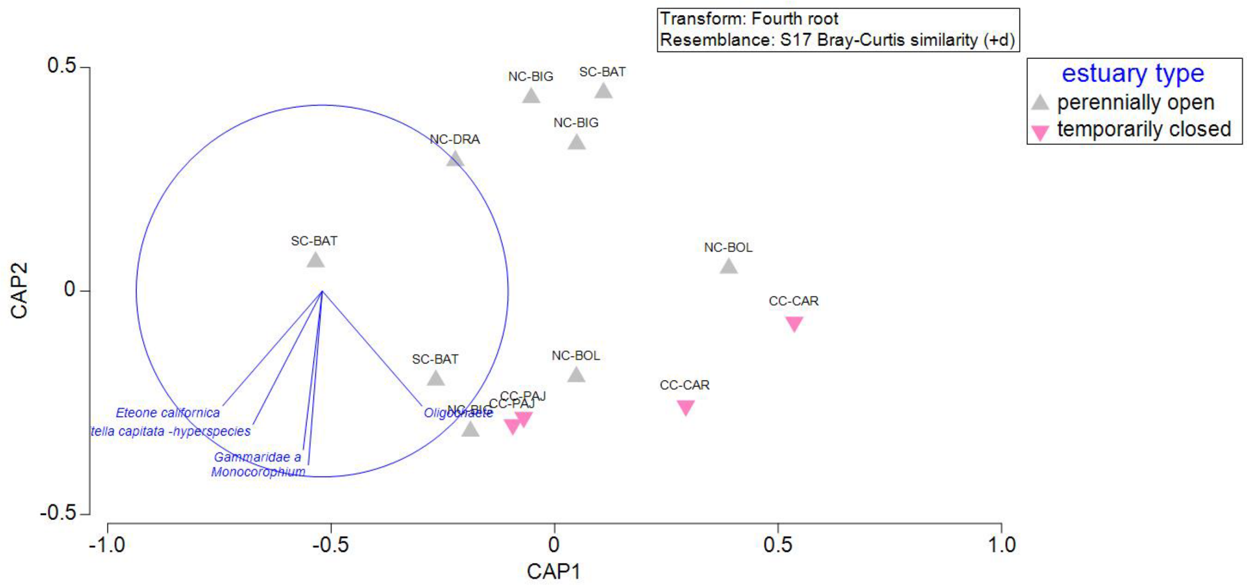


Figure C- 26. Intertidal infaunal community composition by species. Canonical Analysis of Principal coordinates (CAP) plot depicting infaunal invertebrate community composition in Fall 2023 in all regions combined. Five invertebrate morphospecies drove community differences (75% contribution) (Eteone californica polychaete, Capitella capitata hyperspecies polychaete, unknown Gammaridae amphipod, Monocorophium spp. amphipod, and oligochaetes, p < 0.001), appearing in greater abundance in temporarily closed estuaries. Points represent the community composition from each core analyzed from Fall 2023. Colors denote the estuary type (grey: perennially open and pink: temporarily closed).

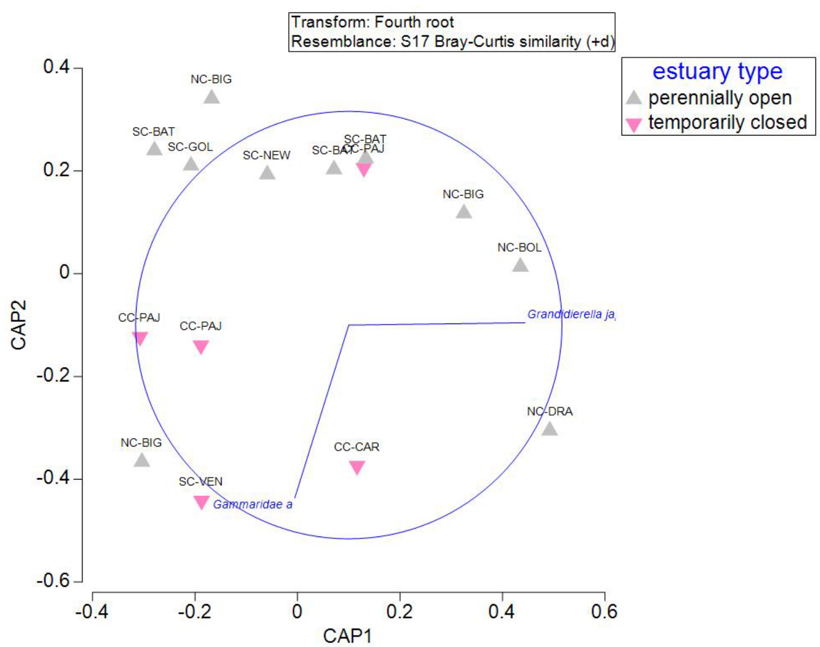


Figure C- 27. Subtidal infaunal community composition by species Canonical Analysis of Principal coordinates (CAP) plot depicting infaunal invertebrate community composition in Fall 2023 in all regions combined. While no significant differences existed between estuary types, two invertebrate morphospecies correlated with community differences (75% contribution) (unknown Gammaridae amphipod), appearing in greater abundance in temporarily closed *estuaries while Grandidierella japonica (introduced amphipod) was more abundant in the northern estuaries. Points represent the community composition from each core analyzed from Fall 2023. Colors denote the estuary type (grey: perennially open and pink: temporarily closed).*

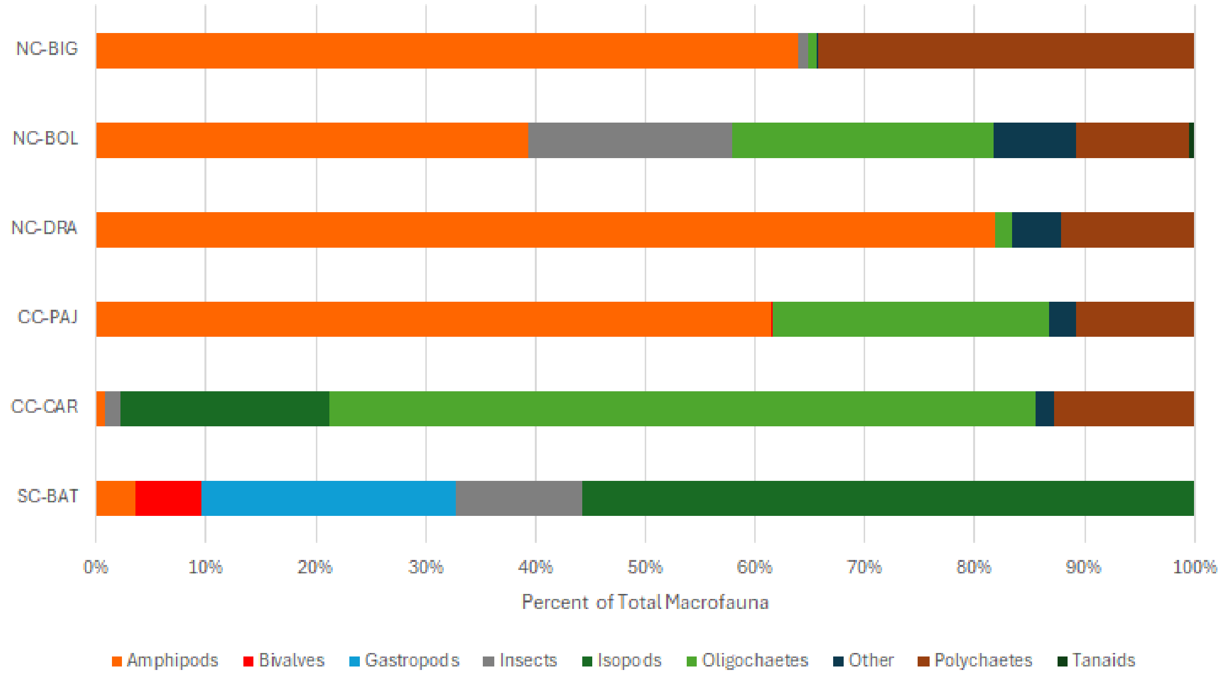


Figure C- 28. Percent of total abundance of intertidal infaunal invertebrate community in Fall 2023 by higher taxonomic grouping. "Other" includes nemerteans, flatworms, mites, and various echinoderms, which are rare in each sample.

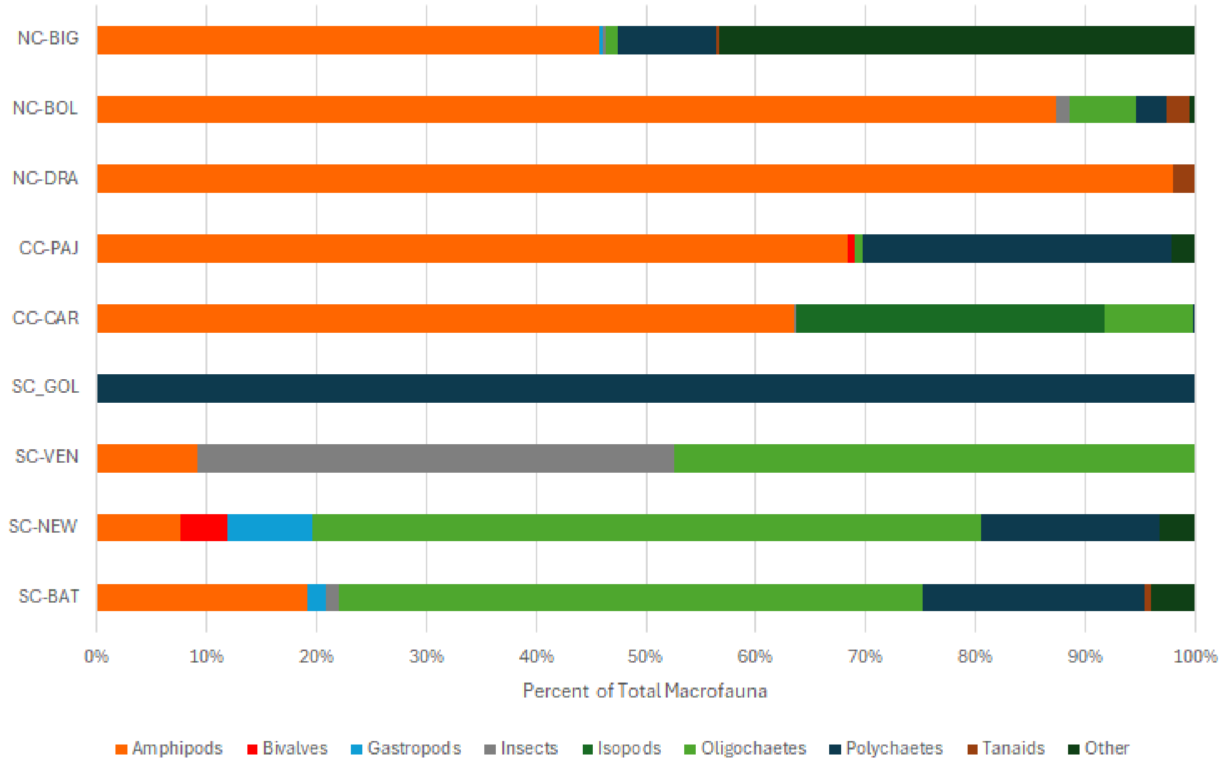


*Figure C- 29. Percent of total abundance of subtidal infaunal invertebrate community in Fall 2023 by higher taxonomic grouping. "Other" includes nemerteans, flatworms, mites, and various echinoderms, which are rare in each sample. *Note: SC-GOL only represents 1 sample with one organism found.*

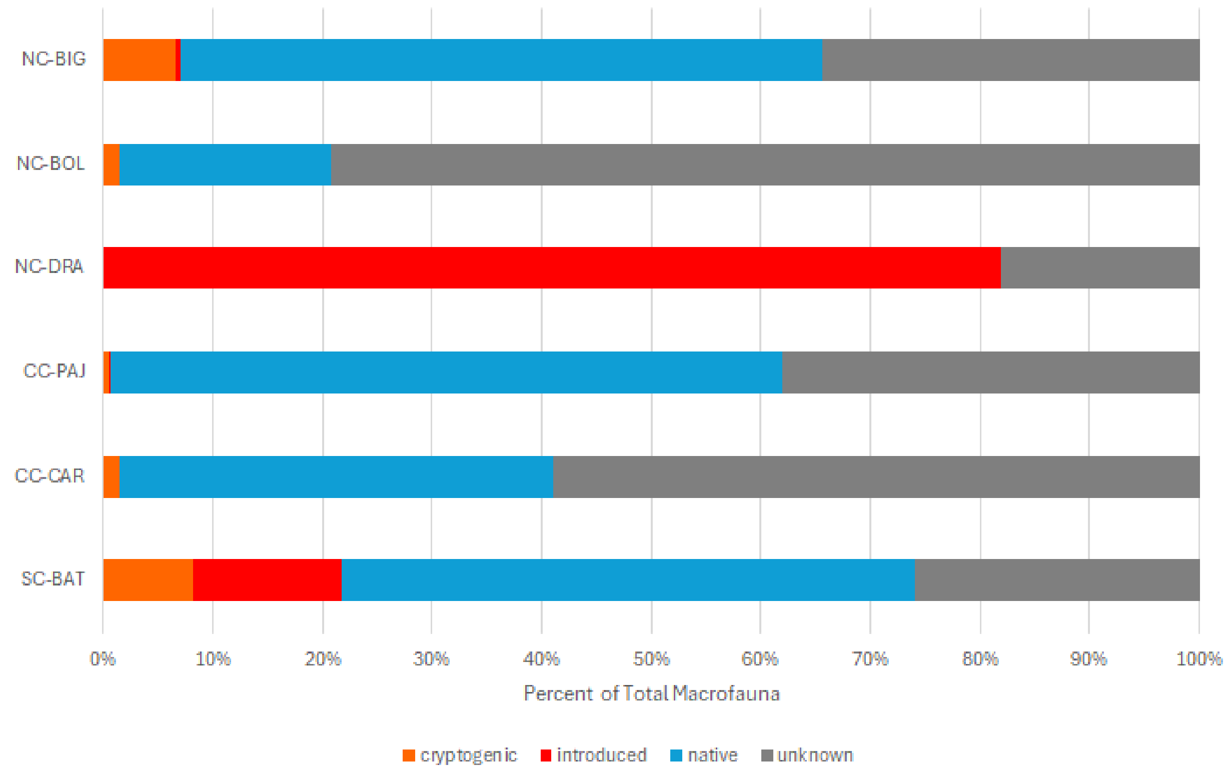


*Figure C- 30. Percent of total abundance of intertidal infaunal invertebrate community in Fall 2023 by invasive status. Red boxes represent the proportion of invertebrates that were confirmed as introduced and blue boxes represent the proportion of invertebrate morphospecies that were confirmed as native. Because some specimens are not identified to species, invasive status cannot be determined or even if species is identified, status is unknown (cryptogenic). Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

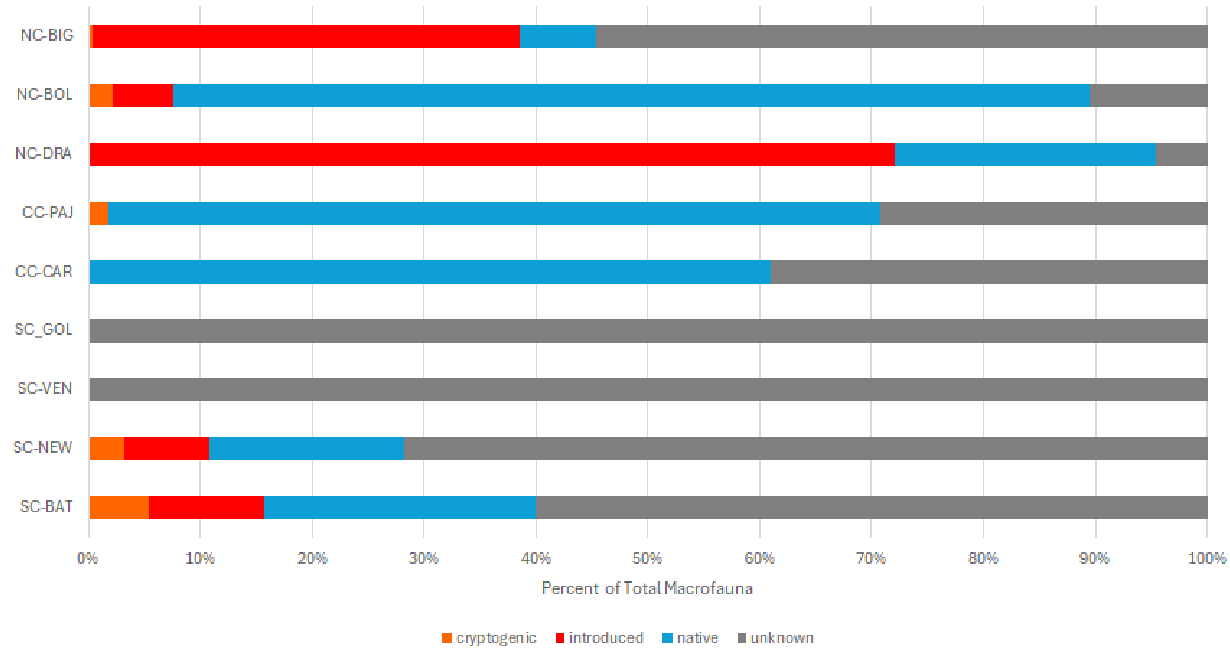


*Figure C- 31. Percent of total abundance of subtidal infaunal invertebrate community in Fall 2023 by invasive status. Red boxes represent the proportion of invertebrates that were confirmed as introduced and blue boxes represent the proportion of invertebrate morphospecies that were confirmed as native. Because some specimens are not identified to species, invasive status cannot be determined or even if species is identified, status is unknown (cryptogenic). Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

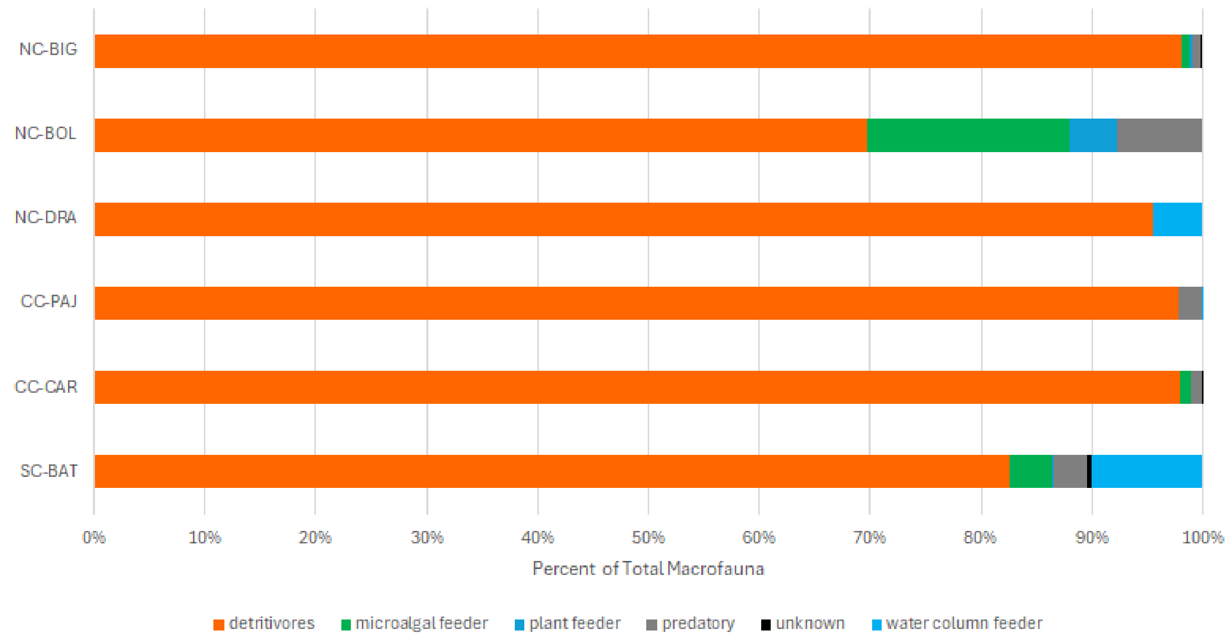


*Figure C- 32. Percent of total abundance of intertidal infaunal invertebrate community in Fall 2023 by feeding group. Because some specimens are not identified to species, feeding type cannot be determined or even if species is identified, how they feed is unknown. Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

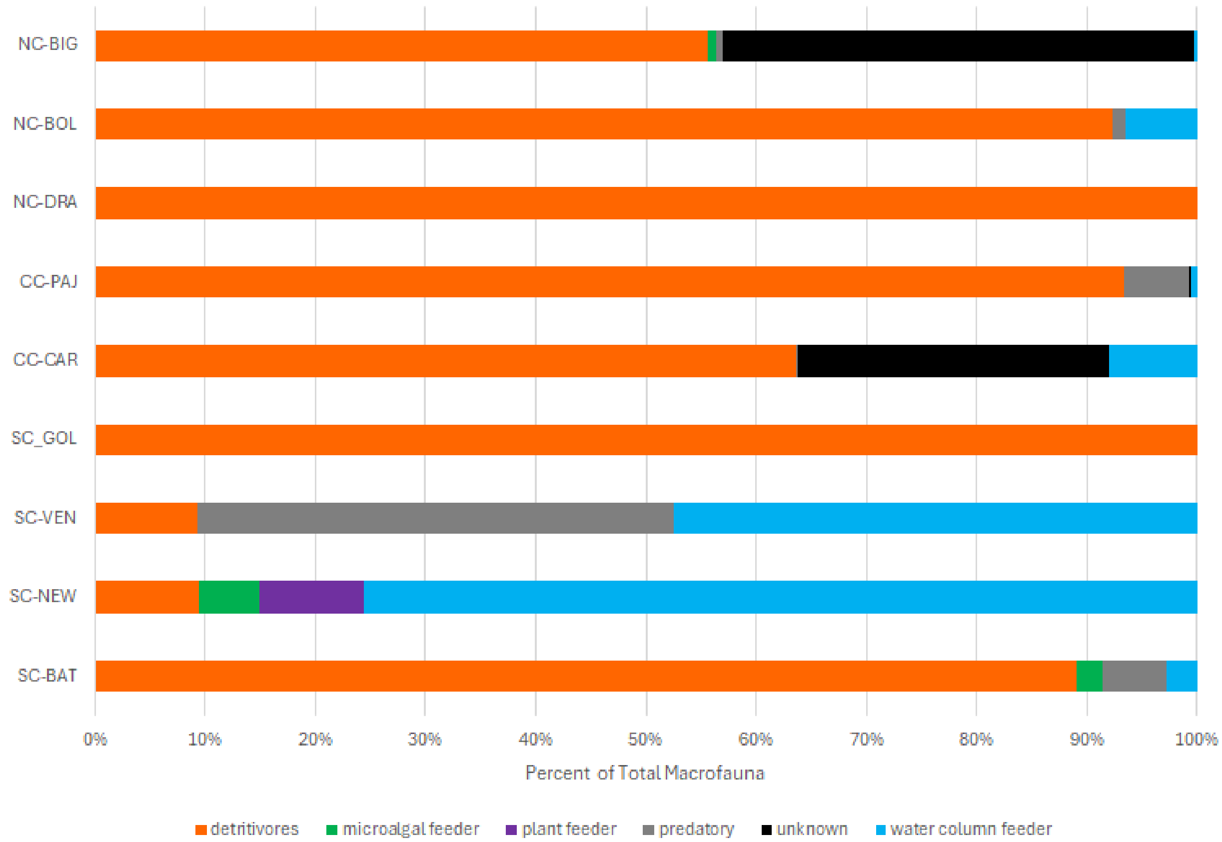


*Figure C- 33. Percent of total abundance of subtidal infaunal invertebrate community in Fall 2023 by feeding group. Because some specimens are not identified to species, feeding type cannot be determined or even if species is identified, how they feed is unknown. Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

Due to limited data, we cannot score this condition statement at present.

Condition Indicator 3: The native fish and crustacean community composition is representative of the estuary type, and salinity and temperature regime (indicator: fish).

To begin to evaluate and understand representativeness, we took a multi-tier approach to start to outline a method for scoring this indicator. The first step, completed in this report, is to present community composition (both presence/absence) and abundance by species to understand the data collected. Next steps, completed in this report, include using multivariate statistical techniques to associate this community composition with potential environmental correlates (including salinity, temperature, dissolved oxygen, SAV presence, inlet status, etc.). A preliminary list of "expected" estuarine fish taxa was developed for each region (south, central, north) (Appendix D: Fish Species Regional Lists). For demonstration purposes in this report, this expected list was compared to the community composition of fish caught in Fall 2023 (See below). Final steps, not completed in this report, include convening an expert panel with taxonomists, fish experts, and BCG practitioners. The panel will evaluate proposed regional expected fish lists, calibrate the conceptual BCG with data for specific estuaries, and develop quantitative decision rules for assigning sites to BCG levels for that system using a combination of expert elicitation and consensus.

