Estuary Marine Protected Area

2021 Data Analysis Report

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EMPA
Monitoring Program

OCEAN
PROTECTION
COUNCIL

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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) 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. A monitoring manual and associated website 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[1] 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 pilot implementation, including an inventory and characterization of the study sites, a summary of the sampling effort, a sample function-based data analysis and interpretation, and concludes with lessons learned from the first year of data collection. 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.

Overview of Estuary Monitoring Needs and Key Management Questions

Estuaries are one of the most productive ecosystems, supporting great biodiversity and many ecological services. At the intersection 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, and 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 values and restore lost values. Establishing a statewide monitoring framework that can document the range of existing ecosystem values and track changes driven by management decisions is a primary goal of this program.

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

Coastal resource managers have long recognized that the health of coastal estuaries is integrally linked to the surrounding landscape stressors and to the health of adjacent marine habitats. In August 2020, EMPA team members circulated a survey to members of the Management Advisory Council (MAC) to gather input on elements of an EMPAs monitoring framework that would best meet their needs (Table 1). A suite of seven questions were asked and the EMPA team received valuable feedback from the California Department of Parks and Recreation (CDPR), the California Department of Fish and Wildlife (CDFW), the U.S. Fish and Wildlife Service (USFWS), Santa Monica Bay Foundation (SMBF), State Coastal Conservancy (SCC), and National Marine Fisheries Service (NMFS).

Table 1. List of Management Advisory Committee survey questions.

1.	What are your group's key management questions with regards to EMPAs, and what information and data do you need to address those questions?
2.	Are there specific estuary types, habitat types, and/or stressors for which the collection, analysis, and interpretation of new information is a high priority for your organization?
3.	Do you have specific management concerns related to climate change and public/recreational/cultural use of estuaries, and if so, what are they?
4.	What type of information (or output) is most useful to you?
5.	What existing and/or anticipated data sources, tools, and conceptual models do you rely on to inform decision making?
6.	Do you have partners, neighboring landowners/managers, or other stakeholders with similar or related information/data needs?
7.	Do you have preferences or requirements regarding data submittal, storage, and access?

Responses to the questions fell into two categories: those related to management actions in EMPAs and non-EMPA estuaries, and those related to management of the monitoring enterprise itself (who would pay for it, who would manage data, how would metrics be standardized, etc.).

Some key themes of the responses included:

- Assessing baseline conditions and subsequent trends of key metrics in EMPAs and non-EMPA estuaries:
  - Abundance, distribution, and conditions of habitats
  - Populations of native, culturally important, and special-status species
  - Populations of invasive species
- Assessing the impacts of the following on EMPA and non-EMPA conditions:
  - EMPA designation
  - Recreation
  - Climate change, including sea level rise, ocean acidification, and flow/sediment delivery
  - Upstream water diversions, pollution, and watershed management
  - Shoreline development
- Selecting appropriate estuarine reference sites to support management
- Developing information to support planning for:
  - Mouth/inlet management

    - Restoration, enhancement, and adaptive management
    - Inland migration of habitats
    - Infrastructure re-alignment
- Assessing how EMPAs support offshore ecological communities

Recommended types of data outputs and information were very diverse, and tended to reflect the responsibilities of the responding MAC member. Priority data needs of agencies ranged from raw data to Processed, QA/QC'd, and summarized data, to technical reports, to Interpretive indices/report cards with user-friendly graphics aimed at public outreach. Most responders emphasized the need for data collected with public funds to be accessible online, transferrable, and uploaded to the California Ocean Protection Council Data Repository.

This feedback from the MAC Survey helped guide the EMPA Team in the selection of assessment protocols and the compilation and analysis of monitoring results.

EMPA Monitoring Framework

During the first project year in 2020, the EMPA Team went through an iterative process to select the estuaries, assessment protocols, and indicator species for inclusion in the Estuary MPA Monitoring Project. The process was captured in a Technical Memo[2] which lays out the goals and objectives of this project, describes the considerations and process used to select estuary sites, monitoring protocol, and species focus, and presents the proposed sample frame to the Management Advisory Committee (MAC) for consideration. The resulting monitoring framework is intended to capture a representative diversity of estuaries assessed using the selected protocols to support management actions and aquatic species in estuaries throughout California.