Fish Community and Species Metrics

To fully understand if fish communities are representative of their estuary type, we evaluated species richness, abundance, and community composition. The EMPA program uses beach seines to monitor fish species. Five beach seines are pulled at each estuarine station for a total of 15 seine nets per estuary. Replication may vary between estuaries due to the number of sampling stations and accessibility during tide events. Results are shown in Figure C- 34 through Figure C- 41.

Overall, fish species richness by net replicate (the number of fish species caught in each net) was similar across all sites. However, total species richness (the total number of fish species caught at each site) was highest in four south coast estuaries - Ventura River, Bolsa Chica, Newport Bay, and Batiquitos Lagoon - as compared to estuaries in other regions. Across all sites, the most common fish caught were in the Atherinopsidae family (topsmelt silversides and jacksmelt silversides), goby (e.g., arrow goby), and Pacific staghorn sculpins. Three-spine stickleback were common in the central and north coast, and California killifish were common in the south coast. The south coast was the only region that caught any invasive fish, such as the inland silverside and rainwater killifish.

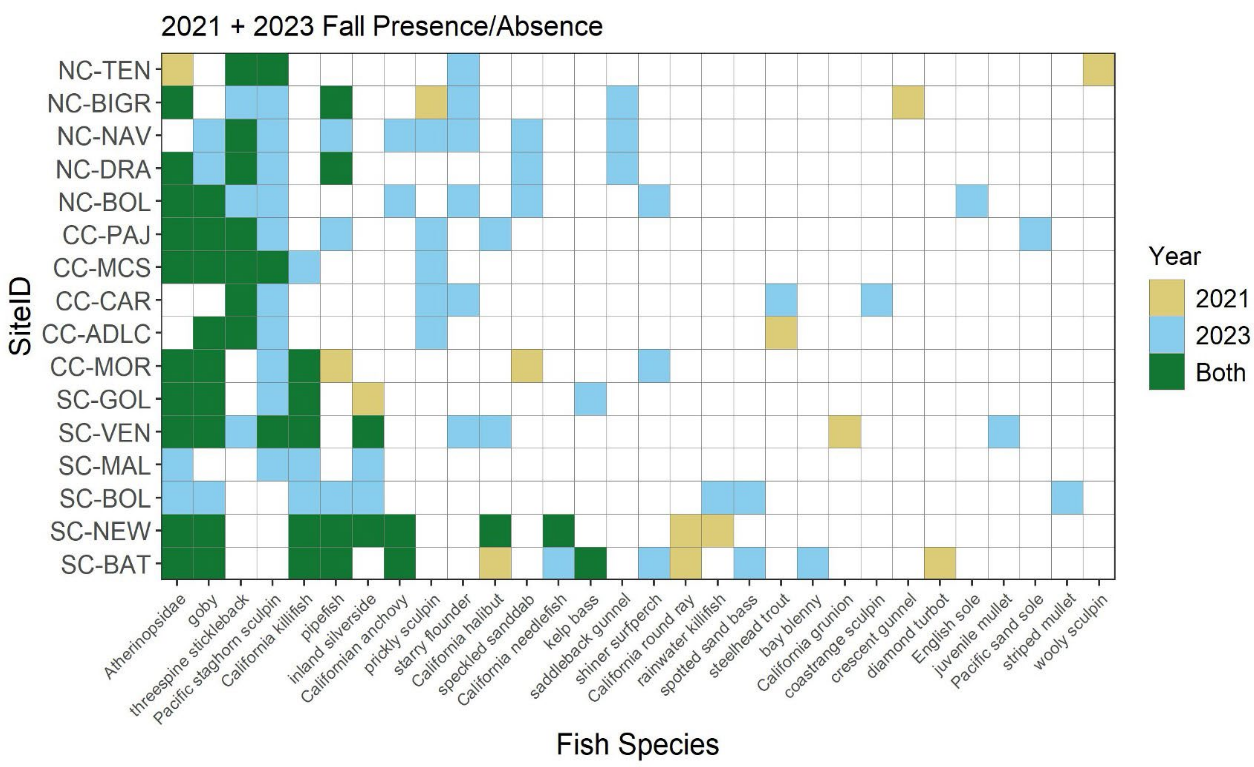


Figure C- 34. Fish species presence in Fall 2021 and 2023 caught in seine nets. Yellow boxes represent fish presence in 2021, blue boxes represent fish presence in 2023, and green boxes represent fish presence in both 2021 and 2023. Goby species were pulled into one class "Goby".

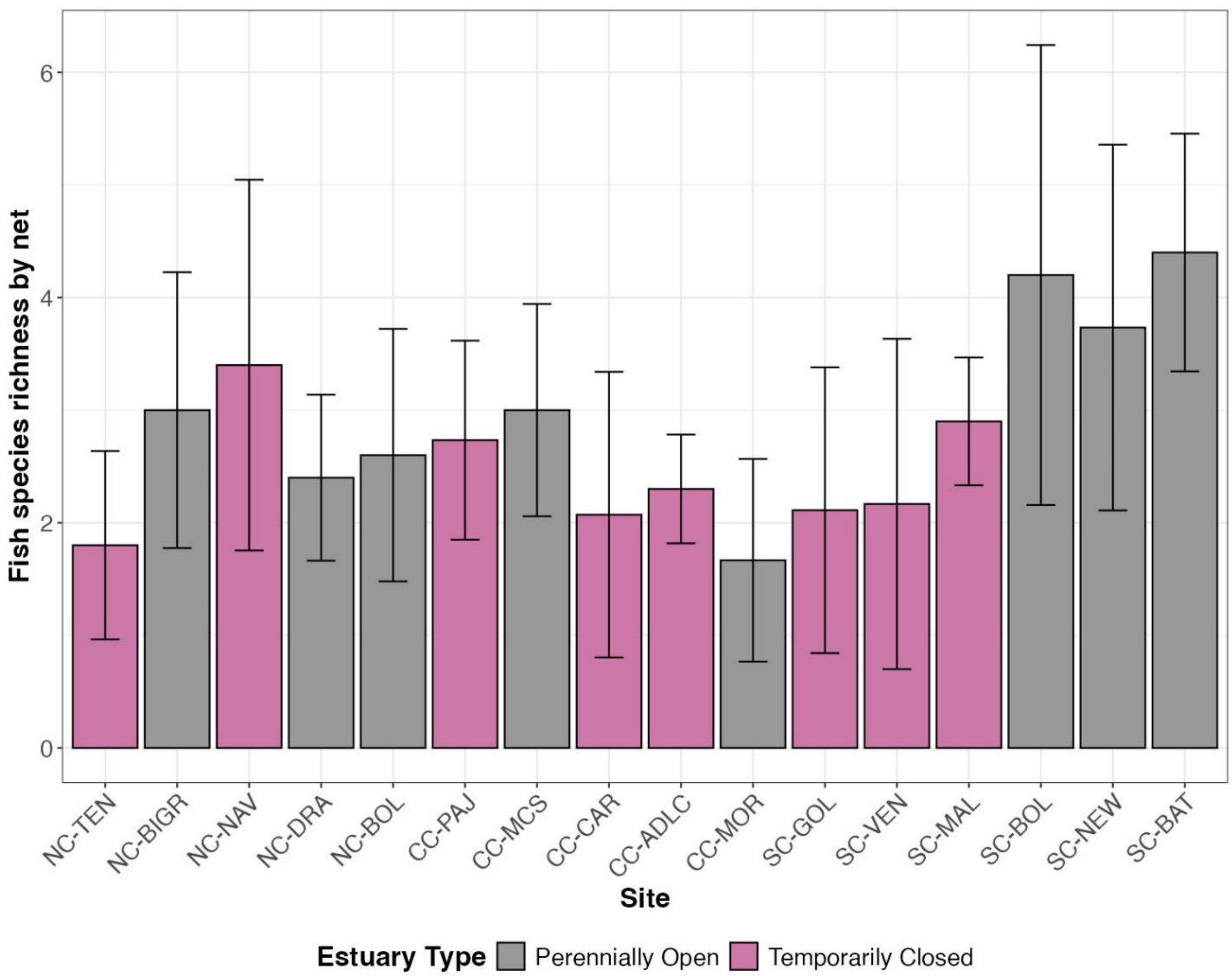


Figure C- 35. Fish species richness by seine net replicate in Fall 2023. Grey boxes represent sites that are perennially open and pink boxes represent sites that are temporarily closed.

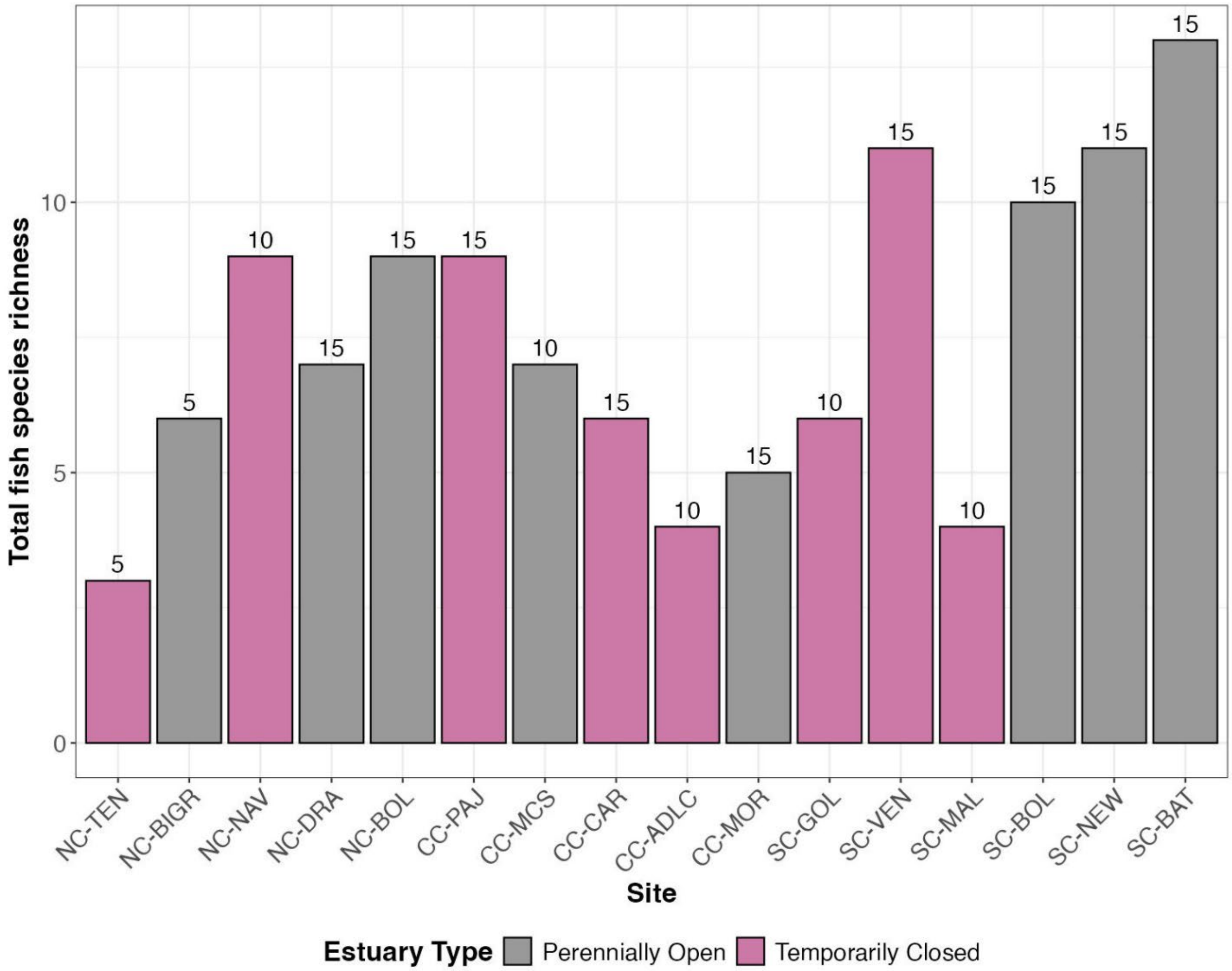


Figure C- 36. Total fish species richness caught across the site in Fall 2023. Grey boxes represent sites that are perennially open and pink boxes represent sites that are temporarily closed. Numbers above bars are the total number of seine net replicates.

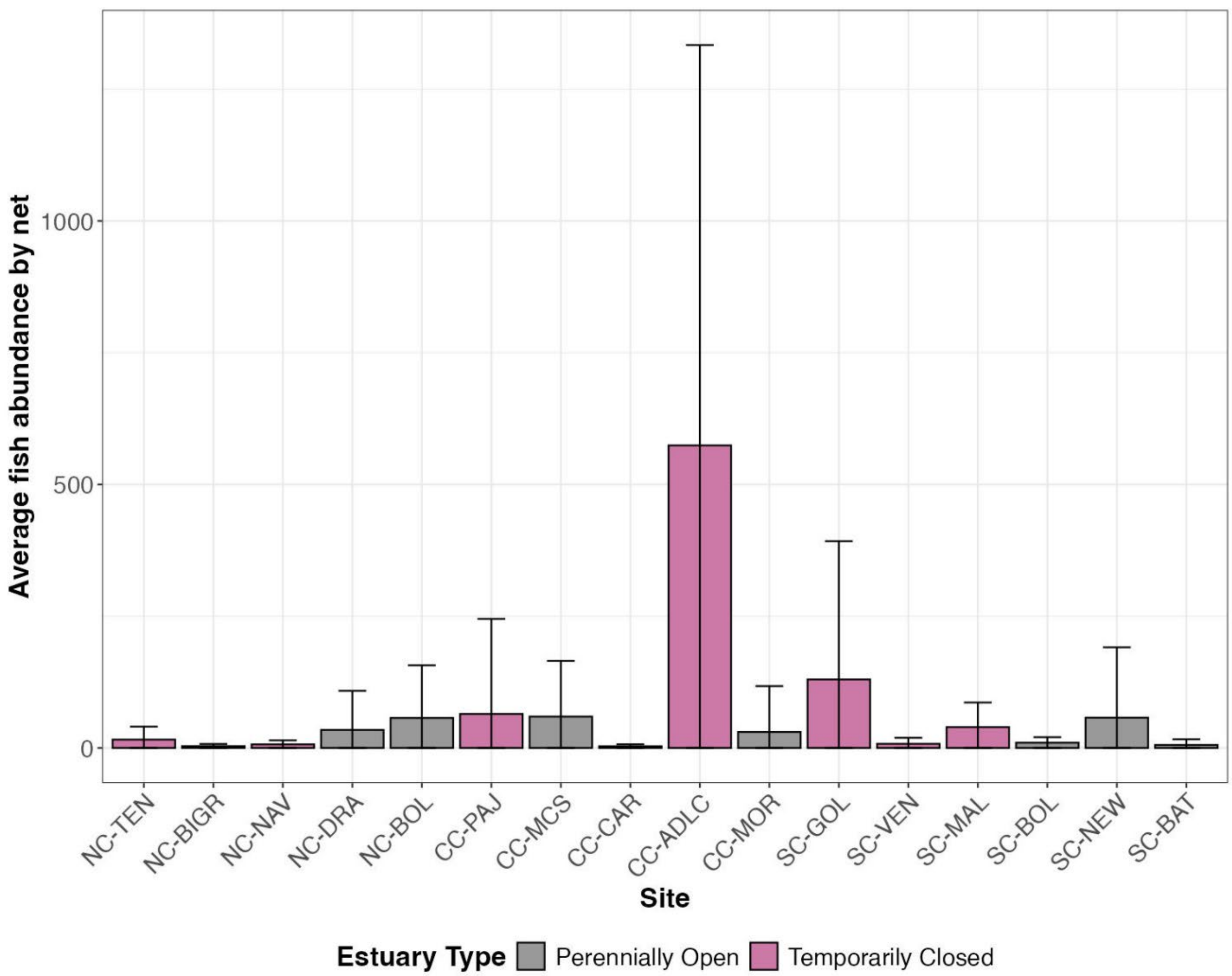


Figure C- 37. Average fish abundance by seine net replicate in Fall 2023. Grey boxes represent sites that are perennially open and pink boxes represent sites that are temporarily closed.

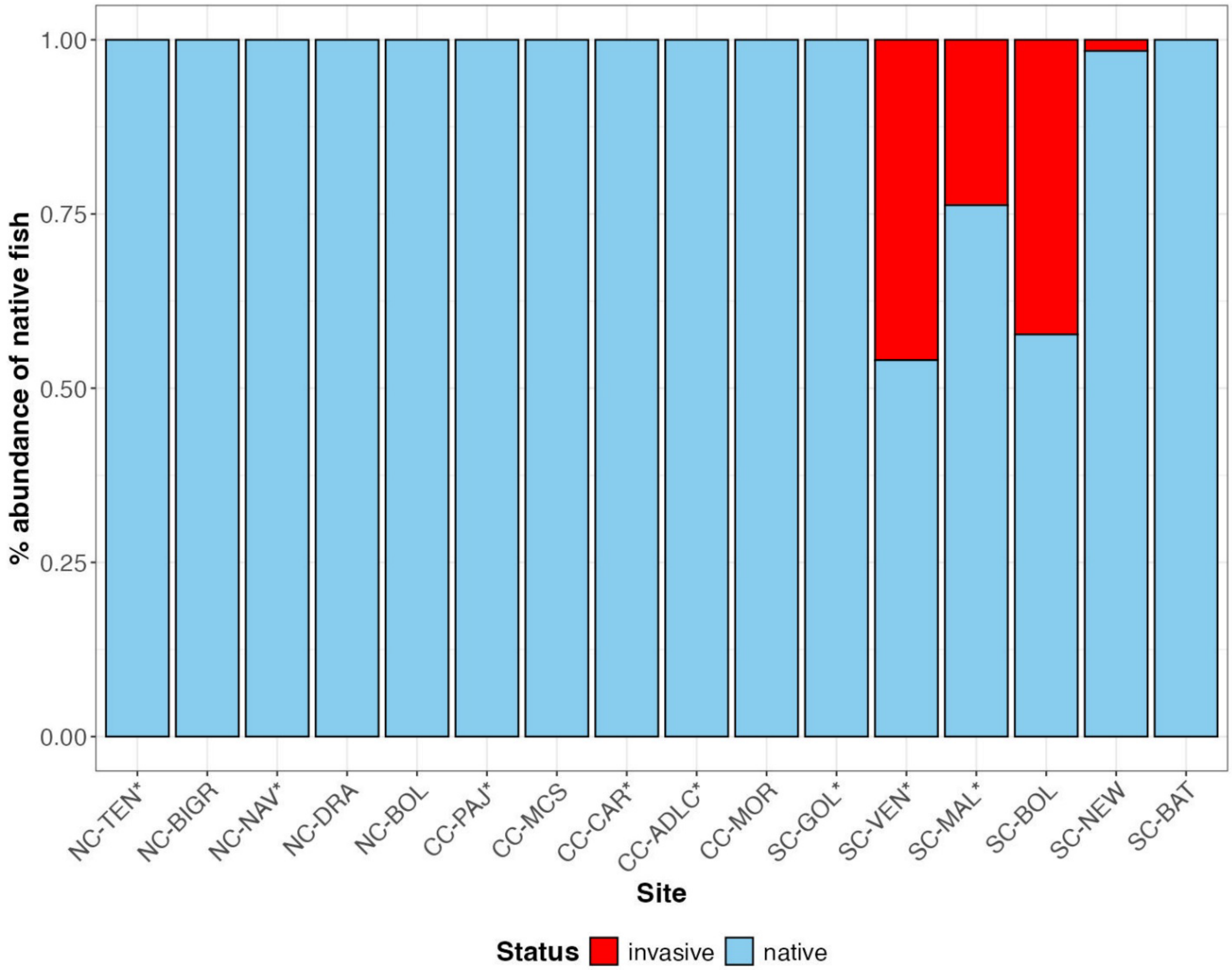


*Figure C- 38.Percent of total abundance of fish caught in Fall 2023 that were native or invasive. Red boxes represent the proportion of fish that were invasive and blue boxes represent the proportion of fish that were native. Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

Fish Community Composition Metrics

To better understand drivers of fish community composition, we used multivariate techniques to understand the associations between community composition and potential environmental correlates (including salinity, temperature, dissolved oxygen). In the south coast, five fish species drove community differences (topsmelt silverside, inland silverside, California killifish, arrow goby, and bay pipefish, $p < 0.001$), as well as average conductivity ($p < 0.01$) (Figure C- 39). In the central coast, seven fish species drove community differences ($p < 0.001$), as well as average DO and average conductivity ($p < 0.01$) (Figure C- 40). These species included two types of goby: the arrow goby and the endangered tidewater goby. In the north coast, five fish species drove community differences (Pacific staghorn sculpin, bay pipefish, topsmelt silverside, arrow goby, prickly sculpin; $p < 0.001$), as well as average temperature, DO, and conductivity ($p < 0.01$) (Figure C- 41). Overall, estuary type (perennially open and temporarily closed) was the main predictor of fish community composition, which is most likely due to inlet or mouth status.

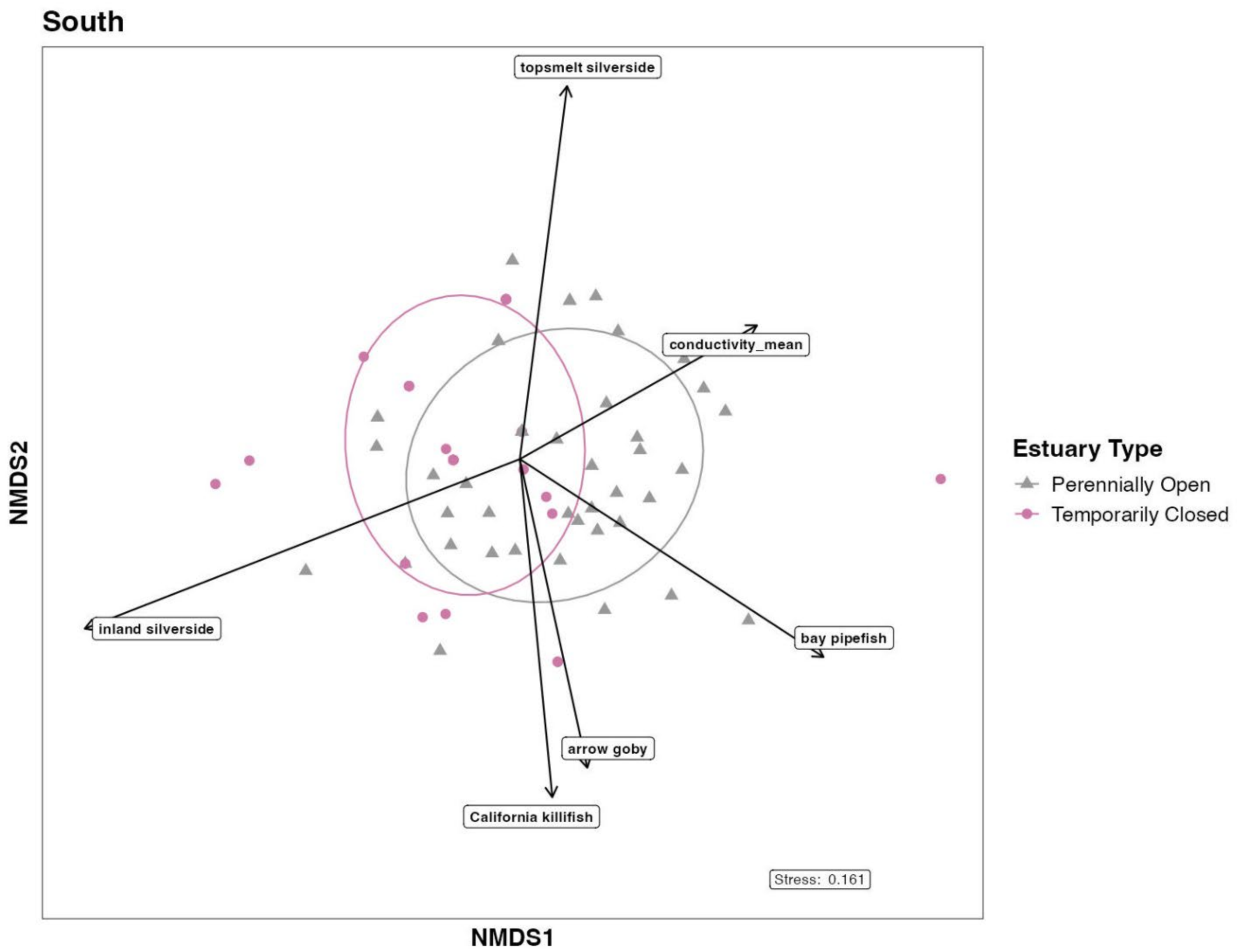


Figure C- 39. nMDS plot depicting fish community composition in Fall 2023 in the south region. Five fish species drove community differences (topsmelt silverside, inland silverside, California killifish, arrow goby, and bay pipefish, $p < 0.001$) as well as average conductivity ($p < 0.01$). Points represent the community composition from each net replicate in Fall 2023. Colors and shapes denote the estuary type (grey: perennially open and pink: temporarily closed).

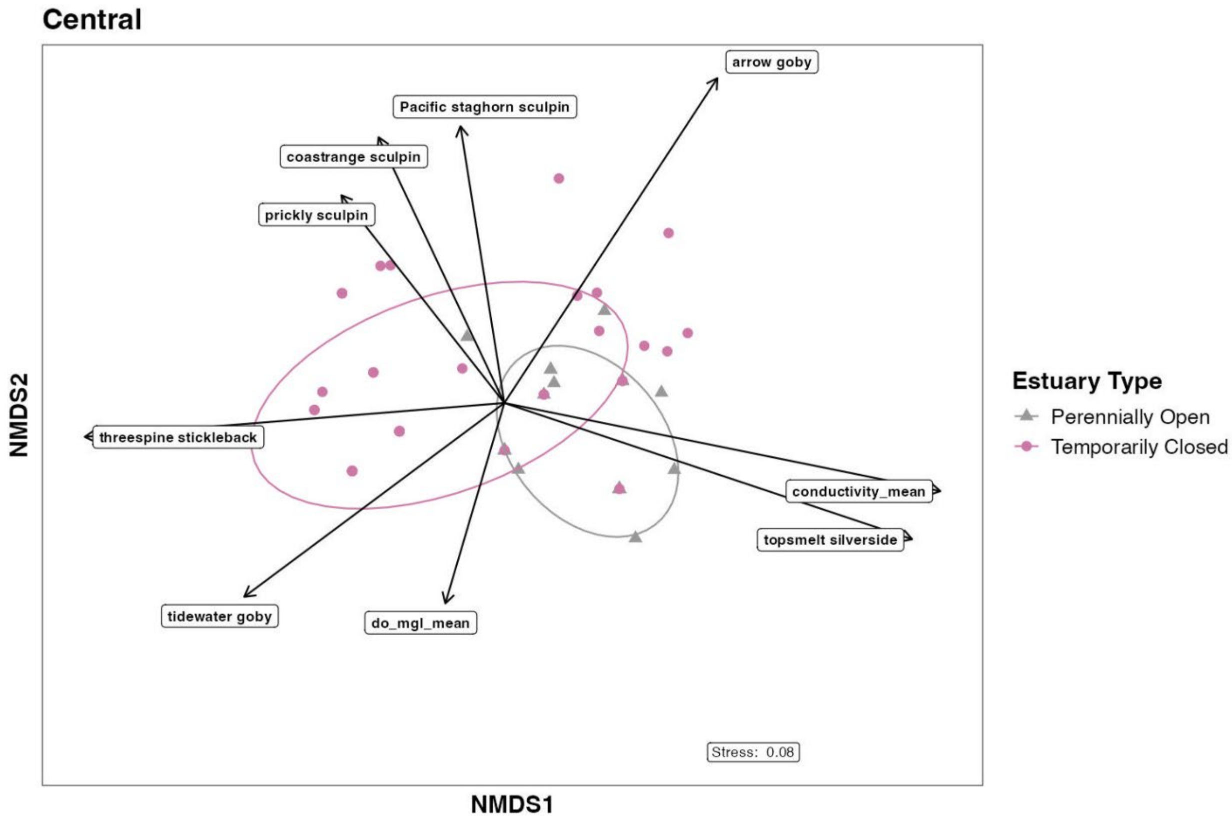


Figure C- 40. nMDS plot depicting fish community composition in Fall 2023 in the central region. Seven fish species drove community differences (p <0.001), as well as average DO and average conductivity (p <0.01). Points represent the community composition from each net replicate in Fall 2023. Colors and shapes denote the estuary type (grey: perennially open and pink: temporarily closed).

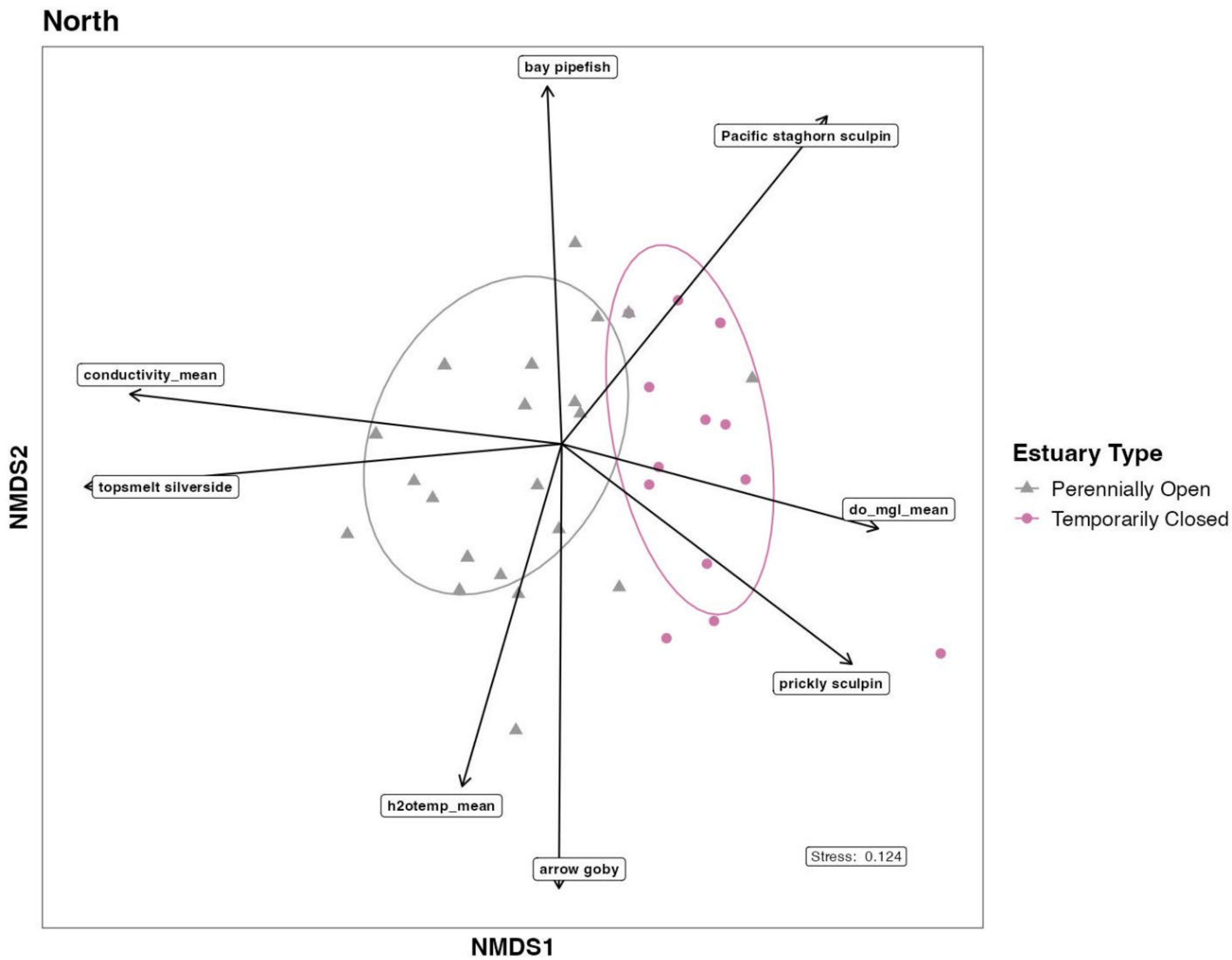


Figure C- 41. nMDS plot depicting fish community composition in Fall 2023 in the north region. Five fish species drove community differences (Pacific staghorn sculpin, bay pipefish, topsmelt silverside, arrow goby, prickly sculpin; p <0.001), as well as average temperature, DO, and conductivity (p <0.01). Points represent the community composition from each net replicate in Fall 2023. Colors and shapes denote the estuary type (grey: perennially open and pink: temporarily closed).

Demonstration of Observed Versus Expected Fish Communities

In this sample analysis, a "sample lagoon", with community composition developed from the expected fish community list (See Appendix D: Fish Species Regional Lists), was compared to the samples from other southern California lagoons in Fall 2023. In this pilot case, community composition in each estuary did not differ from the expected southern California estuarine fish community (PERMANOVA (unrestricted permutation), p-perm > 0.05). However, it was also useful to compare percent similarity among estuaries using clustering, a hierarchical clustering algorithm used to group samples based on their distance in the MDS space (Figure C- 42).

This pilot study demonstrated that this observed to expected comparison using multivariate and similarity analysis has potential as a method to evaluate and score fish community indicators and functions. However, it does have caveats that clustering should be used in combination with other techniques where there is a range or gradient in community structure across sites as well as evidence of strong environmental forcing (e.g. large range of salinity, sediment grain size, depth of water column, etc.). Since these factors exist along the large latitudinal range of the monitored sites in this study, we will suggest using clustering in conjunction with ordination techniques for future scoring and evaluation.

In addition, for use beyond the pilot, more thought will be given to specify a threshold similarity level (or levels) at which to 'cut' the dendrogram (Figure C- 42 shows a division for a threshold of 60 and 80%). Threshold levels will vary with standardization, taxonomic identification level, presence/absence versus abundance, and choice of coefficient. Despite these caveats and suggestions for improvement in the future, the pilot of observed versus expected community composition comparisons suggests that this is a useful method to compare entire community composition among nekton communities.

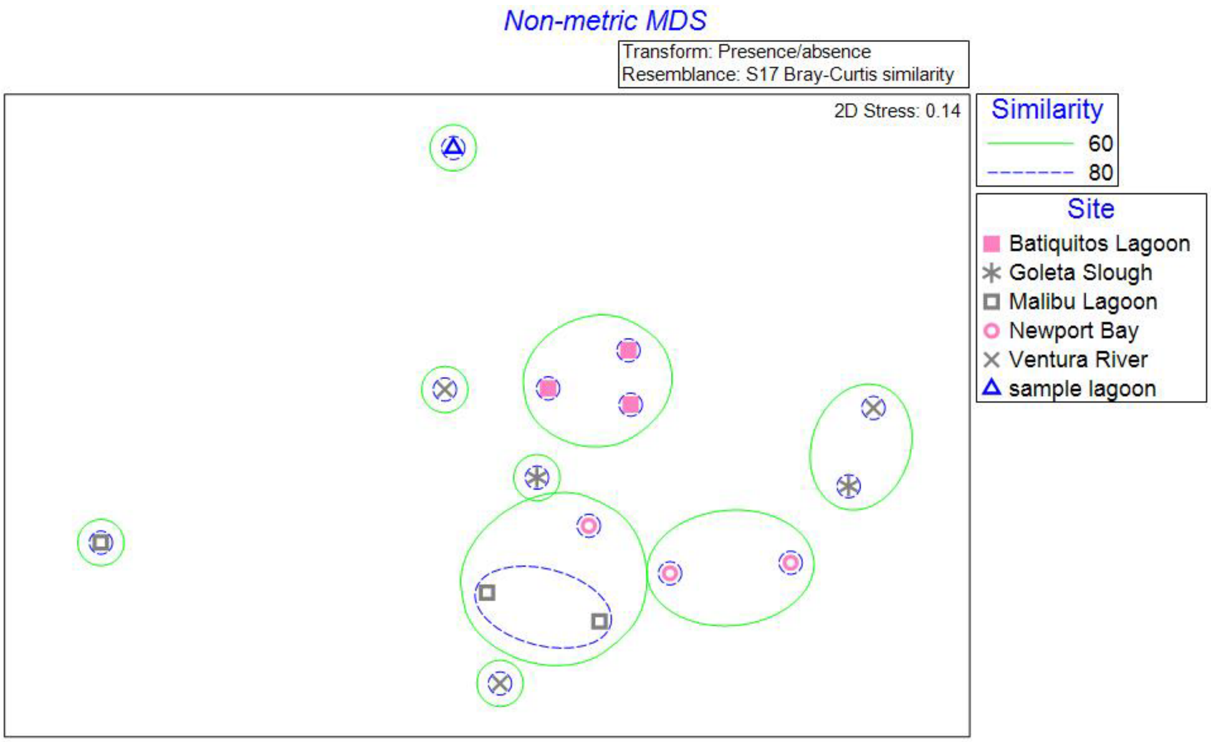


Figure C- 42. nMDS plot depicting fish community composition in Fall 2023 in the south region. Points represent the community composition from each net replicate in Fall 2023, and the sample lagoon point represents the expected fish community composition list (Appendix D). Colors denote the estuary type (grey: perennially open and pink: temporarily closed). The circles on the plot were created using the "cluster" function within the MDS analysis. They allow the user to identify and visually group similar data points (samples) based on their similarity, essentially creating clusters of related samples at the 60 and 80% similarity level.

Nekton Invertebrates

Similar to fish, to fully understand if the invertebrate communities are representative of their estuary type, we evaluated species richness, abundance, and community composition. The EMPA program identifies invertebrate communities in both beach seines and intertidal and subtidal traps (Figure C- 43). More work needs to be completed to better evaluate nekton invertebrates.

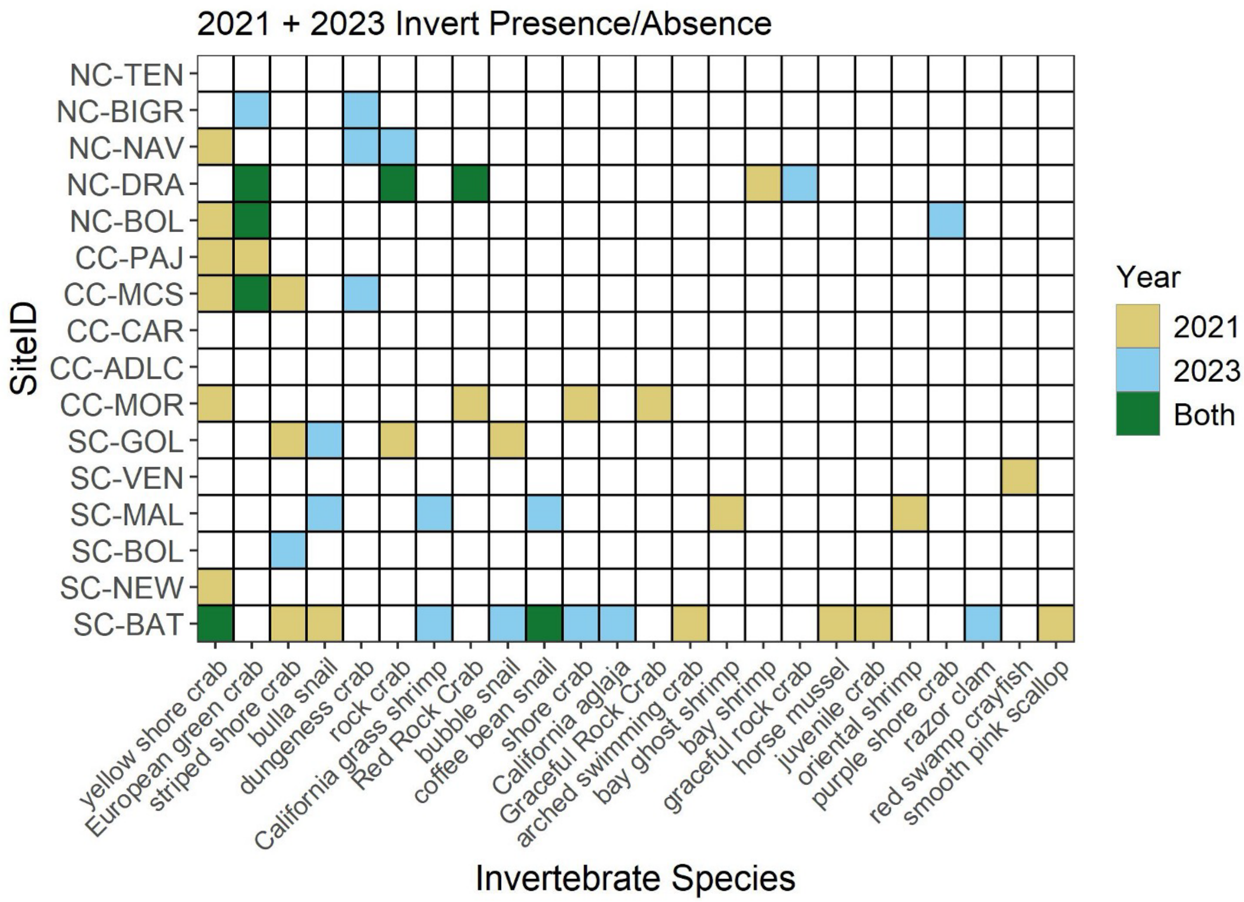


Figure C- 43. Invertebrate species presence in Fall 2021 and 2023 caught in seine nets and intertidal and subtidal traps. Yellow boxes represent invertebrate presence in 2021, blue boxes represent invertebrate presence in 2023, and green boxes represent invertebrate presence in both 2021 and 2023.

Supporting invertebrate and shellfish habitats and populations are an important function of California estuaries (Hughes et al. 2014). Commercially and recreational shellfish species are sensitive to changes in water quality, mouth condition, and community structure. Therefore, estuaries need to support habitats that can sustain these important species.

Here we specifically focus on two species of crab that are key indicators of other estuarine functions: nursery support and invasive species resistance, and therefore are critical species for evaluating nekton habitat. One species in particular, Dungeness crab (*Metacarcinus magister*), are well known to use estuaries as juvenile nursery grounds before migrating to deeper ocean habitats once they reach sub adult to adult stages (Hughes 2014, Grimes 2020). Preliminary data analyses from our Fall 2023 EMPA trapping efforts identifies four estuaries as possible Dungeness crab nurseries (Figure C- 44). These data also support the statewide distribution of Dungeness crab with a southern population range distribution that ends in central California.

We also explored one of the major marine invasions to take over California estuaries: European green crab (*Carinus maenas*). When left unchecked, invasive green crab can alter benthic communities and consume important shellfish species, such as the native Olympia oyster (Kimbro et al. 2009). We summarized trapping efforts of European green crab using our EMPA sampling efforts from 2021-2024, and found two central and three northern California estuaries with European green crab populations. These estuaries varied in type from perennially opened to seasonally closed lagoons, indicating that green crab habitat requirements are broad, which to date is poorly understood (Figure C- 45).

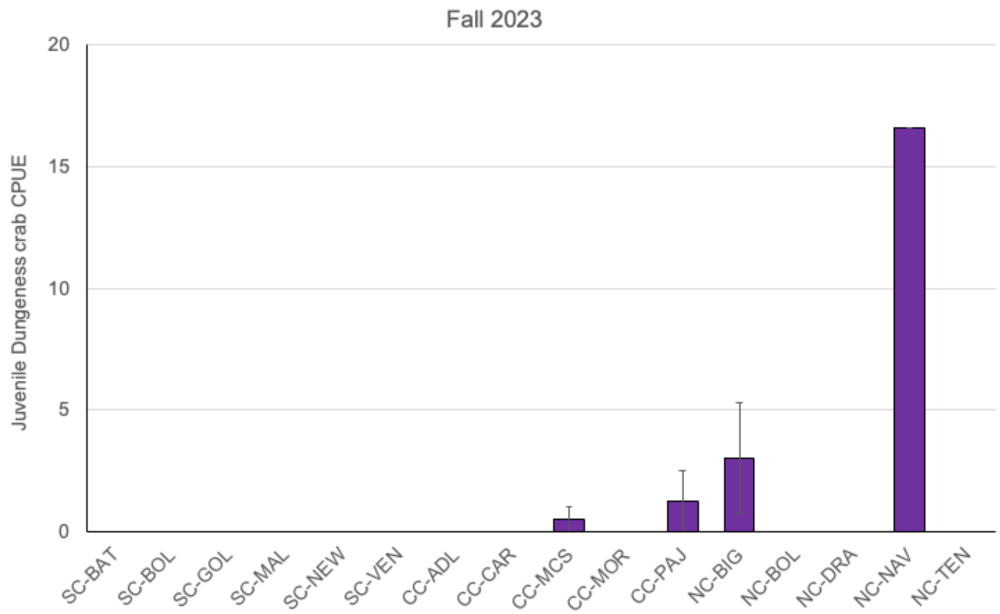


Figure C- 44. EMPA trapping efforts from Fall 2023 identified 4 central and northern California estuaries that could be considered as Dungeness crab nurseries. Crabs caught in the traps were exclusively of juvenile size or subadults, which indicates that these systems are providing an important nursery function. CPUE = Catch Per Unit Effort (24-hour soak time), and error bars represent +/- SE.

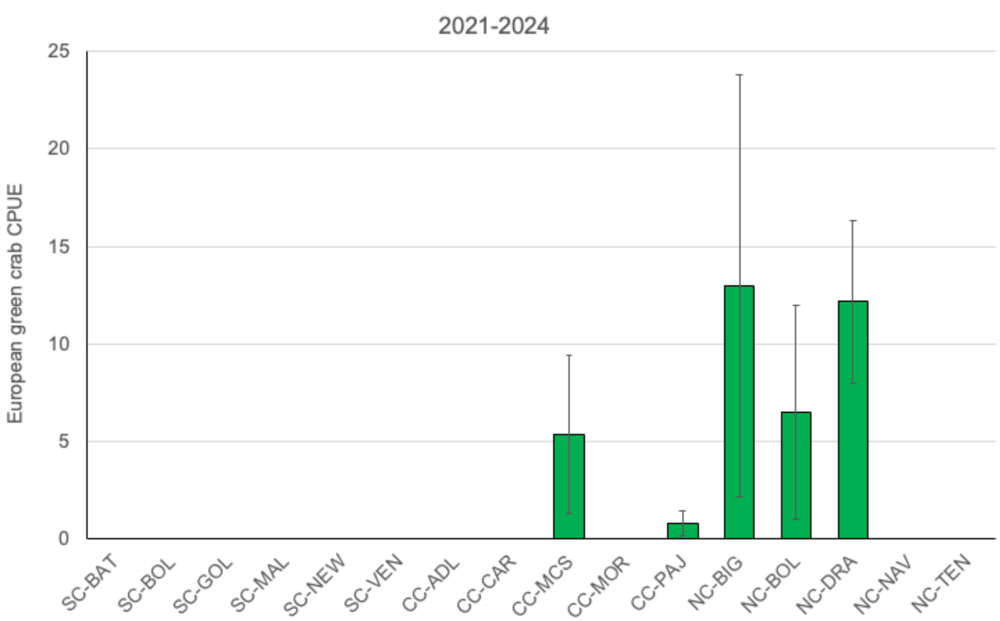


Figure C- 45. EMPA trapping efforts from 2021-2024 identified 5 central and northern California estuaries that could be considered as strongholds for invasive European green crab. CPUE = Catch Per Unit Effort (24-hour soak time), and error bars represent +/- SE.

Scoring

In this report, we took a multi-tier approach to start to outline a method for scoring this indicator, but we are not assigning a score for this indicator as additional data (E.g. SAV distribution) needs to be collected. The next step to realize scoring is to convene an expert panel with taxonomists, fish experts, and BCG practitioners. The overall goal of this panel will be to develop quantitative decision rules for assigning sites to BCG levels for that system using a combination of expert elicitation and consensus. By developing a BCG, we can then use an index to score this condition statement.

Condition Indicator 4: The extent and distribution of ephemeral macroalgae is low enough to allow for native fish and crustacean communities (indicator: macroalgae).

High cover of ephemeral macroalgae within an estuary can be indicative of impairment to aquatic life. Therefore, condition statement 4 assesses the extent of both intertidal and floating subtidal macroalgae. We evaluate the average percent cover of macroalgae across intertidal transects and subtidal visual estimates (Figure C- 46). We bin cover into tertiles with the upper bin being demarcated at 70%. Cover that is greater than 70% can be indicative of impairment to aquatic life, such as fish and crustaceans (Sutula et al. 2014). For sites with 0-35%, 35-70%, or 70-100% average algal cover, the estuary received a score of 3, 2, or 1, respectively. We average the scores for a final compiled score (Table C- 11).