Development Approach and SOPs

The overall goal of the EMPA Monitoring Program is 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 those estuaries. The intent of developing a standardized monitoring protocol is to support its uses by the MPA program and partner organizations aimed at assessing estuary function, condition, or health of other California estuaries to easily compare results among systems and between programs.

To support a statewide monitoring program, sampling protocol and data analysis focuses on documenting the ecological functions supported by the estuary rather than specific flora or fauna (Table 2). This allows the monitoring

Table 2. List of estuarine functions included in the EMPA Monitoring Framework.

Ecological Functions
▪ Nekton Habitat ▪ Primary Production ▪ Secondary Production ▪ Protected Species Support ▪ Nutrient Cycling ▪ Sea Level Rise Amelioration and Resiliency ▪ Bird Habitat ▪ Shellfish Support ▪ Nursery Habitat ▪ Support of Vascular Plant Communities ▪ Wildlife Support

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

framework to accommodate different estuary types and assimilate data from existing monitoring programs, while maintaining underlying statewide comparability. In service of assessing functional performance, we have developed standard protocols to assess key estuarine features, coupled with standard data collection and storage templates and guidance on data analysis, synthesis, and reporting. The framework focuses on four principles – flexibility, comparability, interpretability, and practicality.

The focus on Functional Analysis guided the drafting of a Field Assessment Manual[3] with 14 SOPs that describe the range of data collection procedures. Each SOP describes data collection methods linked to a specific indicator of condition. Each indicator of condition is then linked to one or multiple ecological functions.

Goals of Pilot Implementation

The initial implementation of the EMPA Monitoring Program took place in 2021 across 15 estuaries in California (10 MPAs and 5 reference). The goals of the pilot implementation effort were as follows:

1. Test and refine protocols to ensure the data that are being collected can be used to easily infer the ecological functions of interest
2. Revise the Field Assessment Manual after each field effort to allow for consistent application
3. Demonstrate the application of the overall Monitoring Framework, with a focus on Function-based analysis
4. Provide an example set of data analysis and interpretation with the caveat that many of the management questions raised by the MAC will require longer-term data collection

Pilot Implementation

During 2021, the EMPA Team conducted a pilot implementation of the Monitoring Framework. The state divided into three regions (North, Central, South)[4] within which a field team based out of a California State University campus was established to conduct the monitoring effort. Field and technical support were provided by other EMPA Team members, including University of California faculty and students, and SCCWRP staff.

Sampling Site Selection

California is a large state with a 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 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

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

[4] North= Oregon border to SF Bay, Central=SF Bay to Pt. Conception, South= Pt. Conception to Mexico border

hydrogeomorphic dynamics drive 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 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 (also known as bar-built 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).

The Technical Team generated a set of guidelines/filters to select 15 estuaries from the initial list of 50 MPA and non-MPA (reference) estuaries[6] for inclusion in the first year of this study[7]. The list of possible reference[8] (non-MPA) estuaries in California was generated from Appendix C in 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.

The site selection filters included:

1. Regional representation of each estuary type:
2. Presence of an MPA within the estuary which would allow for sampling both inside and outside of the designated estuary MPA boundaries:
3. Presence of the PMEP focal species in the estuary:
4. Proximity of the estuary to an offshore MPA, allowing for studies of the interaction between the estuary and offshore MPA:
5. Representation of a range of conditions according to existing CRAM data:

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

[7] See EMPA Monitoring Project Tech memo

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

Inventory and Characterization of Studied Sites

The 15 selected sites represent a range of estuary types, sizes, and levels of protection in California (Table 3).

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.

All estuary images provided below were obtained from the California Coastal Records Project[9], unless otherwise noted.

[9] www.californiacoastline.org

Table 3. Name, location, size and other pertinent information on the fifteen 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 Estuary	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 Estuary	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
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 meter. 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.

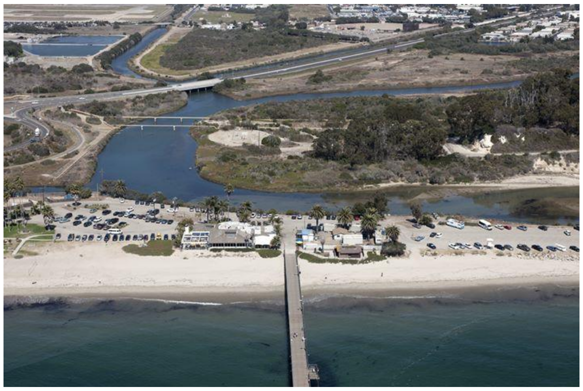
Morro Bay (MPA) – Embayment

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.