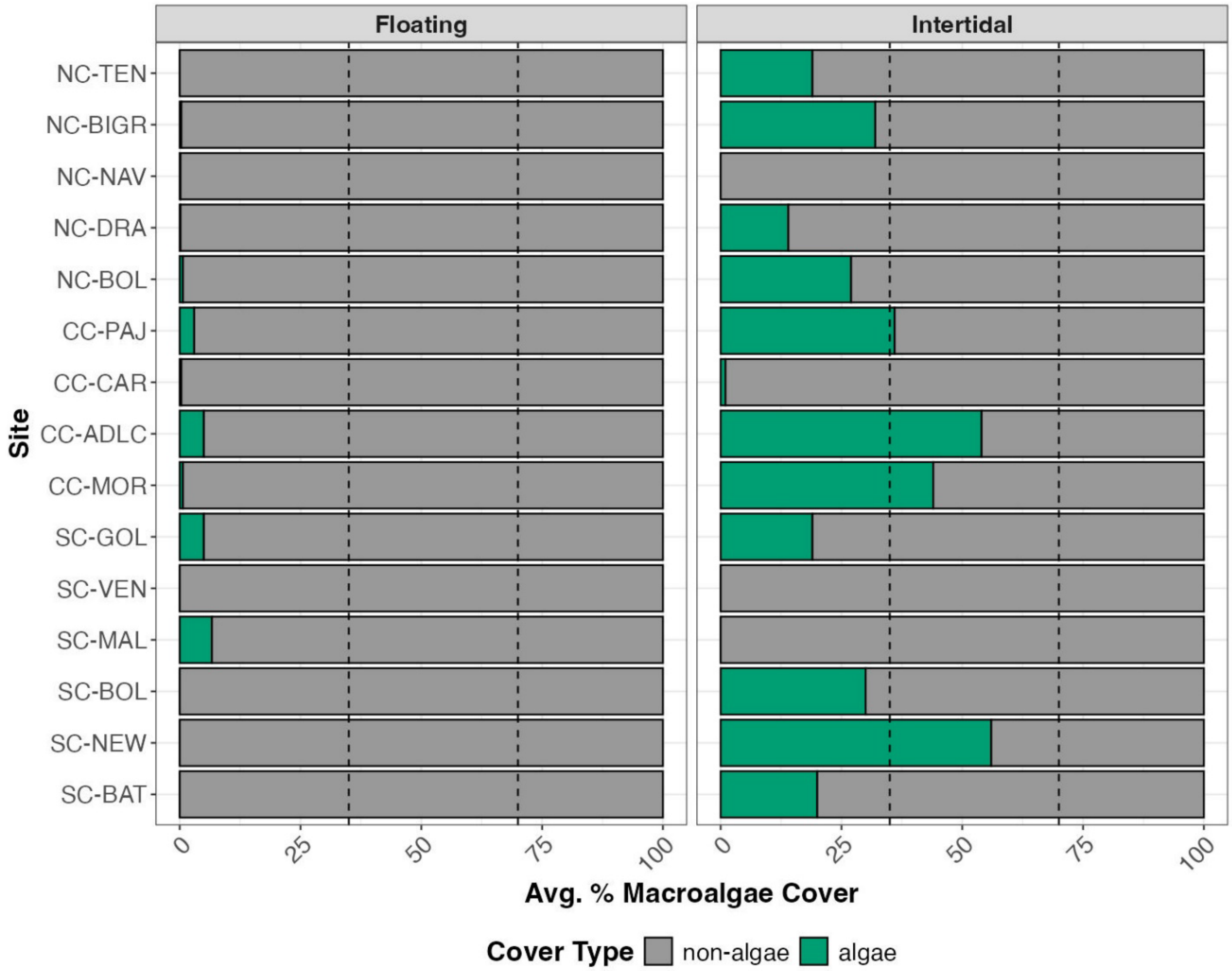


Figure C- 46. Percent macroalgae cover from Fall 2023 for subtidal floating and intertidal algae. Green bars represent algae cover and grey bars represent non-algae cover.

Table C- 11. Scoring table for the macroalgae cover (As part of the nekton function). Percent cover was divided into tertiles with the upper bin being demarcated at 66%. For sites with 0-33%, 33-66%, or 66-100% proportion of seines with SAV, the estuary received a score of 1, 2, or 3, respectively. Compiled score is an average of prior two columns.

Estuary	Region	Floating	Intertidal	Compiled Score
Ten Mile River	North	3	3	3
Big River	North	3	3	3
Navarro River	North	3	3	3
Drakes Estero	North	3	3	3
Bolinas Lagoon	North	3	3	3
Pajaro River	Central	3	2	2.5
Moro Cojo Slough	Central	NA	NA	NA
Carmel River	Central	3	3	3
Arroyo de la Cruz	Central	3	2	2.5
Morro Bay	Central	3	2	2.5
Goleta Slough	South	3	3	3
Ventura River	South	3	3	3
Malibu Lagoon	South	3	3	3
Bolsa Chica	South	3	3	3
Newport Bay	South	3	2	2.5
Batiquitos Lagoon	South	3	3	3

Condition Indicator 5: The extent and distribution of SAV is representative of the estuary type (indicator: SAV).

In subsequent reports, we hope to better incorporate SAV monitoring data in evaluating nekton habitat. In the interim, we evaluated the proportion of fish seines that were pulled near SAV beds (Figure C- 47). Although there is sampling bias in the location of fish seines, we can start to understand the percentage of sampling stations with SAV. We use this data cautiously; for example, we know that Newport Bay (SC-NEW) has extensive eelgrass beds, yet our sampling efforts were not correlated with the eelgrass beds. This is most likely due to the depth of eelgrass beds within Newport Bay, where we pull seines shallower than the beds.

We also estimated the proportion of sampling stations with known SAV in the fall 2023 (Figure C- 47). This was done post-hoc, where we asked regional field leads to note whether or not the sampling stations had SAV near or adjacent to the sampling station. Sometimes a seine may have SAV in it, but a regional lead may estimate that the station does not have SAV. This is why it is critical to incorporate SAV into monitoring while in the field, rather than post-hoc estimates.

We bin the proportion of seines with SAV and the proportion of stations with SAV into tertiles with the upper bin being demarcated at 66%. For sites with 0-33%, 33-66%, or 66-100% proportion of seines with SAV, the estuary received a score of 1, 2, or 3, respectively. We average the scores for a final compiled score (Table C- 12).

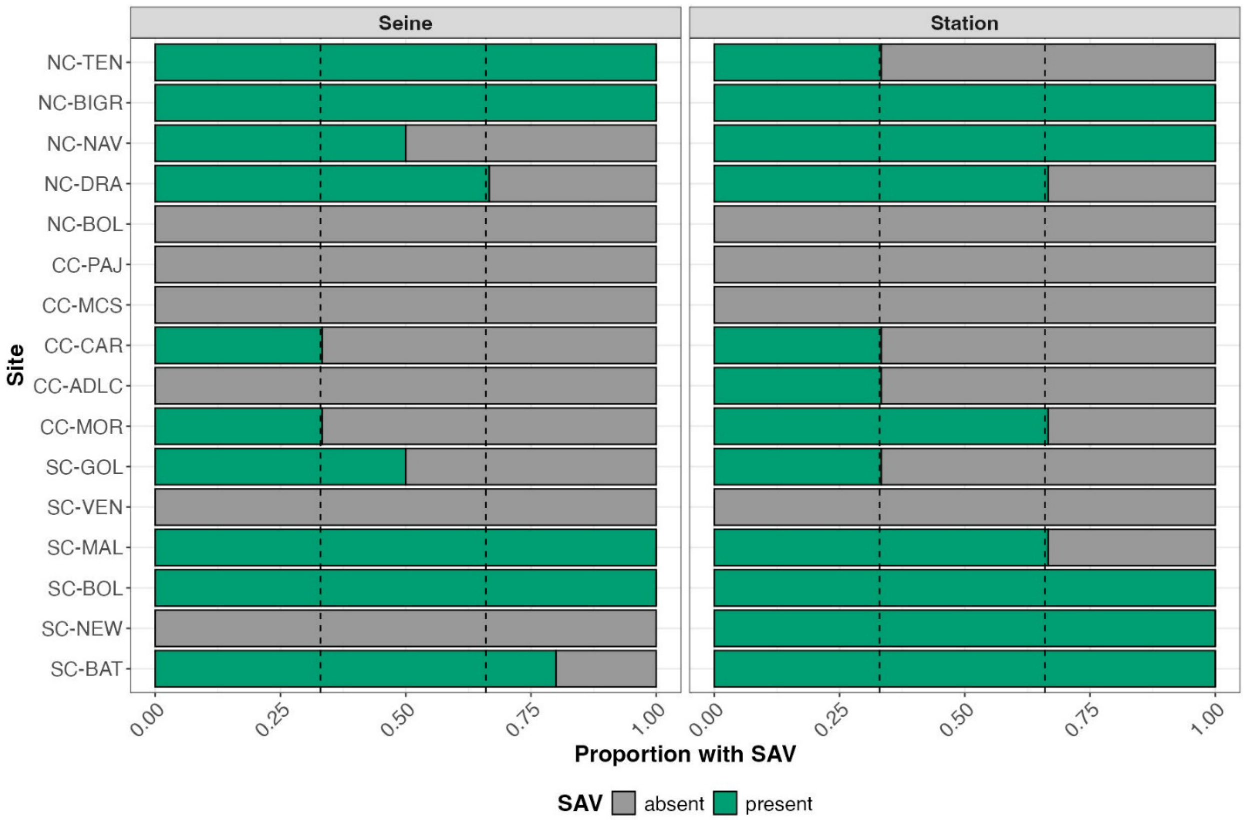


Figure C- 47. Proportion of fish seines with SAV from Fall 2023 and proportion of stations with SAV estimated by regional field leads. Green bars represent seines with SAV (present) and grey bars represent seines without SAV (absent).

Table C- 12. Scoring table for the extent and distribution of SAV (As part of the nekton function). Proportion of seines with SAV and the proportion of stations with SAV were divided into tertiles with the upper bin being demarcated at 66%. For sites with 0-33%, 33-66%, or 66-100% proportion of seines with SAV, the estuary received a score of 1, 2, or 3, respectively. Compiled score is an average of prior two columns.

Estuary	Region	Proportion of fish seines with SAV	Proportion of sampling stations with SAV	Compiled Score
Ten Mile River	North	3	1	2
Big River	North	3	3	3
Navarro River	North	2	3	2.5
Drakes Estero	North	2	2	2
Bolinas Lagoon	North	1	1	1
Pajaro River	Central	1	1	1
Moro Cojo Slough	Central	1	1	1
Carmel River	Central	1	1	1
Arroyo de la Cruz	Central	1	1	1
Morro Bay	Central	2	2	2
Goleta Slough	South	2	1	1.5
Ventura River	South	1	1	1
Malibu Lagoon	South	3	2	2.5
Bolsa Chica	South	3	3	3
Newport Bay	South	1	3	2
Batiquitos Lagoon	South	3	3	3

Condition Indicator 6: There is high habitat complexity and interspersion across the estuary as defined by a variety of physical habitat types (indicator: level 1-CRAM).

We leveraged existing rapid assessment methods, CRAM. Individual metric scores were averaged for all available CRAM data from 2014-2024. We converted alphabetic CRAM scores into numeric scores: A = 3, B = 2, C-D = 1. We then averaged scores across both metrics for a compiled score (Table C- 13).

Table C- 13. Submetric scores for condition statement 6: topographic complexity and patch richness. Scores were averaged for a compiled score.

Estuary	Region	Topo Complexity Score	Patch Richness Score	Compiled Score
Ten Mile River	North	2.3	2.3	2.3
Big River	North	2.7	3.0	2.8
Navarro River	North	1.3	1.7	1.5
Drakes Estero	North	NA	NA	NA
Bolinas Lagoon	North	NA	NA	NA
Pajaro River	Central	1.7	1.3	1.5
Moro Cojo Slough	Central	1.0	1.0	1.0
Carmel River	Central	2.7	2.7	2.7
Arroyo de la Cruz	Central	1.0	3.0	2.0
Morro Bay	Central	NA	NA	NA
Goleta Slough	South	1.3	1.7	1.5
Ventura River	South	2.0	2.3	2.2
Malibu Lagoon	South	1.3	2.0	1.7
Bolsa Chica	South	NA	NA	NA
Newport Bay	South	2	2	2.0
Batiquitos Lagoon	South	1.3	1.3	1.3

Functional Analysis 4: Secondary Production

Below we describe the methods to evaluate each condition statement and provide initial results when possible. This function analysis is still under development, similarly to nekton habitat, as many of the condition statements require greater than five years of data to make definitive inferences. We outline the initial narratives around each condition statement and provide next steps when possible.

Condition Indicator 1: The estuary does not experience periods of extended hypoxia, high water temperatures, or extreme salinity that significantly exceeds or impedes physiological limits of organisms responsible for organic matter transformation (indicator: water quality).

Changes to all of these abiotic factors can directly impact secondary production by affecting the availability of nutrients required by organisms further up the food chain. Metrics and analyses will be similar to Nekton Habitat (as described above), as many of the same metrics will inform secondary production.

Condition Indicator 2: The estuary supports high vegetation cover in the upper marsh elevation habitats (e.g., the mid and high marsh zones; indicator: vegetation).

We evaluated the percent cover of vegetated and non-vegetated cover collected using visual estimates within quadrats along vegetation transects in the mid and high elevation zones Figure C- 48. We bin cover into tertiles. Estuaries that had vegetated cover of 0-33%, 34-66%, or 67-100% received a score of 1, 2, or 3, respectively (Table C- 14).

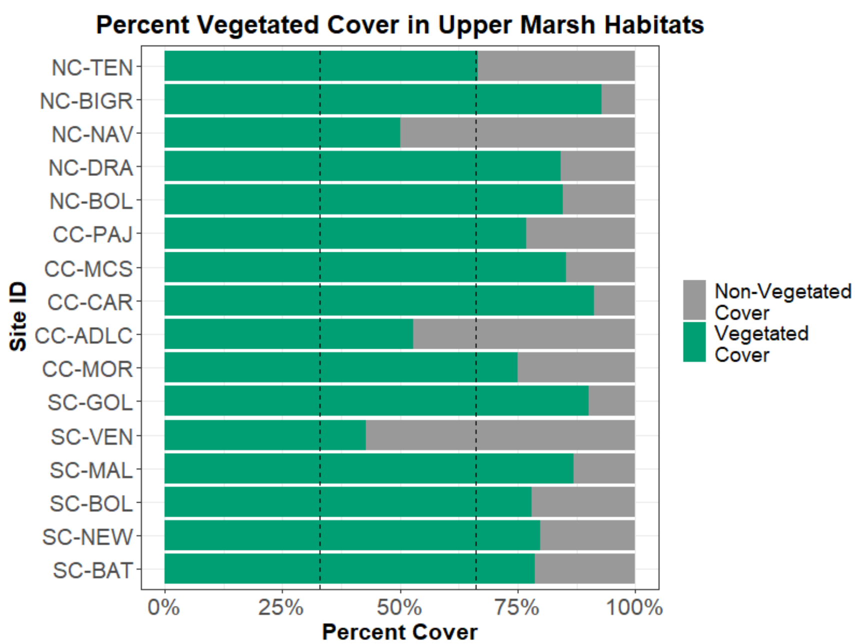


Figure C- 48. Percent cover of vegetated and non-vegetated cover estimates at each estuary. Vegetated ground metric scores of 1, 2, and 3 were given to estuaries that had 0-33%, 34-66%, or 67-100% vegetated cover, respectively. Green bars represent vegetated cover and grey bars represent non-vegetated cover.

Table C- 14. Vegetation Cover score for each estuary.

Estuary	Vegetation Cover
Ten Mile River	3
Big River	3
Navarro River	2
Drakes Estero	3
Bolinas Lagoon	3
Pajaro River	3
Moro Cojo Slough	3
Carmel River	3
Arroyo de la Cruz	2
Morro Bay	3
Goleta Slough	3
Ventura River	2
Malibu Lagoon	3
Bolsa Chica	3
Newport Bay	3
Batiquitos Lagoon	3

Condition Indicator 3: The benthic infauna community composition is representative of the estuary type and salinity regime and contains habitat-appropriate composition of feeding types (indicator: benthic infauna).

Initial results of benthic infauna community composition are show in Figure C- 49. As mentioned above, this indicator is still being evaluated to understand how to best relate benthic infauna to nekton habitat and secondary production. Benthic infauna will be evaluated for overall abundance and community composition (species-level, invasive status, feeding type). Metrics and analyses will be similar to Nekton Habitat, as many of the same metrics will inform secondary production.

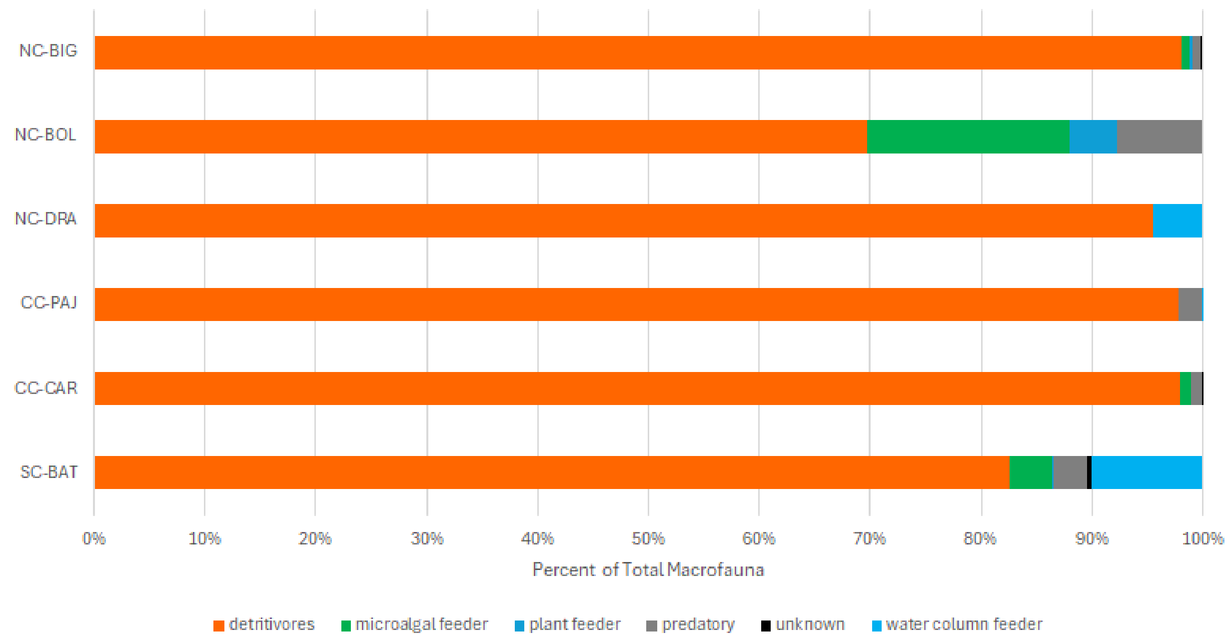


*Figure C- 49. Percent of total abundance of intertidal infaunal invertebrate community in Fall 2023 by feeding group. Because some specimens are not identified to species, feeding type cannot be determined or even if species is identified, how they feed is unknown. Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

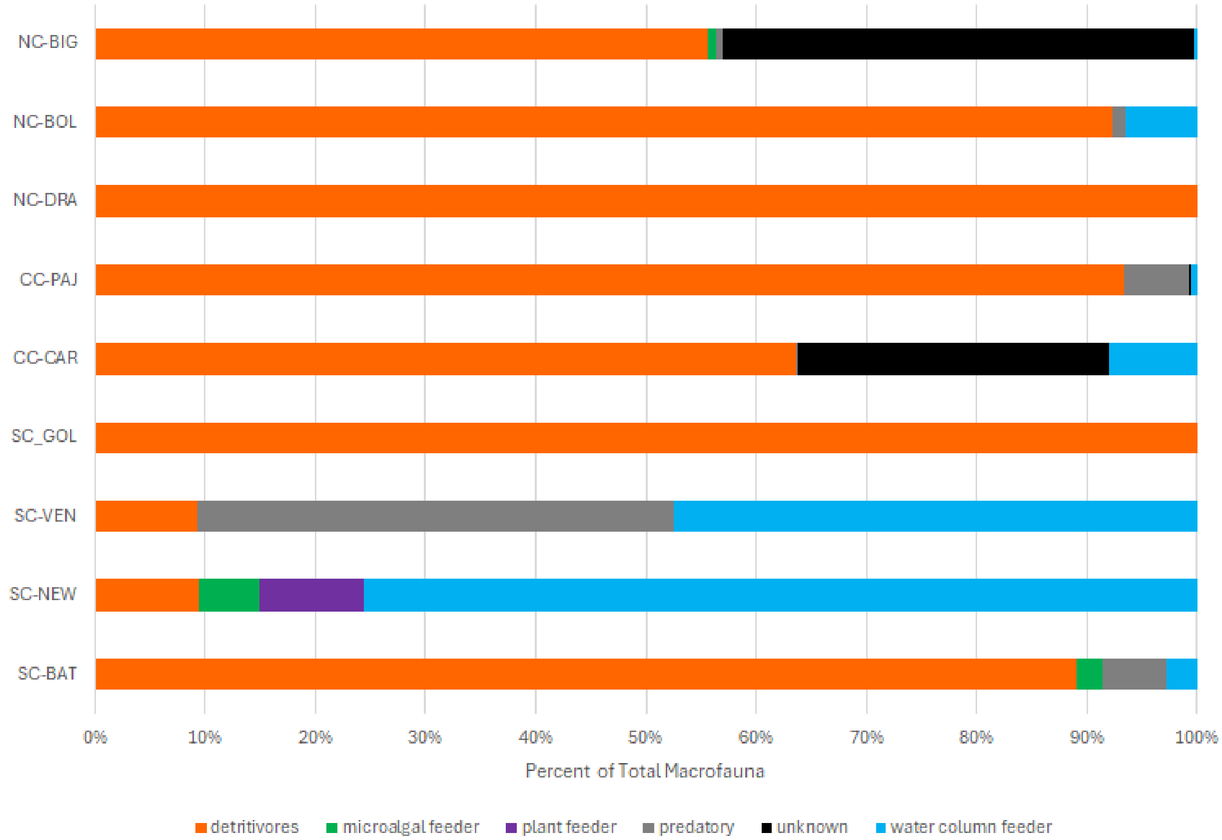


*Figure C- 50. Percent of total abundance of subtidal infaunal invertebrate community in Fall 2023 by feeding group. Because some specimens are not identified to species, feeding type cannot be determined or even if species is identified, how they feed is unknown. Sites with a * depict the temporarily closed estuary type, sites without an asterisk are perennially open.*

Condition Indicator 4: There is high habitat complexity and interspersion across the estuary as defined by a variety of physical habitat types (indicator: level 1-CRAM).

High habitat complexity and interspersion across the estuary can provide a variety of physical habitats for nekton 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. Scores will be derived following the same process described above.

Condition Indicator 5: The extent and distribution of SAV is representative of the estuary type (indicator: SAV).

Submerged Aquatic Vegetation (SAV) provides an important role in the ecology of coastal systems, as it provides unique structure and enhancement of biogeochemical processes. SAV can serve as temporary refuge from predators, enhance carbon and nitrogen cycling, and serve as a productivity hot spot for commercially and societally important fauna, as well as protected species like sea turtles. SAV provides critical habitat for meiofauna and macrofauna. As mentioned above, we don't have robust enough data to begin evaluating this condition statement and hope to do so in subsequent reports.

Condition Indicator 6: Sediment nutrient ranges are indicative of optimal benthic infauna productivity (indicator: sediment nutrients).

Benthic infauna productivity is directly tied to secondary production. One way to evaluate an optimal benthic infauna community is to evaluate whether or not sediment nutrients (TOC: Total Organic Carbon and TN: Total Nitrogen) are in ranges consistent with optimal benthic infauna communities. In southern California, there are established thresholds of sediment organic matter concentrations in muddy sediments associated with changes in macrobenthic community composition (Walker et al. 2022). Therefore, sediment nutrient thresholds can be used to determine the probability of the systems having biological integrity (Table C- 15). These numeric thresholds have only been validated in southern California and are only appropriate for samples dominated by mud (<60% sand). Average concentrations of TN and TOC during Fall 2023 sampling are shown in Figure C- 51. The proportion of muddy samples in southern California that met the 0.6 threshold are shown in Figure C- 52.

Table C- 15. *Different TOC or TN thresholds (mg/g) that are predictive of a 0.8, 0.7, and 0.6 probability of having a benthic community in good condition given that amount of TOC or TN (Walker et al. 2022).*

Parameter	Sediment Type	Probability		
		0.6	0.7	0.8
TN	Mud	3.68	2.58	1.23
TOC	Mud	28.96	22.9	15.51

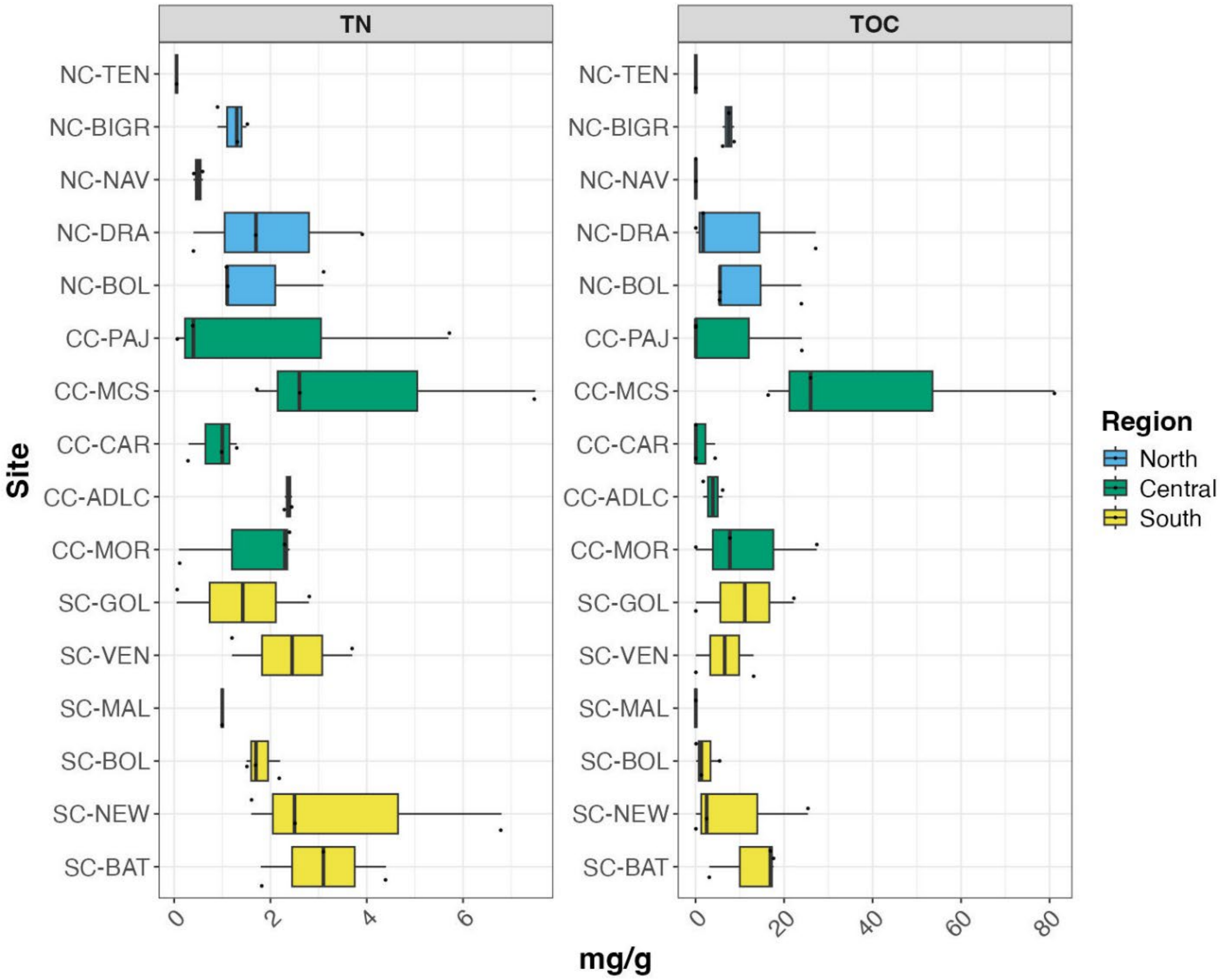


Figure C- 51. Average concentrations of TN and TOC within a sample for Fall 2023. Boxplots show median (bold lines) and interquartile range (boxes), with outliers greater than 1.5 × IQR (whiskers).

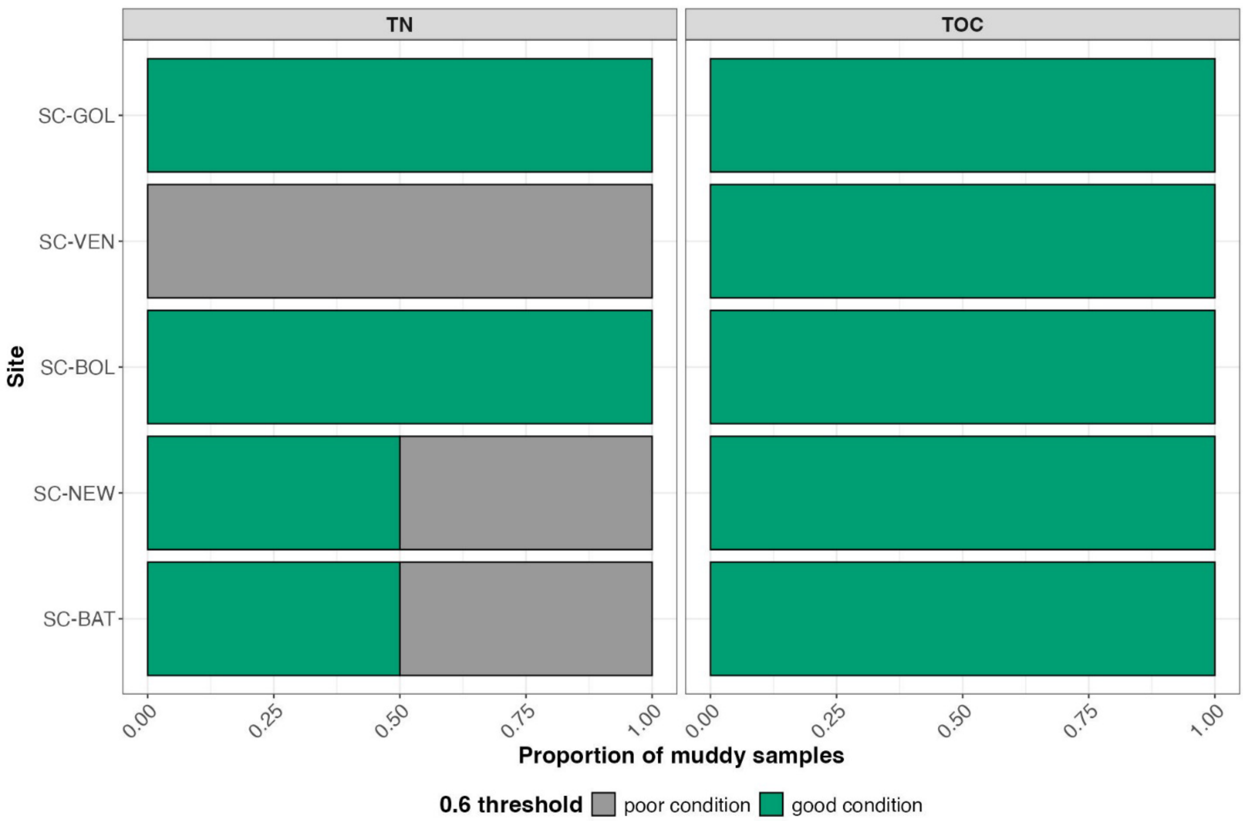


Figure C- 52. Proportion of muddy samples in southern California that met the 0.6 threshold (3.68 mg/g of TN and 28.96 mg/g of TOC). Green bars represent the percent of samples that met the threshold and therefore have good benthic condition and grey bars did meet the threshold. Note: sample size was not consistent among sites. Malibu lagoon did not have any samples dominated by mud.

At this time, no scores were assigned to this condition statement indicator due to lack of validation across the California coast and low sample size.

Appendix D: Fish Species Regional Lists

Table D- 1. Expected ("null model") fish list for southern California estuarine fish communities. Species list was generated from the Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) fish distribution lists and compared to several resources including Allen et al. 2006, data from other studies, and expert opinion.

Scientific name	Common name	Status	How to potentially interpret presence
Clevelandia ios	arrow goby	native	Expected in southern CA estuaries, estuarine resident
Syngnathus auliscus	barred pipefish	native	Expected in southern CA estuaries, estuarine resident
Paralabrax nebulifer	barred sand bass	native	Expected in southern CA estuaries
Myliobatis californica	bat ray	native	Expected in southern CA estuaries
Hypsoblennius gentilis	bay blenny	native	Expected in southern CA estuaries
Syngnathus leptorhynchus	bay pipefish	native	Expected in southern CA estuaries, estuarine resident
Menticirrhus undulatus	California corbina	native	Expected in southern CA estuaries
Leuresthes tenuis	California grunion	native	Expected in southern CA estuaries
Paralichthys californicus	California halibut	native	Expected in southern CA estuaries, marine migrant
Fundulus parvipinnis	California killifish	native	Expected in southern CA estuaries, estuarine resident
Symphurus atricauda	California tonguefish	native	Expected in southern CA estuaries but rare
Engraulis mordax	Californian anchovy	native	Expected in southern CA estuaries, marine migrant
Ilypnus gilberti	cheekspot goby	native	Expected in southern CA estuaries, estuarine resident
Anchoa compressa	deep body anchovy	native	Expected in southern CA estuaries
Hypsopsetta guttulata	diamond turbot	native	Expected in southern CA estuaries, marine migrant
Mustelus californicus	gray smoothhound	native	Expected in southern CA estuaries, marine migrant
Pleuronichthys verticalis	hornyhead turbot	native	Expected in southern CA estuaries
Menidia beryllina	inland silverside	introduced	Found regularly in southern CA estuaries
Atherinopsis californiensis	jack silverside	native	Expected in southern CA estuaries, marine migrant
Paralabrax clathratus	kelp bass	native	Expected in southern CA estuaries - expect mainly recruits
Triakis semifasciata	leopard shark	native	Expected in southern CA estuaries
Gillichthys mirabilis	longjaw mudsucker goby	native	Expected in southern CA estuaries
Psettichthys melanostictus	Pacific sand sole	native	Expected in southern CA estuaries
Leptocottus armatus	Pacific staghorn sculpin	native	Expected in southern CA estuaries, estuarine resident
Porichthys notatus	plainfin midshipman	native	Expected in southern CA estuaries
Lucania parva	rainwater killifish	introduced	Found regularly in southern CA estuaries - freshwater indicator?
Urobatis halleri	round stingray	native	Expected in southern CA estuaries, marine migrant
Quietula y-cauda	shadow goby	native	Expected in southern CA estuaries
Cymatogaster aggregata	shiner surfperch	native	Expected in southern CA estuaries, marine migrant
Atherinops sp.	silverside	native	Expected in southern CA estuaries
Paralabrax maculatofasciatus	spotted sand bass	native	Expected in southern CA estuaries, estuarine resident
Pleuronichthys ritteri	spotted turbot	native	Expected in southern CA estuaries, marine migrant
Mugil cephalus	striped mullet	native	Expected in southern CA estuaries
Eucyclogobius newberryi	tidewater goby	native	Expected in southern CA estuaries - brackish conditions
Atherinops affinis	topsmelt silverside	native	Expected in southern CA estuaries
Genyonemus lineatus	white croaker	native	Expected in southern CA estuaries
Acanthogobius flavimanus	yellowfin goby	introduced	Found regularly in southern CA estuaries
Pleuronichthys coenosus	C-O turbot	native	Expected in southern CA estuaries - outer estuary
Micrometrus minimus	dwarf perch	native	Expected in southern CA estuaries, marine migrant
Synodus lucioceps	California lizardfish	native	Expected in southern CA estuaries, indicative of presence of deep channel habitat
Rhinobatos productus	shovelnose guitarfish	native	Expected in southern CA estuaries
Anchoa delicatissima	slough anchovy	native	Expected in southern CA estuaries
Gasterosteus aculeatus	Three-spined stickleback	native	Indicative of fresher conditions, typically found further north
Cheilotrema saturnum	black croaker	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Raja inornata	California skate	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Heterostichus rostratus	giant kelpfish	native	Indicative of open inlet status - rare in estuaries
Acipenser medirostris	green sturgeon	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Girella nigricans	opaleye	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Squatina californica	Pacific angelshark	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Citharichthys sordidus	Pacific sanddab	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Anisotremus davidsonii	Xantic sargo	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Rhinobatos productus	shovelnose guitarfish	native	Indicative of open inlet status with large embayment at inlet (sand, good flow)
Cynoscion nobilis	white seabass	native	Indicative of open inlet status - expect juveniles

Appendix E: Outreach and Engagement to Build Capacity for Estuarine Monitoring in the North Coast of California

Prepared by the San Francisco Estuary Institute

Introduction

Estuaries are dynamic and diverse systems with unique biotic communities that vary substantially along the coast of California. Statewide coordinated monitoring allows for condition assessment over time and an improved understanding of impacts due to human stressors, including climate change. This summary report documents efforts to support growing awareness and adoption of the Estuarine Marine Protected Area (EMPA) Monitoring Program and identify existing estuarine monitoring and coordination within the North Coast region of California (Golden Gate Bridge to the California/Oregon border). To date, the North Coast - and particularly, the far north - has been underrepresented within the statewide EMPA Monitoring Program. Participation of individual North Coast monitoring entities in the statewide effort offers a number of advantages, including representation of a diversity of North Coast estuaries and partners in the statewide program, standardized monitoring protocols, statewide program support (e.g., trainings, centralized data management, fundraising opportunities), improved understanding and management of estuaries.

In collaboration with the EMPA Monitoring Program Team ("Program Team" hereafter), the San Francisco Estuary Institute (SFEI) compiled a list of North Coast estuarine monitoring and coordination entities and hosted several informational outreach conversations in spring 2024 to explore the interest, capacity and abilities of additional North Coast institutions and individuals to be involved in the EMPA Monitoring Program. The goals of these activities were to 1) raise awareness towards greater use and expansion of EMPA Monitoring Program standard monitoring procedures (SOPs) and contribution to the statewide effort, 2) explore collaboration opportunities to fund monitoring coordination and expanded estuarine monitoring aligned with the state-wide effort, and 3) identify potential coordination partners. The feedback generally provided insights into potential opportunities and barriers to adoption of EMPA Monitoring Program SOPs and overall participation. Additionally, a number of individual follow-up actions arose, which could be prioritized as part of future outreach.

EMPA Monitoring Program Background

In 2018, the California Ocean Protection Council (OPC) and Department of Fish and Wildlife (CDFW) released the Marine Protected Area (MPA) Monitoring Action Plan, which proposes a monitoring framework to assess MPA effectiveness, track ecological and socioeconomic change in MPAs over time, and inform adaptive management needs. The Action Plan highlighted the unique monitoring needs of the state's 23 estuarine MPAs (EMPAs) and proposed a monitoring framework built around key biotic and abiotic indicators that largely leveraged existing monitoring programs throughout the California coast. Monitoring of EMPAs across the state is designed to assess the condition of estuarine ecosystems to address a variety of objectives, such as what critical functions (e.g., nursery habitat) are being provided by EMPAs or which are being degraded by human stressors (see Appendix 1).

In 2021, the Program Team (including leads from the Central Coast Wetlands Group @ MLML, Southern California Coastal Water Research Project (SCCWRP), Cal State Long Beach, Sonoma State University, University of California, Davis, University of California, LA, and the SF Bay RWQCB), with input from a Management Advisory Committee, developed and piloted implementation of the Monitoring Framework (see Appendix 2). The state was broken up into three regions (North, Central, South), and three regionally-based field teams implemented the framework at 15 estuaries. For purposes of the EMPA, the North Coast region includes the estuaries from the Golden Gate north to the California/Oregon border, a slightly longer stretch of coastline than the North Coast region for offshore MPAs (Alder Creek north to the California/Oregon border). The sites sampled included 10 MPA estuaries and 5 non-MPA estuaries. The 15 selected sites represent a wide range of estuary types and sizes, as well as level of impact in California (Table 1). North Coast estuaries selected for initial sampling include Bolinas Lagoon, Drake's Estero, Navarro River, Big River, and Ten Mile River. Each assessment took about four to five days to complete with a team of four to six people. The Program Team successfully completed sampling in spring and fall of 2021 and fall of 2023. The Program Team will continue sampling each spring and fall through 2026.

The EMPA program is now adopted by the OPC and CDFW MPA management team as part of the larger MPA monitoring program. As outlined in the 2023 EMPA Implementation Blueprint,[1] it is envisioned that the program will be implemented and expanded in the long term as a statewide program administered or coordinated through the California Estuary Monitoring Workgroup of the California Water Quality Monitoring Council. Though regional implementation of the monitoring is considered necessary, statewide program administration and data management would facilitate data compatibility and capacity to address statewide science and management questions.

Monitoring Capacity Limitations and Opportunities

The North Coast is one of California's most historically under-invested regions, yet faces numerous human pressures and experiences the highest rates of relative sea level rise (rSLR) along the California coast. Estuaries in this region tend to be large (larger rivers compared to further south) and remote (difficult to access and far from institutional resources). Organizationally, there are substantial active Tribal programs and stewardship, and other institutions and organizations are relatively low density and tend to be limited in geographic coverage. Overall, North Coast estuaries tend to be under-monitored relative to estuaries on the Central and Southern California coasts, despite the fact that they support a rich diversity of aquatic species and play a key role in supporting numerous Tribal and economically disadvantaged communities. Currently, EMPA North Coast monitoring is conducted by field teams based at Sonoma State University and the UC Davis Bodega Marine Lab, supplemented by support from the CCC Watershed Stewards Program staff at the North Coast Regional Water Quality Control Board (NCRWQCB).

[1] Stein, E.D., Walker, J., O'Connor, K., Toms, C. 2023. Estuary Marine Protected Area Monitoring Program Implementation Blueprint. A report prepared for the California Ocean Protection Council and the California Department of Fish and Wildlife. 20pp

These teams have limited capacity and resources, and unlike the Central and South Coast regions, have historically had no non-academic institutional partners to coordinate and execute long-term monitoring. EMPA program partners and allies including the OPC, CDFW, NCRWQCB, and Coastal Commission have identified the expansion of North Coast estuary and EMPA monitoring capacity as a key priority to:

1. Support improved spatial and temporal coverage of North Coast estuary monitoring activities so these estuaries can be included and evaluated in the statewide EMPA effort and related monitoring programs.
2. Build enduring capacity to monitor North Coast estuaries so that timely, accurate science can inform habitat restoration, climate change adaptation, and environmental justice efforts in the region.
3. Assess the cumulative effectiveness of regulatory and resource stewardship efforts in the region, including watershed/forestry management, cannabis regulations, stream/estuary habitat restoration, and stormwater management.
4. Support increased Tribal stewardship of natural resources, as well as increased Tribal engagement with and co-design of monitoring programs.

Outreach and Engagement Activities to Date

After becoming involved in the fall of 2023, SFEI initially gathered information and communicated with the Program Team to draft an outreach summary describing the program and North Coast outreach and engagement goals (including content presented above) and develop a contact log of North Coast monitoring entities (Appendix 3). An initial exploratory conversation was held with Darren Mierau (Cal Trout) and the Program Team in October 2023. In the spring of 2024, SFEI and Christina Toms of the Program Team held several individual conversations to explore North Coast estuary monitoring priorities and expand the contact log. These entities and individuals included the NCRWQCB, Peter Baye, and Chris Janoesek. In coordination with the Program Team, SFEI subsequently developed an outreach email and interest survey, which was sent to 35 individuals in the contact log (and forwarded along to at least 5 others). Via the survey (16 responses total), we received RSVPs to two informational sessions offered on May 29th and 30th. A total of 11 people attended these hour-long meetings, which included an overview of the EMPA Monitoring Program (provided by Eric Stein and Kevin O'Connor of the Program Team), Q&A, and discussion around adoption and collaboration opportunities (and obstacles). To date, SFEI facilitated one follow-up conversation with Michelle Kunst (Pulikla Tribe of Yurok People), also attended by Kevin O'Connor and Christina Toms. SFEI will also be speaking with Jos Hill (Pew Charitable Trusts) as she was unable to attend one of the informational sessions.

Summary of Findings

Email and survey summary

Of the 35 North Coast outreach emails sent (plus the additional 5 forwards), 24 of the emails were opened (60% opening rate), with 16 responding to the corresponding interest survey. Responses represented a mix of academic, non-profit, Tribal, and private sector organizations, for a total of 14 organizations, including:

- Blue Lake Rancheria (Tribal)
- Cal Poly Humboldt (Academic)
- California Trout (Non-profit)
- CDFW (Agency)
- Michael Love & Associates, Inc. (Private sector)
- North Coast Resource Partnership (Non-profit)
- Noyo Center for Marine Science (Academic)
- Pulikla Tribe of Yurok People (Tribal)
- Sonoma Land Trust (Non-profit)
- Sonoma Water (Agency)
- The Nature Conservancy (TNC, Non-profit)
- The Pew Charitable Trusts (Non-profit)
- USFWS (Agency)
- Wiyot Tribe (Tribal)

Survey responses indicated that most (13, or 81%) were already conducting estuarine monitoring. Estuaries represented included the Smith River, Klamath River, Redwood Creek, Mad River (Baduwa't Estuary), Humboldt Bay, Elk River, Eel River, Noyo River, Big River, Russian River, Estero Americano, and Tomales Bay. Most respondents were working in the Eel River Estuary, Humboldt Bay, and Klamath River. One respondent (Cyndi Dawson, CDFW) noted their work was statewide, and another (Bryan DeAngelis, TNC) noted their work also included Central Coast estuaries of Morro Bay and Elkhorn Slough. Half of the respondents responded “yes” (with others responding “maybe”) to the question: “Do you or your organization have interest in exploring the roles for EMPA monitoring coordination in the north coast, particularly north of Mendocino County?” Those not involved in estuarine monitoring included the North Coast Resource Partnership (NCRP), The Pew Charitable Trusts, and the Sonoma Land Trust.

Informational meetings feedback

The informational meetings held on May 29 and 30, 2024 involved engaging discussions and provided valuable information about existing monitoring occurring within the North Coast region and potential opportunities and challenges for expanding statewide coordination and EMPA Monitoring Program SOPs.

Participant overview

The 11 participants that attended one of the May informational meetings had all responded to the survey. Below is a list of the attendees and a brief summary of why they participated:

- Cyndi Dawson (CDFW): Broadly works in marine regions and habitat conservation, involved in eelgrass work in Humboldt Bay; also noted the environmental monitoring that will be associated with offshore wind installations in Humboldt Bay.
- Shanti Edwards (Sonoma Land Trust): Sonoma Land Trust owns a 127-acre property at Estero Americano and is interested in collaboration to advance estuary monitoring and management efforts needed along the Estero Americano MPA.

- Karen Gaffney (North Coast Resource Partnership): The NCRP is a collaborative coordinating entity - with Tribal, county government, and other stakeholders - for enhancing watersheds and communities of the North Coast region. It is developing a climate resilience program that would include estuaries, as well as products from LiDAR and is interested to know if derivative products would be useful. Potential opportunities for NCRP to help share information and encourage participation.
- Katy Gurin (Cal Trout): Project manager for Elk River restoration project. Cal Trout also has projects on Eel River, Baduwa't (Mad River) Estuary, and Redwood Creek.
- Michelle Kunst (Pulikla Tribe of Yurok People): Involved in Klamath River and Redwood Creek estuaries, primarily doing eDNA and surf smelt sampling as well as some work in the tidally influenced upper part of the estuary. Interested in growing and expanding capacity and giving opportunities for tribal staff to be involved. Note that SFEI and Kevin O'Connor held a follow-up meeting with Michelle in June 2024.
- Jessica Martini-Lamb (Sonoma Water): Sonoma Water is considering doing eDNA for longfin smelt, considering how to monitor transient eelgrass beds. They monitor not just the Russian River estuary but also the Russian River and Petaluma River watersheds.
- Jose R. Marin Jarrin (Cal Poly Humboldt): Lab is focused on monitoring fisheries (primarily Humboldt Bay, Eel, Mad and Klamath River estuaries). Has been supporting Tribal nations to monitor fish species of interest. There is a long history of monitoring in the Cal Poly Humboldt Biology Department.
- Kelsey McDonald (CDFW): Involved in Eel River estuary and Humboldt Bay monitoring.
- Marisa McGrew (Wiyot Tribe): Excited about using standardized protocols but concerned about switching protocols in ongoing monitoring programs. Interested in how Wiyot Tribe protocols might be cross-walked with EMPA Monitoring Program SOPs.
- James Ray (CDFW): Involved in Eel River estuary and Humboldt Bay, and broadly CDFW Region 1 develops large-scale monitoring programs on CDFW lands where they've done restorations. Potential opportunity for collaboration specifically around eelgrass monitoring in the Humboldt Bay.
- Sheila Semans (Noyo Center): Focused on Noyo River water quality assessment.

Existing monitoring within the North Coast, based on outreach

One objective of the North Coast outreach effort was to improve understanding of existing monitoring already ongoing within the North Coast. A summary is provided by estuary below, based on survey responses and informational meeting discussion.

- Klamath River: Fisheries monitoring (focus, using eDNA) by Yurok Tribe with support by Cal Poly Humboldt (Jose Marin Jarrin)
- Redwood Creek: Monitoring associated with restoration project (Yurok Tribe, Cal Trout)
- Baduwa't (Mad River) Estuary: Fisheries monitoring (focus, using eDNA) by Yurok Tribe with support by Cal Poly Humboldt (Jose Marin Jarrin)

- Humboldt Bay: General monitoring (including vegetation) associated with restoration projects (CDFW); Eelgrass monitoring, including for Humboldt Bay MPA (CDFW); monitoring associated with offshore wind development (CDFW)
- Elk River: Fisheries monitoring (and want to use as many indicators as possible) just getting going as part of larger watershed-scale effort (Cal Trout)
- Eel River: Fisheries monitoring (focus, using eDNA) by Yurok Tribe with support by Cal Poly Humboldt (Jose Marin Jarrin); Vegetation and marsh plain elevation as well as fisheries for restoration project monitoring (CDFW)
- Noyo River - water quality (Noyo Center)
- Russian River: Various water quality monitoring for Russian River estuary, with interest in eDNA for longfin smelt and how to monitor transient eelgrass beds (Sonoma Water)

Interest in EMPA Monitoring Program SOPs adoption

Overall, survey responses and the informational meetings indicated that there is strong interest in the EMPA Monitoring Program and statewide coordination. Entities expressed how state protocols and a statewide program can provide support (e.g., avoid reinventing the wheel, training) to the many disparate efforts that are often run with limited budgets. While there is a lot of monitoring happening, there would be added value with more coordination. Entities noted that the best opportunities for SOP adoption are where new monitoring is being considered. Particular areas of interest or SOPs that arose were fisheries/eDNA methods, SAV/eelgrass, and vegetation. Specific opportunities for SOP adoption are summarized here:

- Pulikla Tribe of Yurok Peoples (Michelle Kunz): Based on a June 2024 follow-up call, Michelle mentioned they might have some funding to explore or pilot SOPs, but would want to look for training support and long-term monitoring funding. EMPA Team should follow up with Darren Mierau regarding restoration work happening in Redwood Creek estuary and should follow up with Yurok Tribe regarding Klamath River estuary monitoring. Depending on that follow-up, the Pulikla Tribe might be interested in getting involved.
- Wiyot Tribe (Marisa McGrew): Interested in standardized protocols (noted challenges of switching protocols midstream).
- Collaboration with Yurok Tribe for estuaries for Klamath to Eel River with a focus on fisheries, if data sharing agreements can be established (Jose Marin Jarrin, Cal Poly Humboldt provided this information).
- Eelgrass monitoring: There appear to be several opportunities for possible adoption of EMPA Monitoring Program SAV SOPs. Sonoma Water is interested in eelgrass monitoring methods, and CDFW is involved in initiating an eelgrass monitoring collaborative for the Humboldt Bay MPA (CDFW is happy to be involved, but does not have coordination capacity).
- Elk River monitoring: As part of a watershed-scale effort, Cal Trout is involved in initiating monitoring for the Elk River estuary. There is interest in using as many indicators as possible. Also interested in capacity for cross-walking protocols.
- Eel River restoration project monitoring by CDFW.
- Estero Americano monitoring: Sonoma Land Trust is interested in opportunities to initiate monitoring for this estuarine MPA.