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.

Summary of Sampling Effort

In spring and fall of 2021, our team tested the monitoring framework across three geographic regions and fifteen estuaries (10 MPAs and 5 Non-MPAs) (Figure 1). The recommended temporal sampling frequency and number of replicates for each method is presented in Table 4. Each assessment took approximately three days to complete with a team of 4 to 6 people. Our regional teams were able to successfully collect two seasons of data needed to compile descriptive information about each individual site. We were not able to include an estuary in the far northern region of the state due to limitations on travel associated with the COVID-19 pandemic during the 2021 field season. Furthermore, an effort to collaborate on monitoring with a tribe in the northern region was not successful.

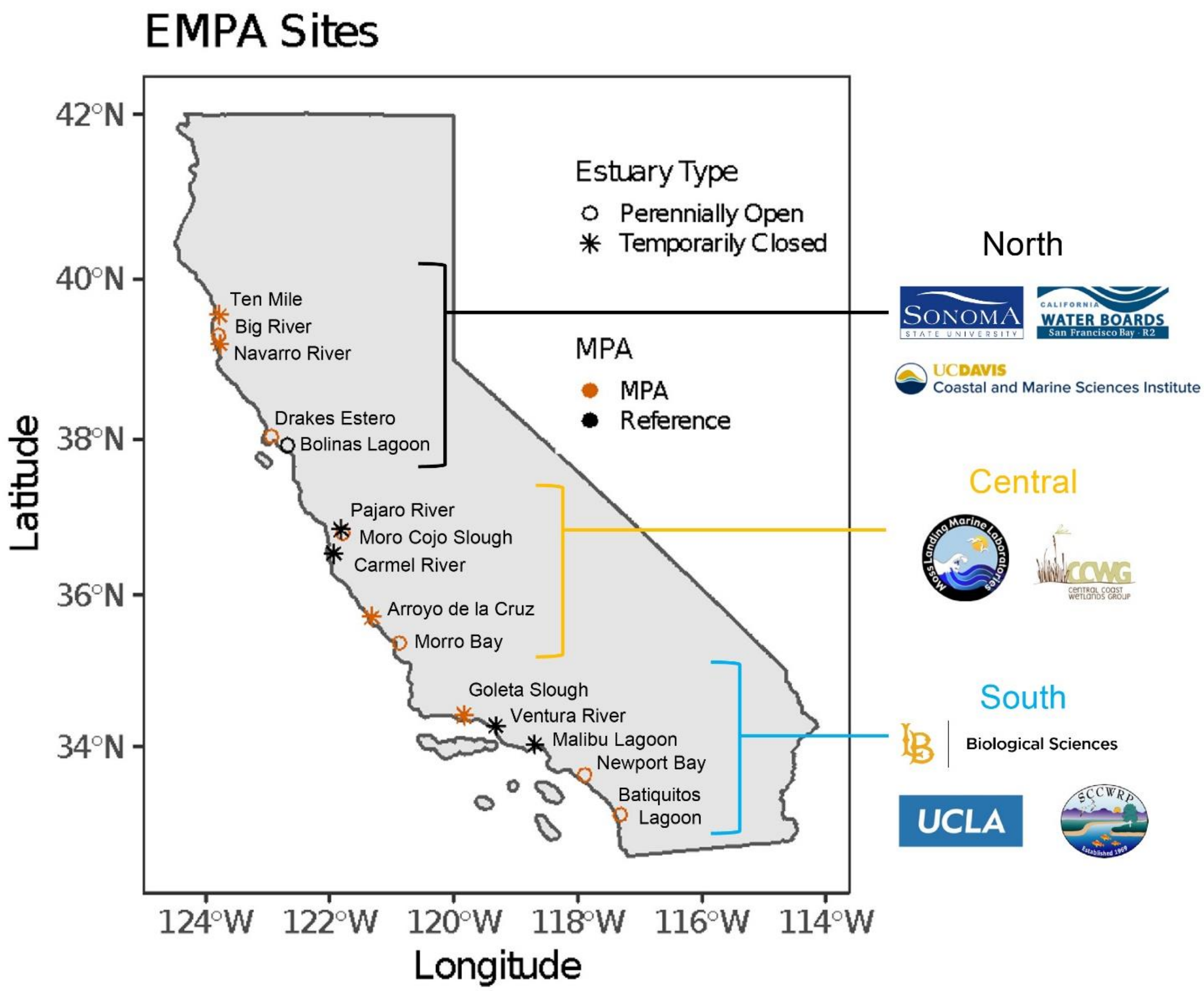


Figure 1. Map of EMPA monitoring sites and associated monitoring teams for each region of the state.

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

SOP	Method	Replication	Continuous	Monthly	Seasonal	Annual	Periodic
SOP 1: Continuous monitoring	VanEssen CTD-Driver with the PME MiniDot	1-2	x				
	Rugged Troll	1	x				
	HOBO TidbiT	6-8	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	1			x		
	Freshwater nutrient Field Blank (FB)	1			x		
	Estuary ambient nutrient replicates	3			x		
	Estuary nutrient Field Blank (FB)	1			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 grainsize	Sediment grainsize core	9				x	
SOP 6: Benthic invertebrates	Subtidal benthic core	3			x	x	
	Intertidal benthic core	3			x	x	
SOP 7: SAV & macroalgal surveys	Transects	Dependent on # of beds		x	x		
SOP 8: Fish - BRUV	BRUV	3-6		x	x		
SOP 9: Fish – Seine & cast net	Seines	9		x	x		
SOP 10: Crab traps	Shrimp pots	3			x	x	
	Minnow traps (3 top and 3 bottom)	6			x	x	
SOP 11: Marsh plain vegetation surveys	Transects (2 per monitoring station)	Minimum 6				x	
SOP 12: Topographic surveys	GPS	Varies					x
SOP 13: Sediment accretion rates	Feldspar	1-3					x
SOP 14: Trail cameras	Trail cameras	1	x	x			
CRAM	CRAM	Depends on estuary size					x

Figure 2 depicts the layout of a typical estuarine monitoring station where the 14 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 (see EMPA Monitoring Manual for more detail). During this pilot implementation of the EMPA framework, the Project Team was interested in collecting data on all 11 ecological functions distributed throughout the estuary.

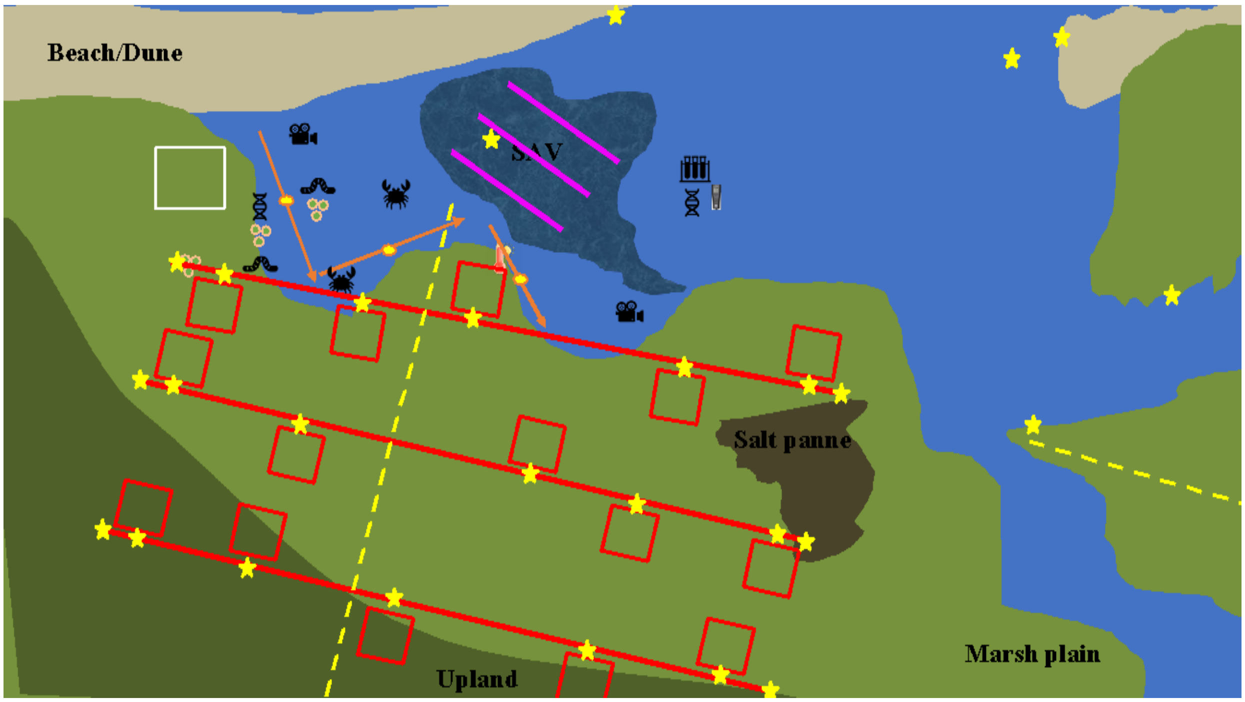


Figure 2. Depiction of a typical monitoring station layout within an estuary. Icons, shapes and colored lines represent each of the 14 SOPs.

General Estuary Water Chemistry

Near-bottom water chemistry monitoring using probes deployed for two weeks, document the frequency of temperature, salinity, and dissolved oxygen values at three estuaries in each of the three regions in April 2021 (Figure 3). These data document the significant variability in water chemistry among sites, regions and types of estuaries. Water temperature ranges were greatest in the north and most similar among estuaries in Central California. Salinity was highest in estuaries with managed (Moro Cojo and Goleta) or permanently open mouth conditions (Drakes, Newport, Batiquitos). Oxygen concentrations were saturated or supersaturated in northern estuaries, saturated to anoxic in southern estuaries and spanned the full range within central estuaries. These data demonstrate the variable nature of estuarine water chemistry and the unique conditions that occur within all of the systems monitored.