Partnership and coordination capacity

Many entities were interested in different aspects of partnership and coordination. Given the financial challenge to adopt new things with limited funding and the general challenge to raise money for ambient monitoring, many were interested in partnering to obtain funding for training and long-term monitoring. The funding need is particularly strong for Tribes. Entities were also open to exploring ways to make existing monitoring data more available. Representatives of CDFW noted that while their work is tied to regional priorities and that they are supporting the coordination of an eelgrass monitoring effort for the Humboldt Bay, they have limited capacity to take on a coordination role. The Sea Level Rise Institute was raised as a coordinating entity in the region, though they did not respond to the outreach email and survey. There is also potential for the EMPA Monitoring Program to become involved in existing Tribal monitoring coordination. Beyond individual Tribes, Jose Marin Jarrin (Cal Poly Humboldt) noted that the Northern California Tribal Fisheries Collaborative (including Tolowa Dee-ni' Nation, Wiyot Tribe, Blue Lake Rancheria, Trinidad Rancheria, Pulikla Tribe of Yurok People) as an entity to connect with. The NCRP is a coordinating entity for the North Coast generally (estuaries are not a particular focus) and could facilitate some aspects of EMPA Monitoring Program coordination.

Other comments of note

Geographic Limitations/Limitation to MPA

Several participants asked questions about whether the program was limited to MPAs, and what the purpose was of monitoring non-MPA estuaries. This will likely be an important point for future communication: that the program is applicable to all estuaries, that the definition of estuary is broad and includes tidal river mouths, and that the purpose of the California EMPA monitoring program is to build data and tools for all estuaries (not to designate additional MPAs).

Aligning SOPs with Existing Protocols and Uploading Data

Where existing monitoring programs are already established, participants expressed that adopting new protocols is often too expensive, or challenging for retaining long-term data consistency, but there was interest to better understand how data from existing monitoring efforts might still be uploaded into the data portal. Several participants had questions about aligning the SOPs with their existing protocols.

Are the data publicly available?

Two participants asked about how the data are managed and noted the importance of data sharing agreements and privacy options to Tribes. The ability to control the sharing settings of the data uploaded is important for Tribal participation.

Another participant was curious about whether the monitoring data was available for use by others. That is, the advantages of the data portal as a means for various science and management entities to access estuarine monitoring data collected by others is a benefit of the EMPA Monitoring Program that might be noted as part of outreach.

Adapting SOPs for North Coast systems

There may be opportunities to explore further adaptation and refinement of SOPs to better align with North Coast estuaries. Additionally, options to better integrate surveys (to improve interpretation around physical and biotic relationships, etc.) also came up as a point of discussion.

Recommendations and Next Steps

This initial outreach and engagement effort for the North Coast 1) identified a number of individuals and organizations with interest in North Coast monitoring, 2) initiated conversations and connections that can develop further over time, and 3) introduced and increased the visibility of the EMPA Monitoring Program in the region. While this initial effort was limited in scope, it produced a number of clear and promising follow-ups. These specific follow-ups have been summarized above relating to interest in SOP adoption, and these and additional follow-up details are provided in the contact log (see Appendix 3). The initial outreach effort also provided valuable information to inform thinking towards the development of a broader and longer-term North Coast engagement and EMPA Monitoring Program expansion strategy.

In the near term, with limited funding for SFEI to continue leading North Coast outreach and no identified funding for training or additional monitoring beyond the current scope through 2026, the EMPA Monitoring Program Team should consider and establish key near-term priorities and goals for the next year. Potential near-term activities, in no particular order, include:

- Continued follow-up conversations around opportunities for SOP adoption (including EMPA Monitoring Program Team support for meetings, data upload, and SOP cross-walking; thought should be dedicated in advance by the EMPA Monitoring Program Team towards how existing monitoring protocols could be refined or incorporated into the larger program),
- Discuss remote sensing monitoring opportunities, and follow up with Karen Gaffney (NCRP) as to whether there might be alignment with currently planned LiDAR derivative products for the North Coast,
- Conduct outreach to those who did not respond to the original email and to newly identified individuals or organizations,
- Scope Tribal engagement strategy,
- Develop a session or workshop (possibly including training) for the Salmon Restoration Federation 2025 Conference, suggested by Christina Toms, since the SRF Conference gathers many North Coast monitoring entities and thus offers an excellent engagement opportunity,
- Articulate recommendations for future EMPA Monitoring Program expansion (e.g., is there interest to add a new EMPA Monitoring Program estuary or simply get more entities using the SOPs), and
- Initial training funding development.

In the longer term, additional priorities include:

- Evaluating potential SOP adaptation for North Coast estuaries,
- Developing a strategy to formally expand the EMPA Monitoring Program within the North Coast, and
- Developing larger- and longer-scale funding for training and/or monitoring: Collaborate with identified North Coast entities on funding proposals. This could include identifying and developing initial key products needed for such proposal submissions.

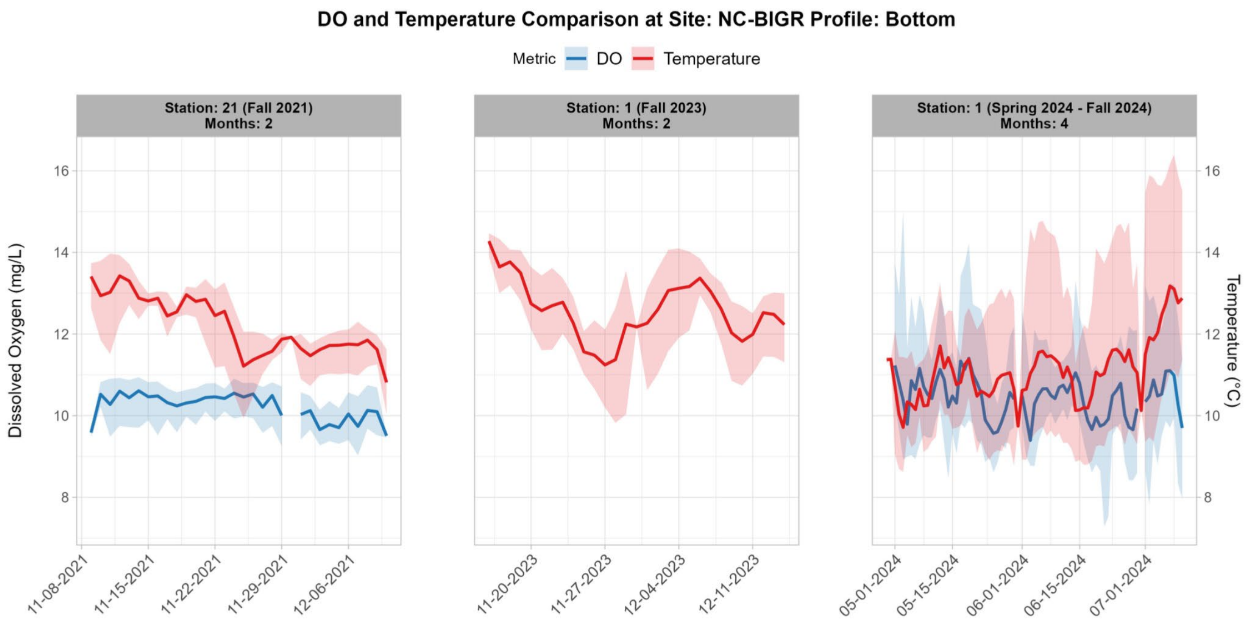
Overall, this initial outreach to expand knowledge about the EMPA Monitoring Program and gather information about existing monitoring entities and coordination potential in the North Coast suggests that there is broad and strong interest in the program, with the ever-present challenges of funding and capacity. As a result of the initial outreach, there is now expanded awareness of the program and identification of a number of specific opportunities for SOP alignment and possible adoption. Generally, there is an improved understanding on the part of the EMPA Monitoring Program of existing monitoring in the North Coast and entities and networks involved. While no single potential entity emerged as one that might coordinate monitoring for the region, coordination entities were identified and the potential to expand the program in terms of North Coast coordination beyond SFEI seems promising (with the funding and existing capacity caveats). This effort provides essential groundwork for growth and expansion of the EMPA Monitoring Program into the North Coast region.

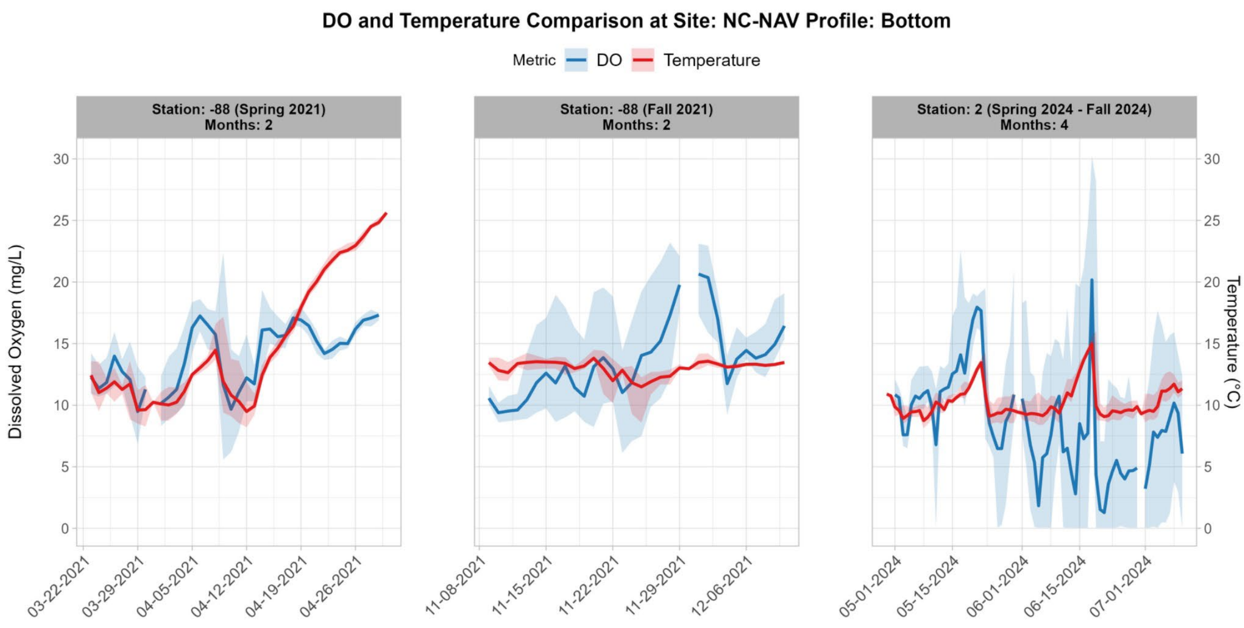
Appendix F: Additional SOP Results

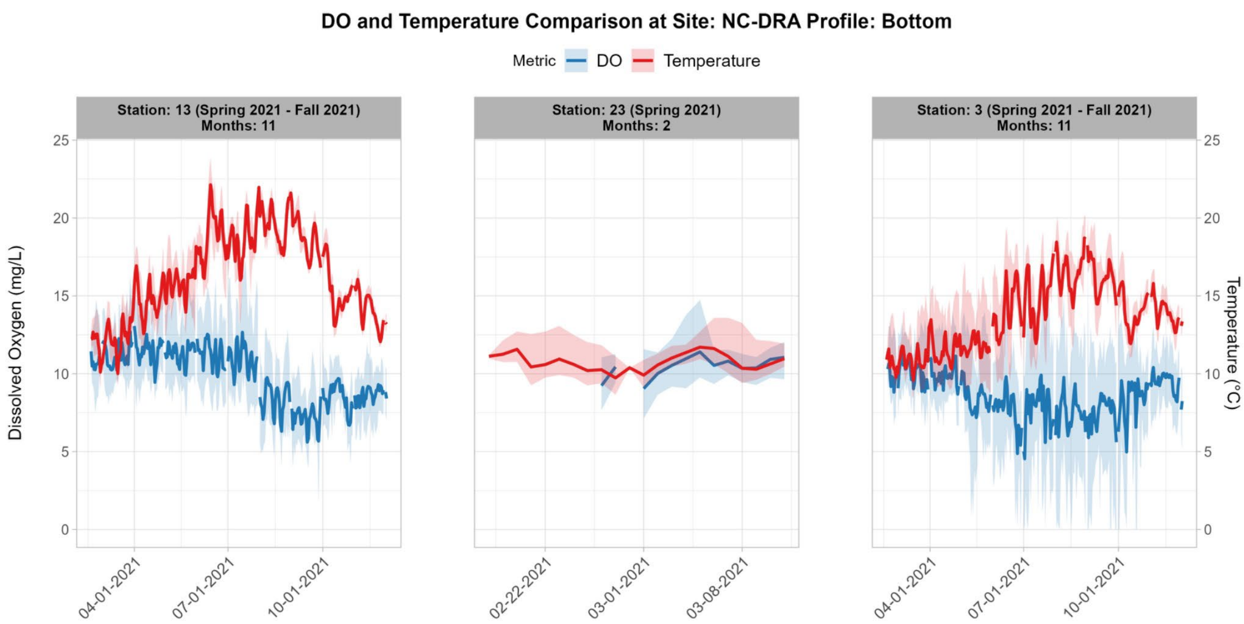
Water Chemistry

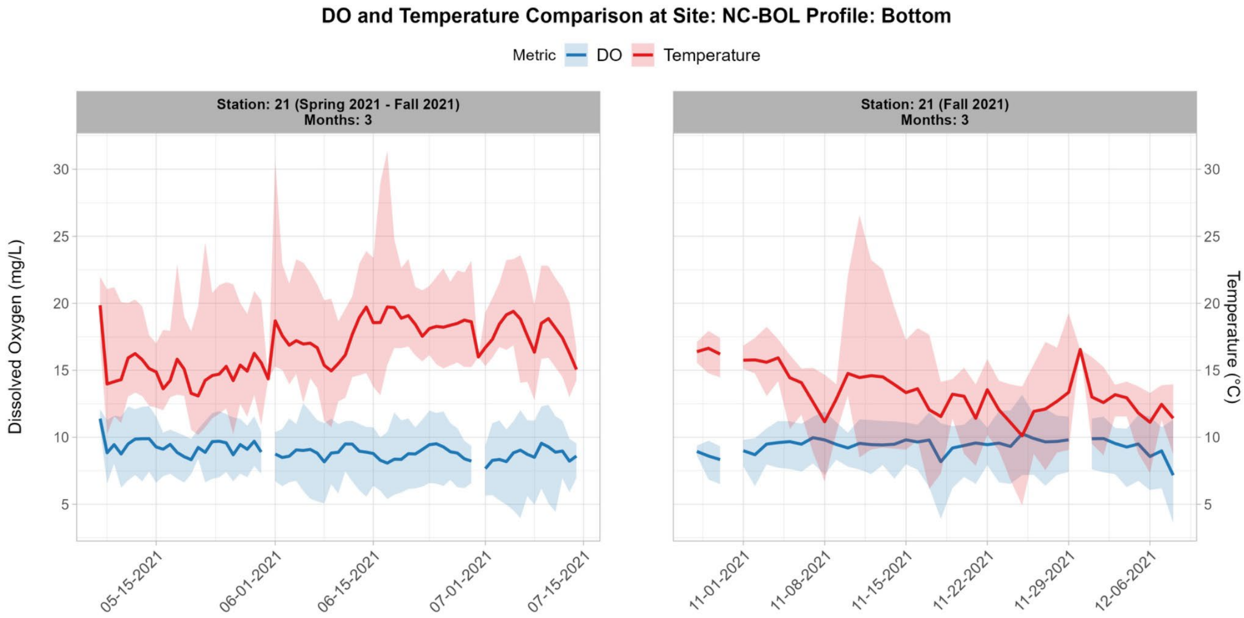
An important consideration when evaluating all the water quality data is the understanding of the typical dynamics of a given system. Estuarine systems are extremely dynamic and naturally experience periods of low DO, variable salinities, and high temperatures. Therefore, to fully realize what systems may be exceeding physiological limits of typical estuarine fish, we must collect consistent time series data over time. We illustrate the available time series data we have for the 16 systems.

Figures below display all available DO and temperature data for each estuary. Loggers were sometimes moved between years and therefore are depicted in different frames. Blue lines show average DO and red lines show average temperature. Shading around lines represent the range of values between then 5th and 95th percentile.




DO and Temperature Comparison at Site: NC-NAV Profile: Bottom
Metric DO Temperature
Station: -88 (Spring 2021) Months: 2
Station: -88 (Fall 2021) Months: 2
Station: 2 (Spring 2024 - Fall 2024) Months: 4
Dissolved Oxygen (mg/L)
Temperature (°C)
0 5 10 15 20 25 30
03-22-2021 03-29-2021 04-05-2021 04-12-2021 04-19-2021 04-26-2021
11-08-2021 11-15-2021 11-22-2021 11-29-2021 12-06-2021
05-01-2024 05-15-2024 06-01-2024 06-15-2024 07-01-2024


DO and Temperature Comparison at Site: NC-DRA Profile: Bottom
Metric DO Temperature
Station: 13 (Spring 2021 - Fall 2021) Months: 11
Station: 23 (Spring 2021) Months: 2
Station: 3 (Spring 2021 - Fall 2021) Months: 11
Dissolved Oxygen (mg/L)
Temperature (°C)
0 5 10 15 20 25
04-01-2021 07-01-2021 10-01-2021
02-22-2021 03-01-2021 03-08-2021
04-01-2021 07-01-2021 10-01-2021


DO and Temperature Comparison at Site: NC-BOL Profile: Bottom
Metric DO Temperature
Station: 21 (Spring 2021 - Fall 2021)
Months: 3
Station: 21 (Fall 2021)
Months: 3
Dissolved Oxygen (mg/L)
Temperature (°C)
30
25
20
15
10
5
05-15-2021
06-01-2021
06-15-2021
07-01-2021
07-15-2021
11-01-2021
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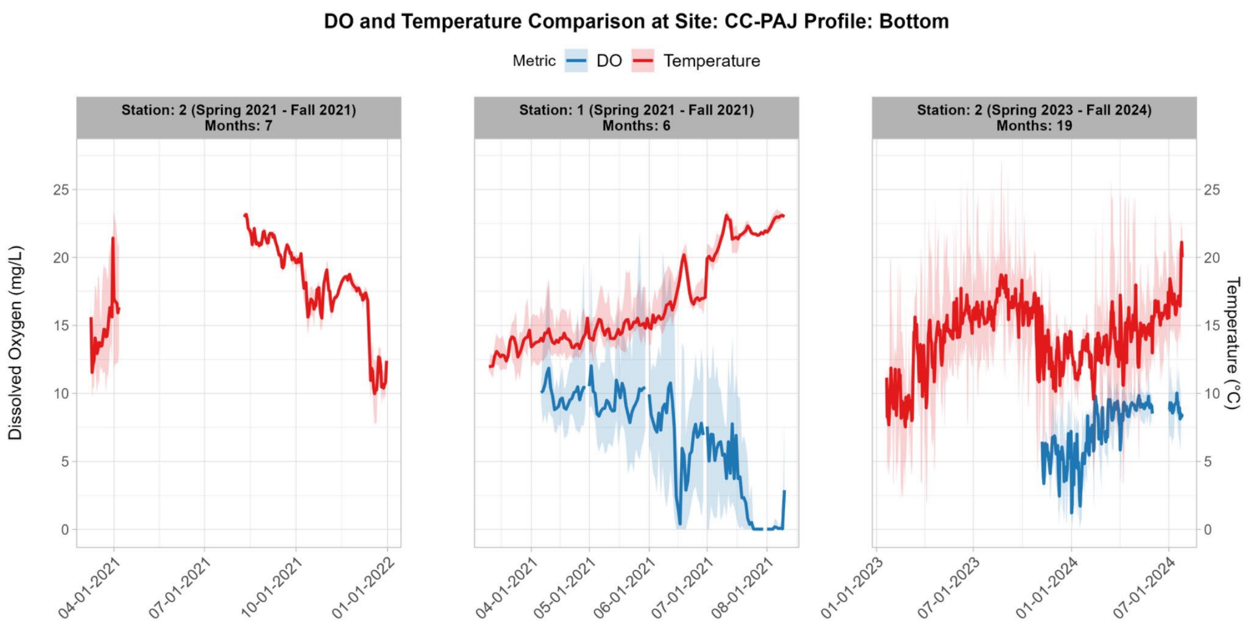
11-15-2021
11-22-2021
11-29-2021
12-06-2021


DO and Temperature Comparison at Site: CC-PAJ Profile: Bottom
Metric DO Temperature
Station: 2 (Spring 2021 - Fall 2021)
Months: 7
Station: 1 (Spring 2021 - Fall 2021)
Months: 6
Station: 2 (Spring 2023 - Fall 2024)
Months: 19
Dissolved Oxygen (mg/L)
Temperature (°C)
25
20
15
10
5
0
04-01-2021
07-01-2021
10-01-2021
01-01-2022
04-01-2021
05-01-2021
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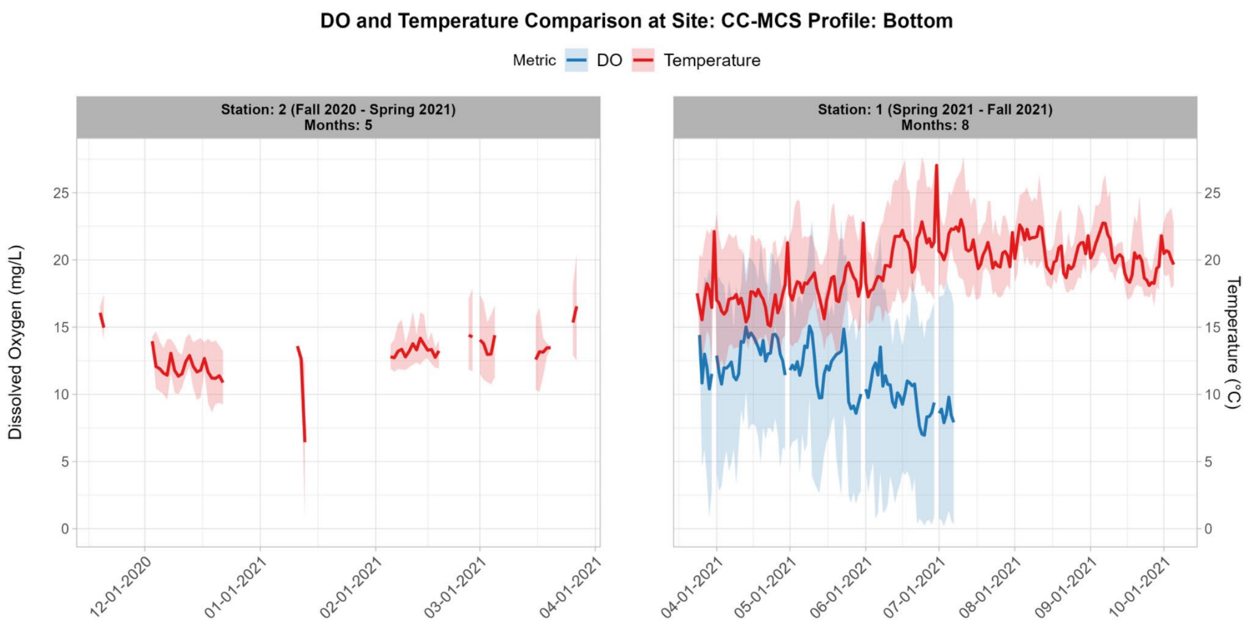
01-01-2024
07-01-2024