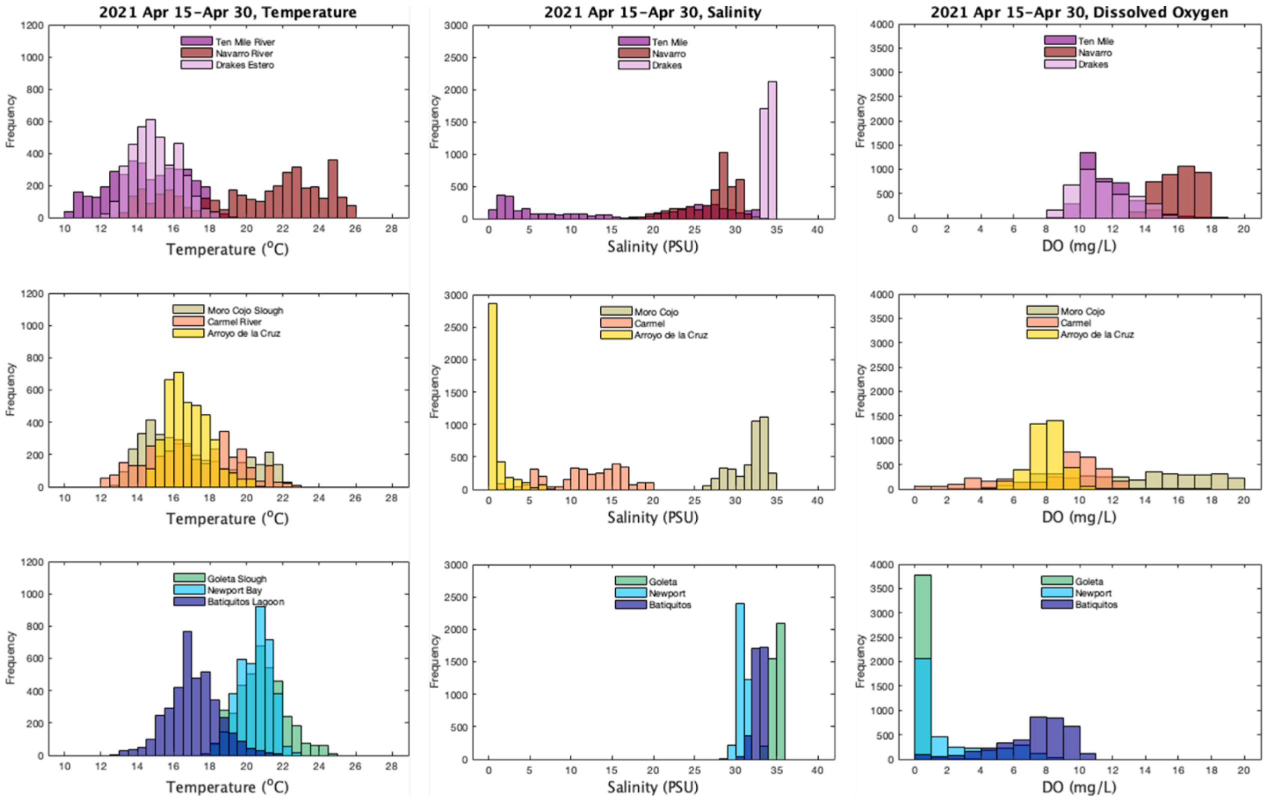


Figure 3. The histograms depicted above show the frequency of temperature, salinity, and dissolved oxygen values at three estuaries in each region during two weeks in April 2021. These visualize the variability between and within each region for different parameters during the same 2021 spring sampling period.

Function-based Data Analysis

A function-based assessment strategy was used to document 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 these systems. An underlying principle of this function-based assessment strategy is that all estuaries should provide a variety of ecological functions at some ideal rate in the absence of anthropogenic disturbance and alteration. Natural variability in ecological functions supported by an estuary is also driven by local hydrogeomorphic factors (salinity range, freshwater input, mouth conditions, watershed acreage) that are also documented within this study design. The EMPA Team identified a suite of indicators from which to assess the various functions and the resulting condition of each estuary, summarized in Table 5 below.

To standardize the assessment of each estuary function, each function was assigned a suite of condition statements that could be analyzed using the indicator data collected by the EMPA Monitoring Program. Each condition statement output (i.e. data interpretation) was then 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 were then averaged for each estuary to give a final function score.

Below we demonstrated this process for three select functions: Support of Vascular Plant Communities, Sea Level Rise Amelioration and Resiliency, and Nekton Habitat/Nursery Habitat. We then list the draft condition statements for the Nutrient Cycling and Bird Habitat functions. 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 date 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.