DO and Temperature Comparison at Site: CC-MCS Profile: Bottom
Metric DO Temperature
Station: 2 (Fall 2020 - Spring 2021)
Months: 5
Station: 1 (Spring 2021 - Fall 2021)
Months: 8
Dissolved Oxygen (mg/L)
Temperature (°C)
0
5
10
15
20
25
12-01-2020
01-01-2021
02-01-2021
03-01-2021
04-01-2021
05-01-2021
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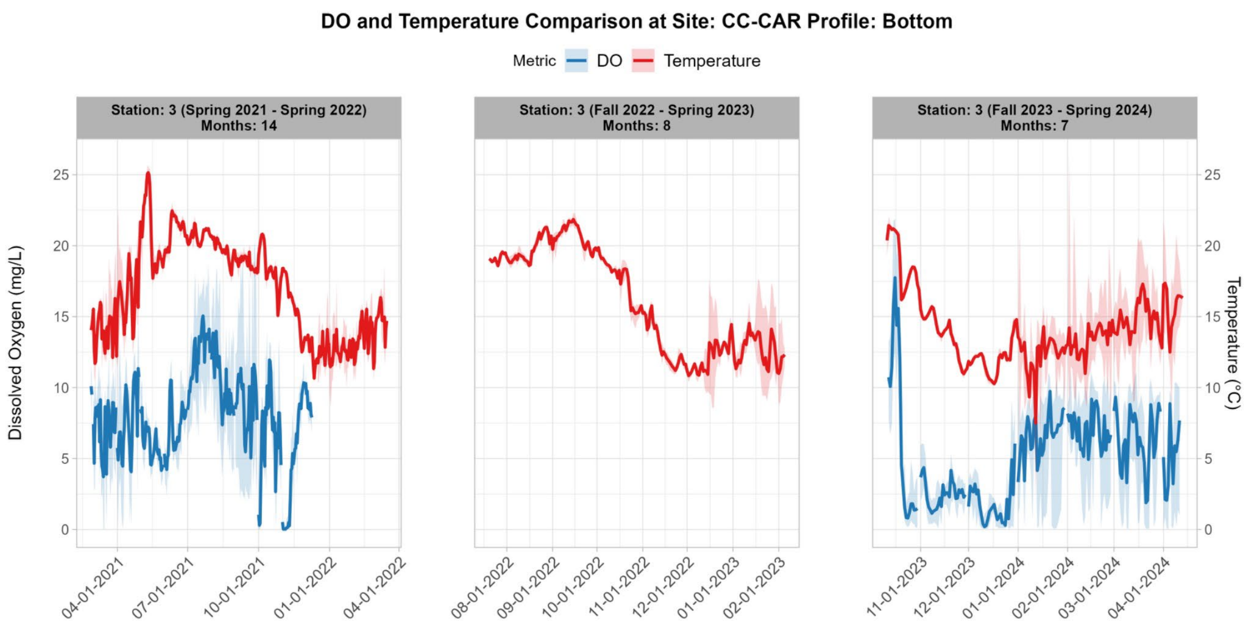
09-01-2021
10-01-2021


DO and Temperature Comparison at Site: CC-CAR Profile: Bottom
Metric DO Temperature
Station: 3 (Spring 2021 - Spring 2022)
Months: 14
Station: 3 (Fall 2022 - Spring 2023)
Months: 8
Station: 3 (Fall 2023 - Spring 2024)
Months: 7
Dissolved Oxygen (mg/L)
Temperature (°C)
0
5
10
15
20
25
04-01-2021
07-01-2021
10-01-2021
01-01-2022
04-01-2022
08-01-2022
09-01-2022
10-01-2022
11-01-2022
12-01-2022
01-01-2023
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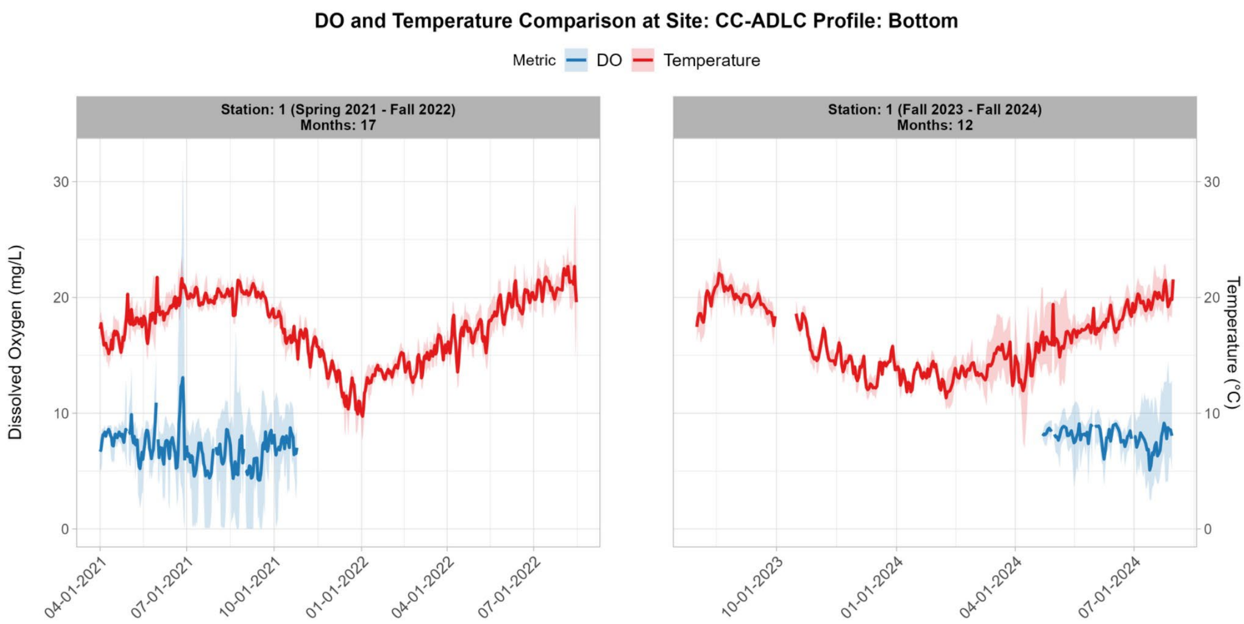
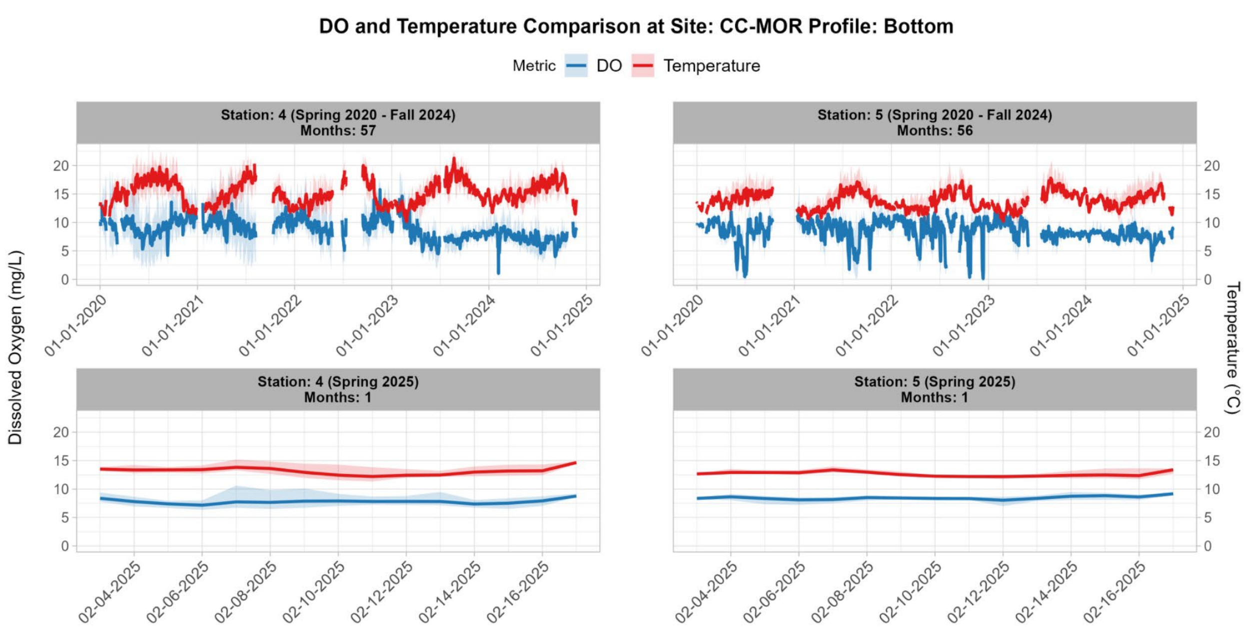
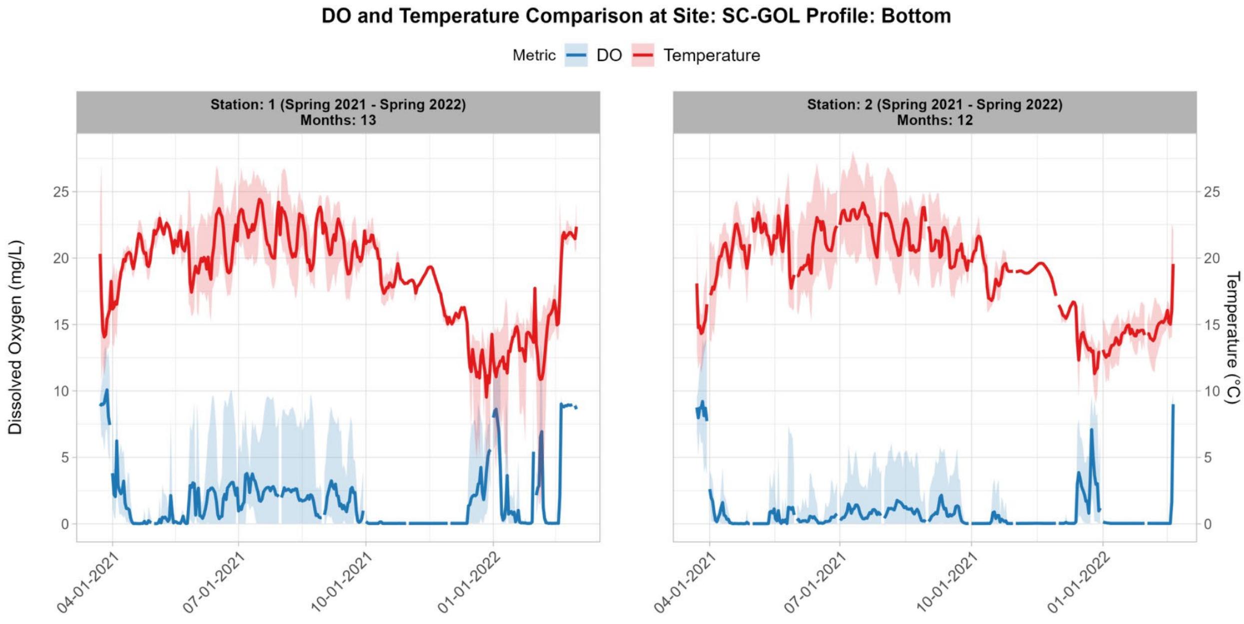
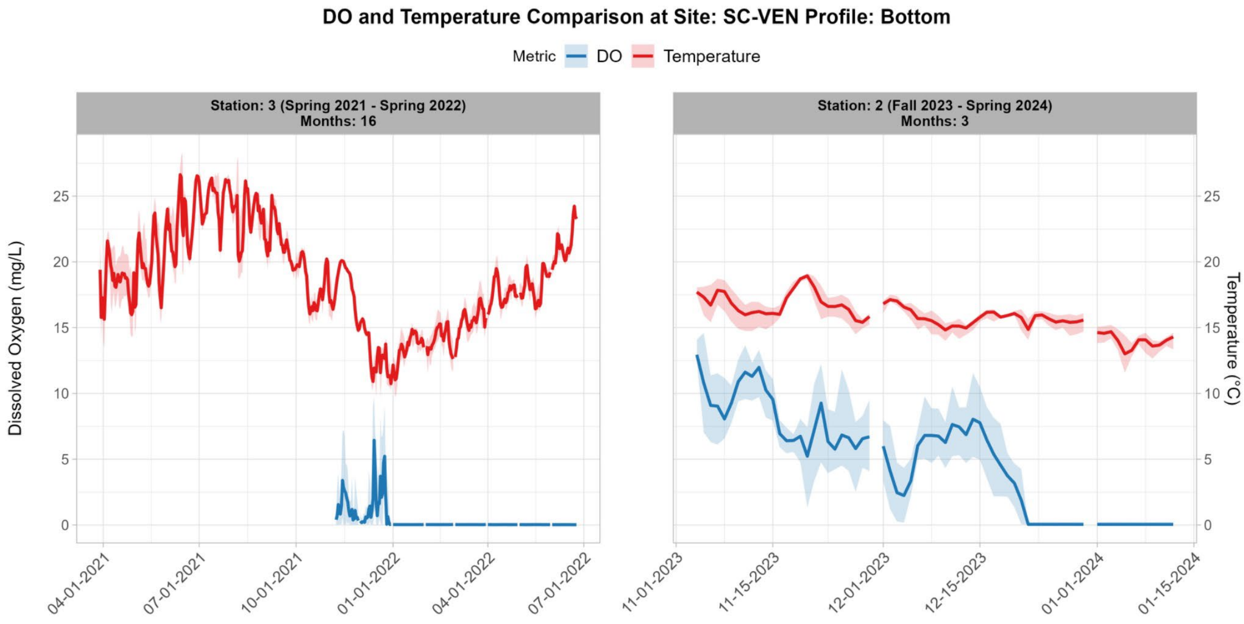
03-01-2024
04-01-2024


DO and Temperature Comparison at Site: CC-ADLC Profile: Bottom
Metric DO Temperature
Station: 1 (Spring 2021 - Fall 2022)
Months: 17
Station: 1 (Fall 2023 - Fall 2024)
Months: 12
Dissolved Oxygen (mg/L)
Temperature (°C)
0
10
20
30
04-01-2021
07-01-2021
10-01-2021
01-01-2022
04-01-2022
07-01-2022
10-01-2023
01-01-2024
04-01-2024
07-01-2024


DO and Temperature Comparison at Site: CC-MOR Profile: Bottom
Metric DO Temperature
Station: 4 (Spring 2020 - Fall 2024)
Months: 57
Station: 5 (Spring 2020 - Fall 2024)
Months: 56
Station: 4 (Spring 2025)
Months: 1
Station: 5 (Spring 2025)
Months: 1
Dissolved Oxygen (mg/L)
Temperature (°C)
0
5
10
15
20
01-01-2020
01-01-2021
01-01-2022
01-01-2023
01-01-2024
01-01-2025
02-04-2025
02-06-2025
02-08-2025
02-10-2025
02-12-2025
02-14-2025
02-16-2025


DO and Temperature Comparison at Site: SC-GOL Profile: Bottom
Metric DO Temperature
Station: 1 (Spring 2021 - Spring 2022)
Months: 13
Station: 2 (Spring 2021 - Spring 2022)
Months: 12
Dissolved Oxygen (mg/L)
Temperature (°C)
0
5
10
15
20
25
04-01-2021
07-01-2021
10-01-2021
01-01-2022


DO and Temperature Comparison at Site: SC-VEN Profile: Bottom
Metric DO Temperature
Station: 3 (Spring 2021 - Spring 2022)
Months: 16
Station: 2 (Fall 2023 - Spring 2024)
Months: 3
Dissolved Oxygen (mg/L)
Temperature (°C)
0
5
10
15
20
25
04-01-2021
07-01-2021
10-01-2021
01-01-2022
04-01-2022
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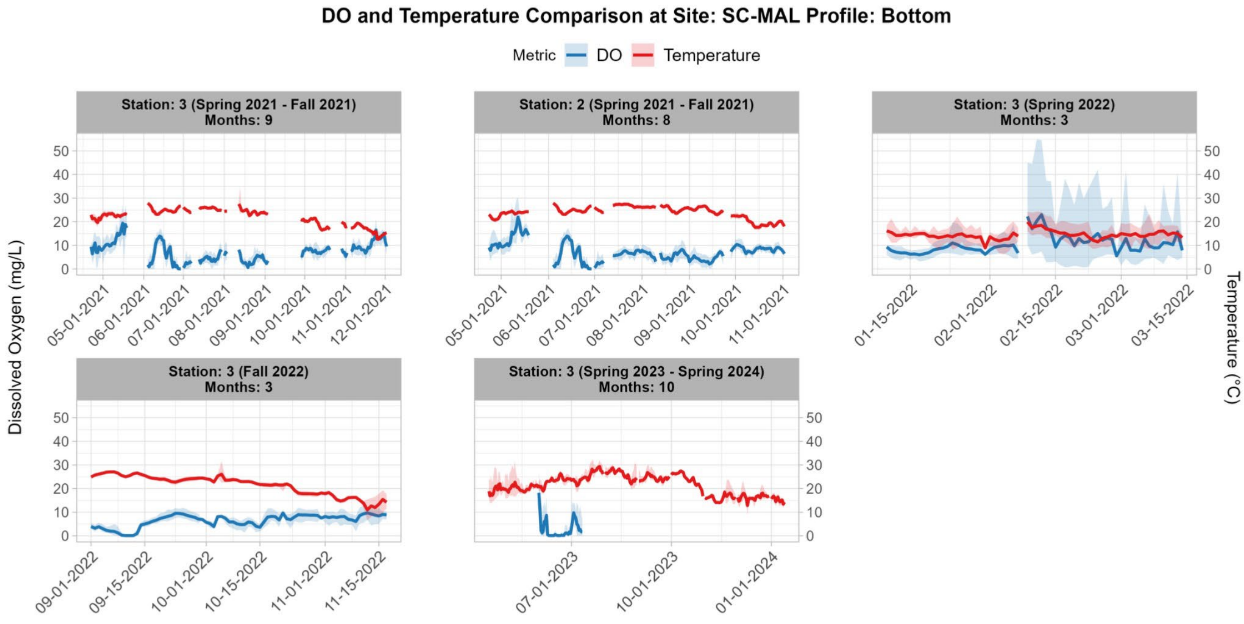
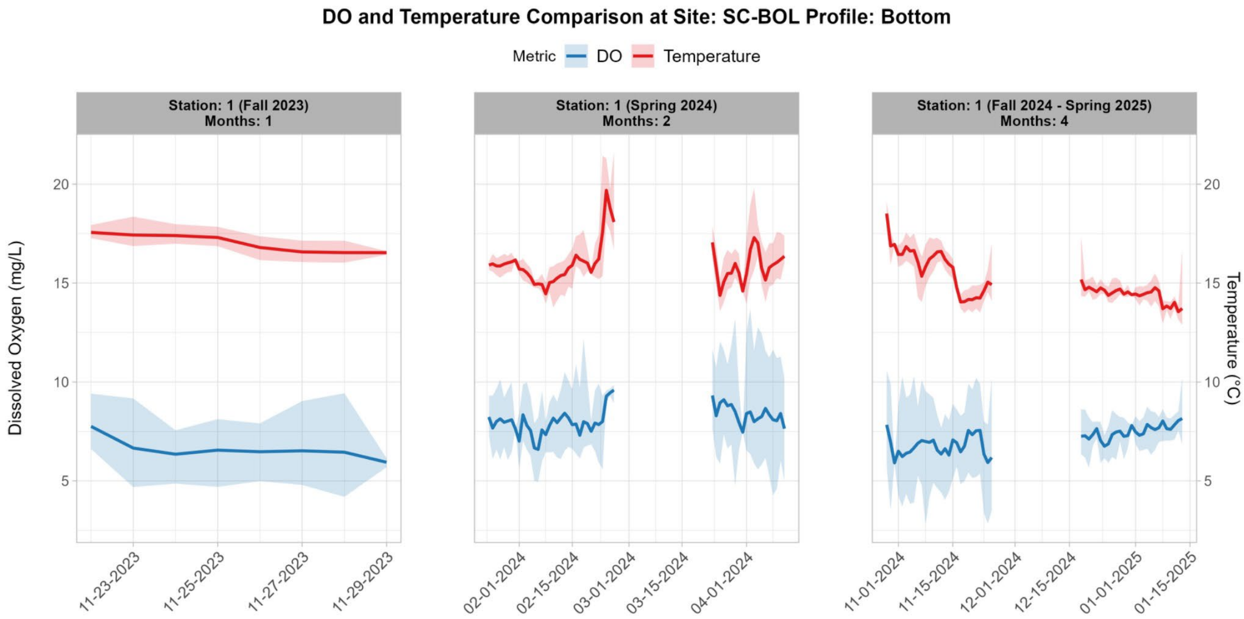
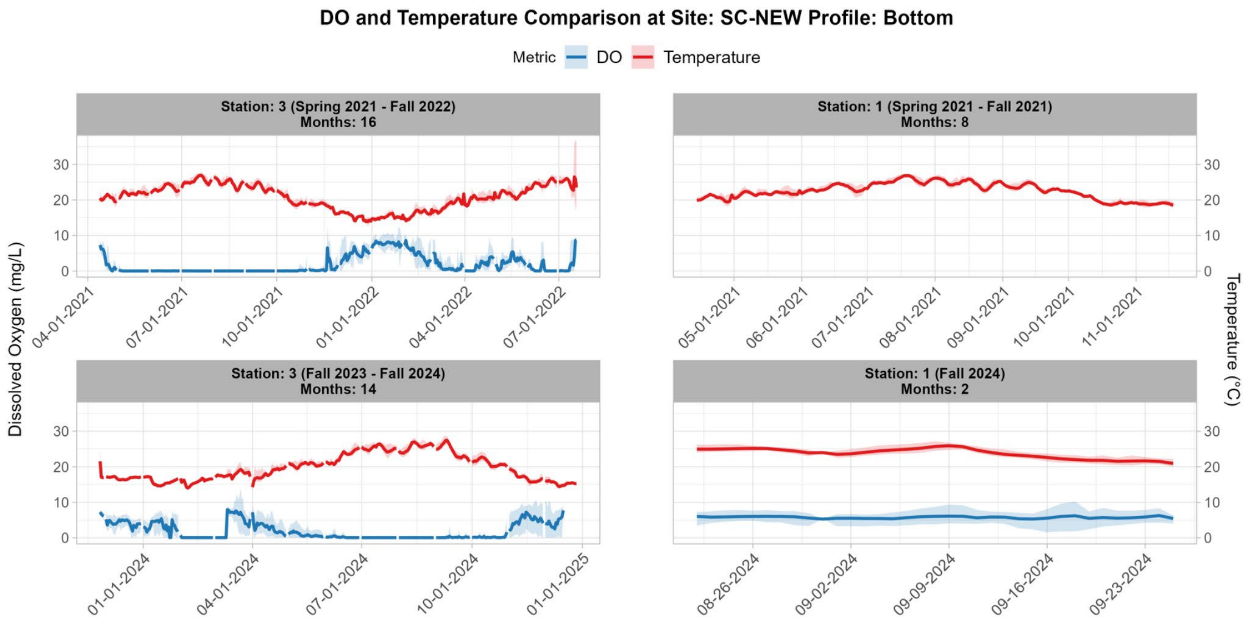
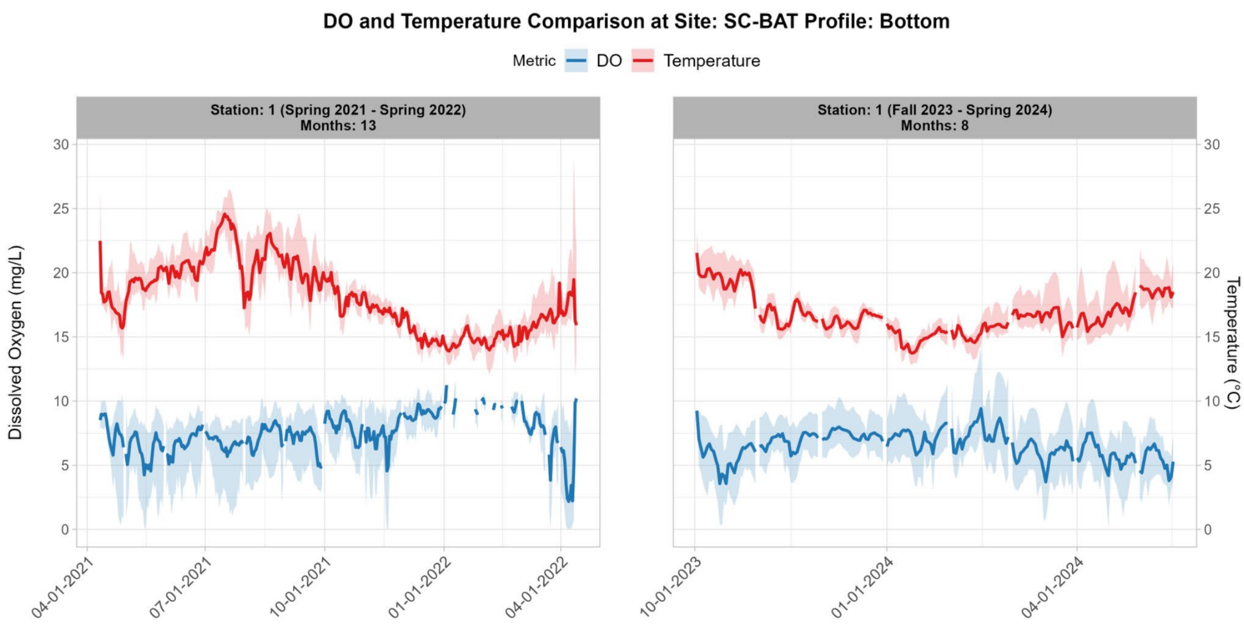
01-01-2024
01-15-2024


DO and Temperature Comparison at Site: SC-MAL Profile: Bottom
Metric DO Temperature
Station: 3 (Spring 2021 - Fall 2021) Months: 9
Station: 2 (Spring 2021 - Fall 2021) Months: 8
Station: 3 (Spring 2022) Months: 3
Station: 3 (Fall 2022) Months: 3
Station: 3 (Spring 2023 - Spring 2024) Months: 10
Dissolved Oxygen (mg/L)
Temperature (°C)


DO and Temperature Comparison at Site: SC-BOL Profile: Bottom
Metric DO Temperature
Station: 1 (Fall 2023) Months: 1
Station: 1 (Spring 2024) Months: 2
Station: 1 (Fall 2024 - Spring 2025) Months: 4
Dissolved Oxygen (mg/L)
Temperature (°C)





Megafauna

We have conducted preliminary analyses of our megafauna surveys and summarized the North Coast efforts at five sites in Spring of 2024. First, we generated a list of known megafauna species that utilize estuaries along the north coast, while likely not a comprehensive list, it is based on decades of observations by our EMPA team, as well as published reports on megafauna. The original list originally included all possible megafauna based on reports from estuaries along the north Pacific, we ultimately removed three species: marten, mink, and boar as there is little evidence that those species are utilizing northern California estuaries exclusively. The list now includes 11 species, while we did not consider most bird species, we included bald eagles, in the future we plan to expand the target list to include larger birds of prey, like great blue herons, egrets, and pelicans. Out of the 11 focal species, 7 were identified during our spring sampling campaign. While species, such as sea otter, cattle, California sea lion, and skunk were not observed; we have observed these species in other seasons in northern California estuaries. The most abundant megafauna species we observed were harbor seals (Figure F- 1 and Figure F- 2), all estuaries except for Drakes Estero had observed harbor seals, although we know that harbor seals utilize the estuary, especially as pupping grounds in the late spring and early summer. The estuary with the greatest diversity of megafauna was Drakes Estero, with 4 megafauna species counted during the Spring 2024 sampling campaign (Figure F- 3).