Table 5. 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												
		Water quality	Water nutrient concentration	General community composition (eDNA)	Sediment characteristics	Benthic infauna abundance/diversity	SAV/macroalgae distribution	Fish abundance/ diversity	Crab abundance/ diversity	Marsh vegetation distribution/ diversity/ invasives	Marsh plain elevation	Sediment accretion rates	Mouth dynamics	General habitat condition
Ecosystem Functions	Nekton Habitat	■	■				■	■	■					
	Primary Production			■	■		■			■	■	■		■
	Secondary Production					■	■			■				
	Protected Species Support	■		■			■	■	■	■	■		■	■
	Nutrient Cycling		■		■	■	■			■		■	■	
	SLR Amelioration									■	■	■	■	■
	Bird Habitat					■	■	■	■	■	■		■	■
	Shellfish Support	■	■	■	■	■	■							
	Nursery Habitat					■	■	■	■				■	
	Support Vascular Plants	■			■		■			■	■	■		■
	Wildlife Support	■	■	■			■			■	■			■

Functional Analysis 1: Support of Vascular Plant Communities

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

Seven condition statements have been drafted (based on the 7 indicators noted in Table 4) to help direct data analysis to quantify the level of vascular plant support provided by each estuary. Plant communities in high performing estuary have:

- High California Rapid Assessment Method (CRAM) scores (Index, Physical, and Biotic attributes)
- High percentage of native plant species
- Dense vegetation cover in higher marsh elevation habitats (mid and high marsh)
- Varied marsh plain topography (levels of rugosity)
- Sediment supply to the marsh plain supports vascular plants
- Appropriate amount of marsh plain inundation from main channel
- Low presence of floating algae in the main channel

Each condition statement was analyzed separately and the resulting scores were averaged to give each estuary a final score for this function.