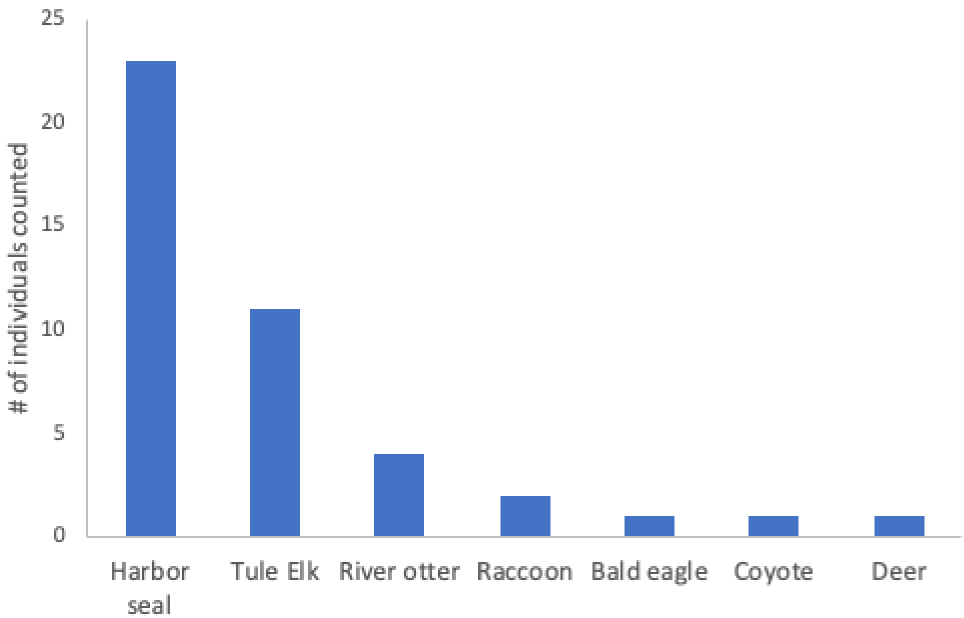


Figure F- 1. Total number of individuals of 7 of the 11 focal megafauna surveys across 5 northern California estuaries during Spring 2024 surveys.

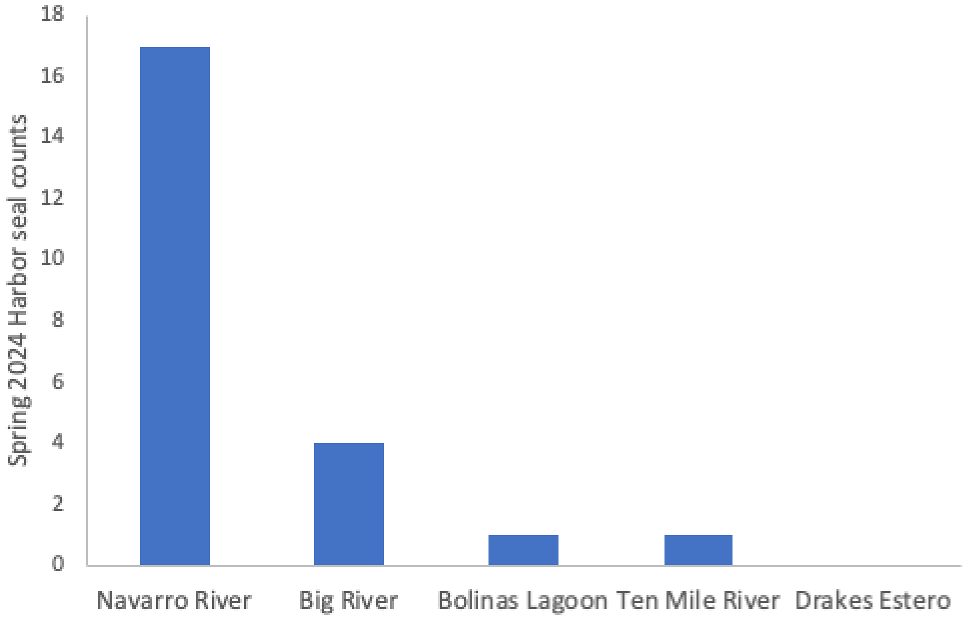


Figure F- 2. Harbor seal counts across 5 northern California estuaries using the EMPA Megafauna surveys. Note: while Drakes Estero did not have any harbor seals observed, we note that they were likely present given that the estuary serves as a harbor seal nursery.

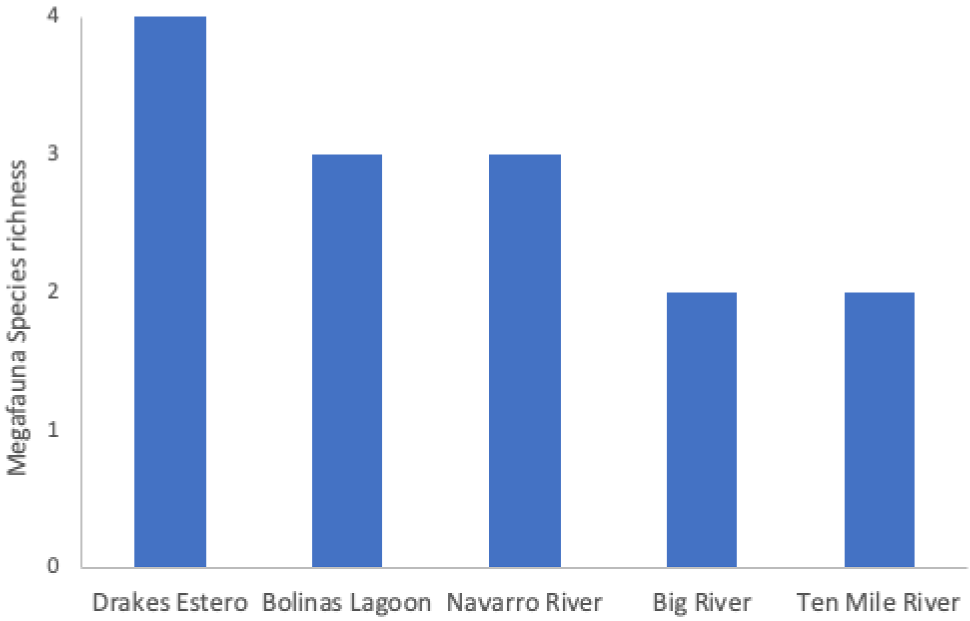


Figure F- 3. Species richness captured in megafaunal surveys during Spring 2024.

eDNA

Preliminary metabarcoding analysis of fish eDNA conducted on water samples from four 2021 study sites (Ten Mile River, Pajaro River, Malibu Lagoon, and Batiquitos Lagoon) produced encouraging results (**Figure F- 4**). At the local level, eDNA recovered the community composition expected from each site, with occasional anomalous observations explainable through processes known to introduce exogenous DNA. At the regional level, eDNA captured faunal patterns relating to differences in latitude, seasonality, and hydrological regime between estuaries, with additional trends likely to become apparent with the inclusion of EMPA environmental metadata into future analyses.

Ten Mile River. eDNA recovered 23 species from Ten Mile River. Prickly sculpin were the most common species in terms of read count, particularly in spring, while three-spine stickleback were most common in fall. Other common species included coastrange and staghorn sculpins, tidewater gobies, and four species of salmon—steelhead, chinook, coho, and chum. Unusual observations of the ocean sunfish were likely caused by scavenger activity or beaching bringing pelagic material inshore, while observations of non-native menhaden may be the result of its inclusion in cattle feed, which may wash into the system from adjacent feed operations.

Pajaro River. Similar to Ten Mile, eDNA recovered 23 species from Pajaro River. In terms of read count, staghorn sculpin were common year-round, but especially dominant in spring. In contrast, topsmelt were the most common species in fall. Pacific herring, California anchovy, three-spine stickleback, arrow goby, and prickly sculpin were other common observations. Three non-native species were recovered from this site—Mississippi silverside, western mosquitofish, and yellow-fin goby.

Malibu Lagoon. 18 species were recovered from Malibu Lagoon, the fewest of the four sites. No single species dominated spring reads, with topsmelt, staghorn sculpin, and striped mullet being similarly abundant. In fall, long-jaw mudsucker and western mosquitofish were equally common in terms of read count. Seasonality in Malibu appeared to relate to mouth condition, with more marine species appearing in spring when the system was open than in fall when it was closed. Similar to Pajaro, three non-native species were recovered from this site—Mississippi silverside, western mosquitofish, and common carp.

Batiquitos Lagoon. eDNA recovered 44 species from Batiquitos Lagoon, the most of the four sites. Most of these species were marine or marine migrants, reflecting the system’s permanently open condition in contrast to the seasonal closure of the other three sites. In terms of read count, striped mullet were most common in spring, while zebra perch and spotted sand bass were most common in fall. Other common species included speckled sanddab, sargo, bay blenny, and topsmelt. Longtail goby was the only non-native species recovered from this site.

		Ten Mile River (18)		Pajaro River (17)		Malibu Lagoon (18)		Batiquitos Lagoon (16)	
Category	**Species**	**Spring (9)**	**Fall (9)**	**Spring (9)**	**Fall (8)**	**Spring (9)**	**Fall (9)**	**Spring (8)**	**Fall (8)**
Freshwater/ lagoonal	Cottus asper*	9	6	4	2				
	Gasterosteus aculeatus*	6	9	2	4				1
	Cottus aleuticus	9	2		1				
	Gambusia affinis		2	1	2	1	9		
	Menidia audens			1	3	6	8		
	Eucyclogobius newberryi	1	4	1	2		1		
	Cyprinus carpio					3			
	Lavinia exilicauda			1					
	Unknown Cottus*		1						
Diadromous	Mugil cephalus				1	9	5	8	3
	Oncorhynchus mykiss*	9	8	1	2				
	Oncorhynchus kisutch	2	7		1				1
	Oncorhynchus tshawytscha		6		1				
	Brevoortia gunteri	1							
	Entosphenus tridentatus	2	6						
	Oncorhynchus keta		1						
Estuarine	Leptocottus armatus*	5	1	9	7	9	2	2	1
	Gillichthys mirabilis	1		1	3	8	6	1	
	Paralabrax maculatofasciatus*							1	4
	Fundulus parvipinnis*					6	7	5	1
	Hypsoblennius gentilis							2	5
	Quietula y-cauda							1	4
	Clevelandia ios			2	6	1		1	1
	Syngnathus californiensis				1				1
	Ctenogobius sagittula								1
	Hypsoblennius gilberti							1	
	Hypsoblennius jenkinsi							1	
	Acanthogobius flavimanus*			2					
Marine migrant	Atherinops affinis			6	7	9	5	4	3
	Clupea pallasii*	2		8	1				
	Roncador stearnsii		1					6	2
	Cymatogaster aggregata		1	1	1			2	
	Menticirrhus undulatus							1	1
	Paralichthys californicus							1	1
	Hypsopsetta guttula					1	1	1	
	Umbrina roncador							4	
	Leuresthes tenuis				1	1		1	
	Platichthys stellatus*			1	1				
	Myliobatis californica							7	
	Hypomesus pretiosus	1							
	Girella nigricans								1
	Porichthys myriaster								1
Marine	Engraulis mordax	1		1	6	5		4	1
	Kyphosus azureus							5	5
	Citharichthys stigmaeus					1		1	
	Anchoa compressa		1			1	6	4	
	Anisotremus davidsonii							5	5
	Sardinops sagax		1			4		5	3
	Atherinopsis californiensis			2		5		2	
	Trachurus symmetricus								1
	Mola mola		1						
	Brachygenys californiensis								1
	Paralabrax nebulifer								1
	Paralabrax clathratus								1
	Rimicola muscarum							1	
	Seriphus politus							1	
	Paraclinus integripinnis					1			
	Strongylura exilis							3	
	Cheilotrema saturnum							1	
	Urobatis halleri							6	2
	Ammodytes personatus		1						
	Cynoscion parvipinnis							1	
	Gymnura marmorata								1
	Hypanus dipterurus							1	
	Total reads	2,169,762	787,780	1,184,699	609,534	777,780	632,886	868,843	662,736

Percent of total reads	> 0.001%	> 0.01%	> 0.1%	> 1%	> 10%	> 20%	> 30%	> 50%	> 70%

Figure F- 4. Preliminary metabarcoding analysis of fish eDNA conducted on water samples from four 2021 study sites (Ten Mile River, Pajaro River, Malibu Lagoon, and Batiquitos Lagoon.

Numbers in parentheses indicate the total number of replicates in a site and season, while numbers in cells indicate the number of positive replicates for a particular species in a site and season. Cell colors represent the percentage of total reads contributed by a particular species in a site and season, with total reads in a site and season listed at the bottom of the table. Species are organized by life mode, with asterisks marking species with flexible habitat requirements. Bolded species are

Appendix G: Bird Monitoring SOP

Objective

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.

The point-count method, in which an observer records all birds detected within either a fixed or an unlimited distance from a point during a specified time period (e.g., Ferry and Frochot 1970, Hutto et al. 1986), is the most widely used counting method in bird population studies (Ralph et al. 1995, Rosenstock et al. 2002). Point counts rely on the assumption that numbers of individuals detected (e.g., seen, heard, or captured) represent a constant proportion of actual numbers present across space and time.

Point-count surveys will be used to estimate population numbers as well as to generate a species list of birds present at time of sampling.

Survey Design

Prior to any sampling efforts for birds, each estuary will assign sampling zones following the EMPA Monitoring Manual[1]. Bird surveys will be conducted within each of these sampling zones.

All sampling zones within an estuary will be sampled on the same day between sunrise to no more than four hours after sunrise.

Count Surveys

Bird point count surveys will be conducted visually using binoculars and a spotting scope. For each estuary, survey effort will be standardized at 20 minutes per sampling zone. Surveys will cover a 100m area around the sampling zone including the marsh, beach, nearshore, and upland habitats. Bird abundance by species will be assessed during these surveys, and, when occurring, high-density, mixed species flocks will be estimated using standardized flock estimation methods.

Flock estimation involves various forms of estimation depending on the situation. The simplest is to estimate the number of birds that you can cover up by your hand and multiplying it by the number of hands to cover the flock. Other specific best practices are covered in by ebird resources[2].

Surveys will not be conducted when weather conditions are unfavorable for the clear visualization of birds or when conditions would impact the behavior of birds. Examples of unfavorable conditions include precipitation or heavy fog, winds in excess of 15 mph, temperatures below 40 ºF or above 80 ºF.

[1] https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/monitoring_manual.pdf

[2] https://support.ebird.org/en/support/solutions/articles/48000838845-how-to-count-birds

Auditory Surveys

Concurrently, the bird assemblage at each site will be assessed auditorily with wildlife recording equipment (Wildlife Acoustics Song Meter Micro bird and wildlife audio recorder[3]). The recording device will be mounted on to an upright object (e.g., fence post or sign) out of the direct path of the wind to avoid background noise and away from the observers at each sampling zone. Recordings will be standardized to 20 minutes per sampling zone and then downloaded to a device with the Micro Configurator App installed. After returning to the lab, recordings will be analyzed using (software such as Raven or Kalaeidescope), and each bird will be identified by song to confirm the presence of birds identified visually and any birds not in view during observations. Once detected, the sounds will be sorted into groups of similar sounds called “clusters.” Clusters can be labeled for species inventory or annotated to create classifiers that can be run on additional recordings.

Time of Sampling

Due to seasonal variation in bird assemblages, estuaries will be sampled in Spring (April and May) and Fall (October and November). During these seasons, 1 to 3 surveys will be conducted on different sampling days, in different months if conditions permit. Replicates of bird counts will be averaged across survey replicates to produce an average abundance and species richness by season for each estuary. If additional funds can be obtained to monitor the bird populations within these Santa Monica Bay estuaries, then surveys in the Winter and Summer are also recommended to capture migratory species.

[3] https://www.wildlifeacoustics.com/products/song-meter-micro

Appendix H: Megafauna SOP

Objective

Estuaries in California are rich in wildlife, including some megafaunal species that utilize estuaries for various reasons, including as migratory corridors, foraging and hunting areas, and places to rest and reproduce. To date, a standardized protocol to document estuarine megafauna has yet to be developed for California. Estuaries that are frequented by humans (boaters, hunters, recreators, etc.) may alter the timing and use of estuarine habitats, which challenges our ability to detect megafauna use. However, estuaries within the EMPA monitoring network have frequent use of wildlife. For example, Drakes Estero, one of the least visited of EMPA sites has a wide diversity of megafauna utilizing the estuary, including: river otters, coyote, cattle, tule elk, California sea lions, harbor seals, and the occasional sea otter, to name a few (see Silliman et al. 2018, Fig. 1).

This protocol allows for the end-user to document and quantify megafauna use of estuaries. While the protocol is aimed to document megafauna uses in estuaries, it does not capture birds, which we acknowledge is an important dimension of the biodiversity of an estuary, and should be considered for future monitoring protocols or could be included in this protocol as an extended protocol. This protocol does not include humans (or their domesticated animals), which requires its own protocols (Note: EMPA is capturing indicators of human use, including monitoring for trash and microplastics – SOP 15). The breadth of monitoring protocols of megafauna is broad, and can include: coordinated distance monitoring (observing from a far for extended periods of time), wildlife camera trapping, scat analysis, eDNA, tagging/relocating, and modelling (Tinker et al. 2017, Sanchez 2021, Hughes et al. 2024). Here we provide a standardized rapid protocol to quantify megafauna in California estuaries.

Parameters

Megafauna presence, megafauna habitat use, megafauna diet and behavior, megafauna density.

Materials

1. Binoculars
2. Timing device
3. GPS/compass
4. Range finder (improves accuracy, but can get inaccurate results depending on topography)

Synopsis

There is no single best time to observe megafauna. Encounters are often most likely when first arriving at a field station, but these observations are frequently supplemented by passive monitoring methods such as camera traps or scat analysis.

Initial Megafauna Sampling

1. Upon arrival to the sampling station, perform a quick survey of the sampling area (marsh down to the subtidal).
    a. Ensure that disturbances are minimized (no loud noises, avoid approaching vehicles in the direction of the location).
    b. Either a single team member or the whole team can perform the survey, which starts with a visual scan of all estuarine habitats to spot and charismatic megafauna.
    c. Note the time started and the time ended.
    d. Note on the map the approximate survey range
    e. Using a print out of the map, or GPS device, note the location of the species/population
    f. For each observation, record:
        i. Date
        ii. Observation start time
        iii. Observation end time
        iv. Species (or lowest taxonomic unit)
        v. Habitat used and number of animals per habitat
        vi. Habitat for each individual or group of individuals (marsh, tidal creek, subtidal channel, seagrass bed, mudflat, etc.)
        vii. Behavior observed in each habitat among individuals or a target member of a group (foraging, swimming, resting, grooming, mating, walking, running, human disturbance, etc.).
2. Initial surveys will likely take no more than 1-15 minutes.
3. Surveys should be conducted by-eye and can be supplemented with binoculars.
4. These surveys can be repeated throughout the visit. Example, a single harbor seal arrives midway through sediment collection. Collect those data as noted above.

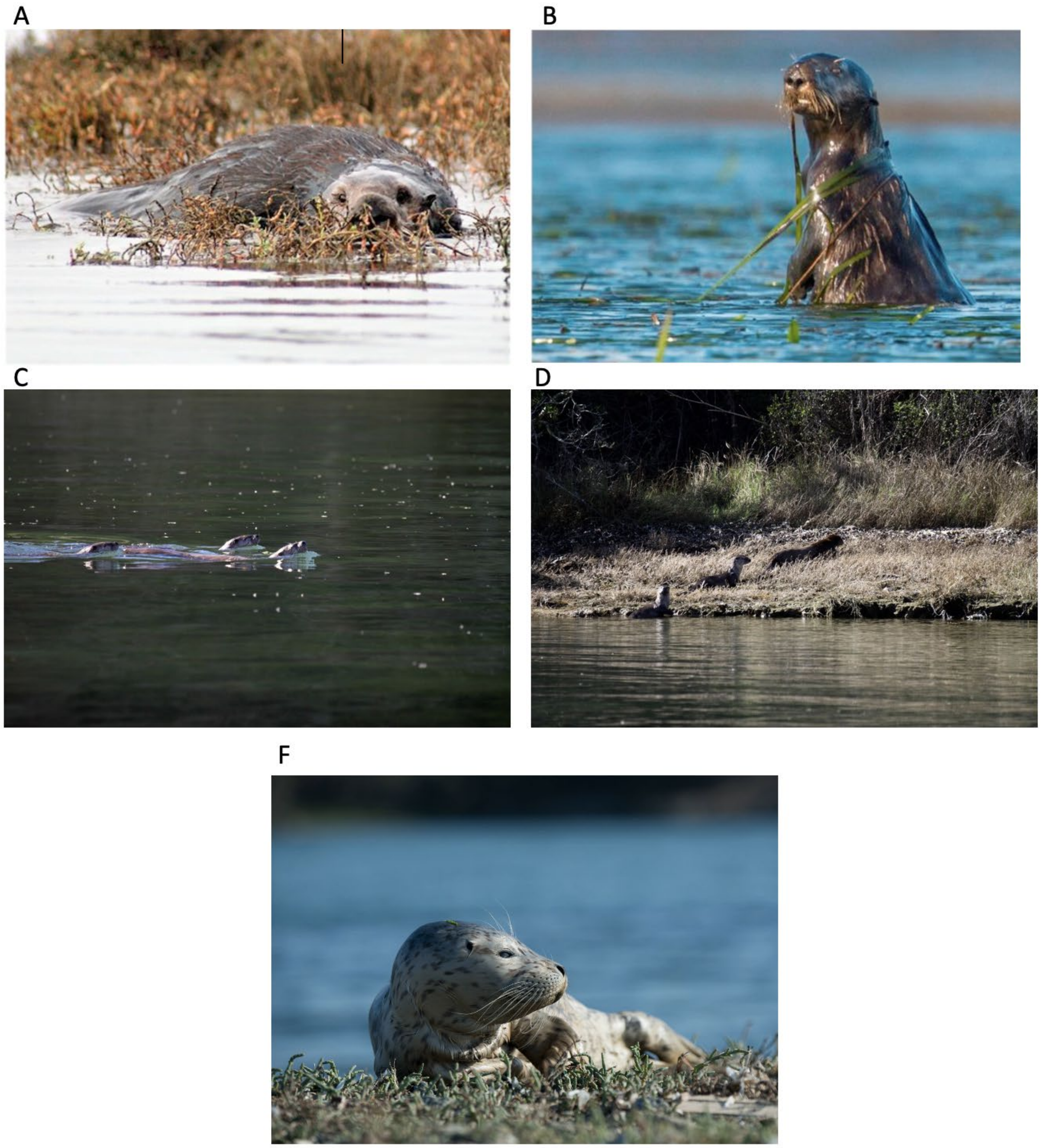


Figure H- 1. Examples of megafauna using estuarine habitats in California. Sea otters using salt marsh (A) and seagrass (B) habitats in Elkhorn Slough (photos: R. Eby; from Silliman et al. 2018). River otters using channel (C) and marsh/upland (D) habitats in Drakes Estero (photos: B. Hughes). (F) Harbor seal hauled out on pickleweed marsh in Elkhorn Slough (photo: Killiii Yuyan).