Our vascular plant functional equation states that high performing systems will have higher average scores for: **General Habitat Condition Score + Marsh Vegetation Distribution & Diversity Score (Average of Percent Native & Dense Vegetation) + Marsh Plain Elevation Score (Marsh Plain Topography (Rugosity) & Marsh Plain Inundation) + SAV/Macroalgae Distribution Score / divided by N (the number of condition statements evaluated).** As additional data are collected and analyzed, the water quality and sediment accretion rate indicators will be added to this analysis. Below we describe the methods to score each condition statement and provide initial results when possible.

Condition Indicator 1: General Habitat Condition Score using California Rapid Assessment Method (CRAM)

Data were compiled to evaluate the condition statement: Plant communities in high performing estuary have High California Rapid Assessment Method (CRAM) (CWMW, 2013) scores (Index, Physical, and Biotic attributes).

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 2014-2022, which were downloaded from EcoAtlas.org. The statewide estuary CRAM Index scores were plotted (N = 140) as a cumulative frequency distribution (CFD) plot and then the CRAM scores for the 15 EMPA estuaries were plotted along the curve as points based on their most recent average CRAM score (Figure 4) (note-7 EMPA estuaries were assessed during the 2021 field assessment effort). This process was repeated for the estuary physical (Figure 5) and biotic attribute scores (Figure 6). For scoring this condition statement, the CFD was divided equally into three condition tertials. Each MPA and reference (non-MPA) 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.

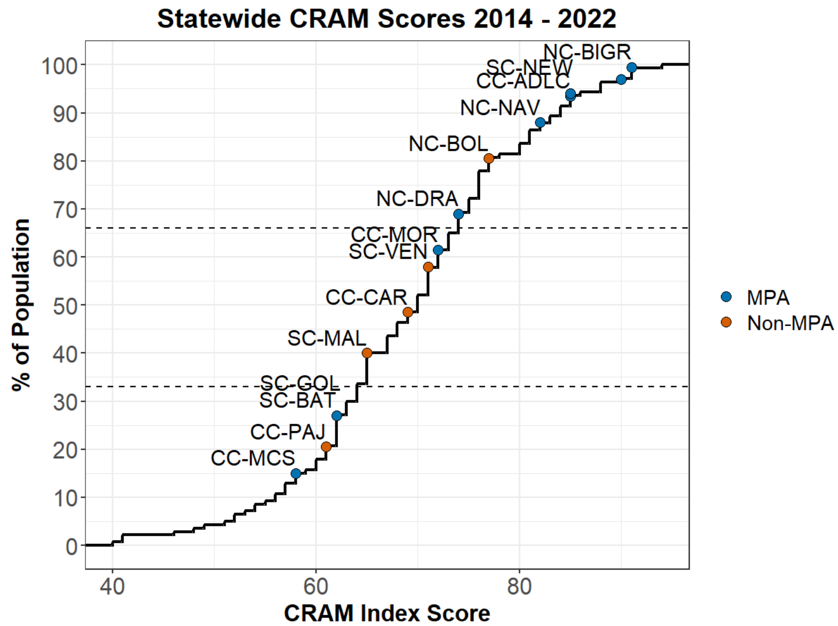


Figure 4. Cumulative frequency distribution plot of statewide estuary CRAM Index score data from 2014-2022 with 15 EMPA estuaries plotted on the line.

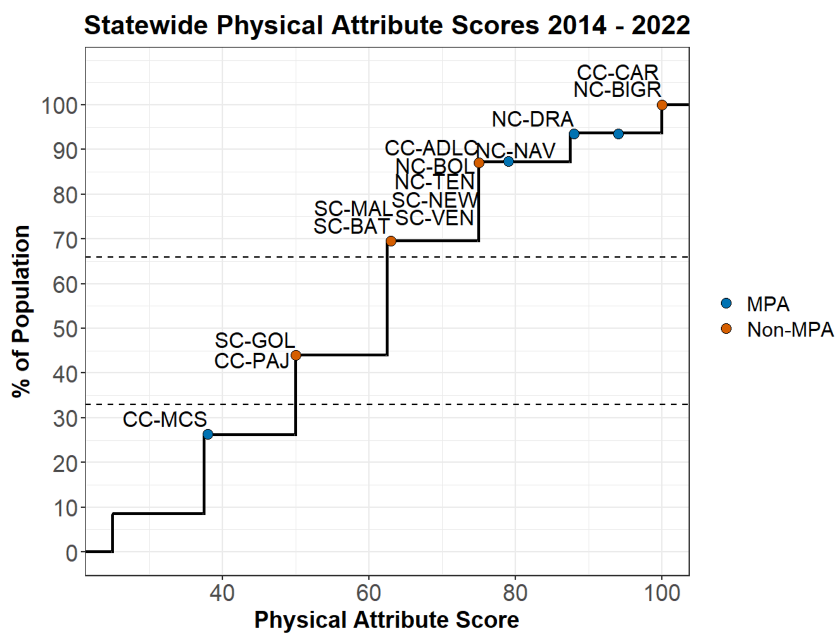


Figure 5. Cumulative frequency distribution plot of statewide estuary CRAM Physical Attribute score data from 2014-2022 with 15 EMPA estuaries plotted on the line

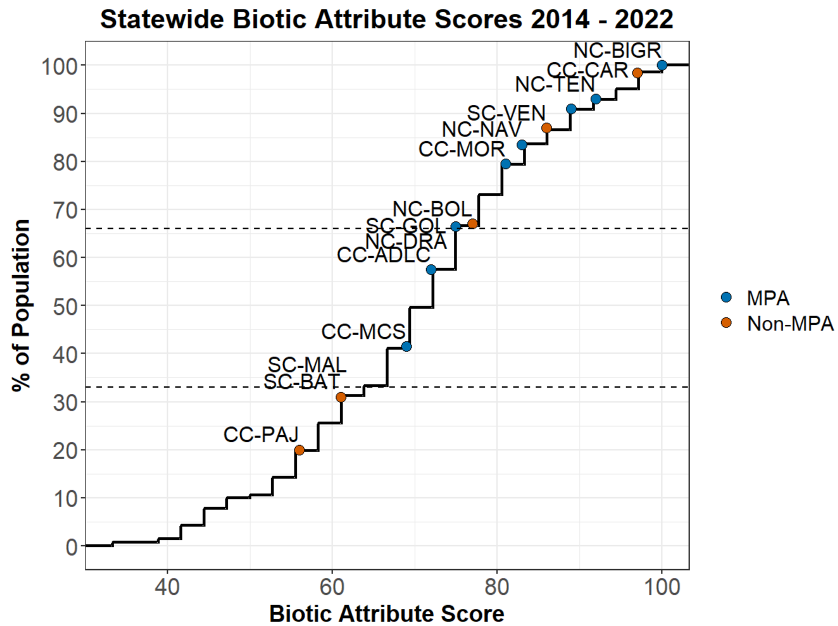


Figure 6. Cumulative frequency distribution plot of statewide estuary CRAM Biotic Attribute score data from 2014-2022 with 15 EMPA estuaries plotted on the line.

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 6.

In general, larger and/or more remote estuaries (Big River, Arroyo de la Cruz, Bolinas) scored higher than estuaries that are managed open and/or in close proximity to stressors (Moro Cojo Slough, Batiquitos, Goleta Slough). Additionally, north coast estuaries overall scored higher than central and south coast estuaries, most likely due to increased stressors, adjacent development (urban and ag), and mouth management.

Table 6. Condition Indicator 1: High California Rapid Assessment Method (CRAM) condition scores

Site	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	3	3	3.00
Drakes Estero	North	3	3	3	3.00
Bolinas Lagoon	North	3	3	3	3.00
Pajaro River	Central	1	1	2	1.33
Moro Cojo Slough	Central	1	2	1	1.33
Carmel River	Central	2	3	3	2.67
Arroyo de la Cruz	Central	3	2	3	2.67
Morro Bay	Central	2	3	3	2.67
Goleta Slough	South	1	3	2	2.00
Ventura River	South	2	3	3	2.67
Malibu Lagoon	South	2	1	3	2.00
Newport Bay	South	3	3	3	3.00
Batiquitos Lagoon	South	1	1	3	1.67

Condition Indicator 2: Marsh Vegetation Distribution & Diversity

To estimate Marsh Vegetation Distribution and Diversity condition, data were evaluated within two categories (subindex) of function that were then combined for a final condition indicator score. For this analysis, plant communities in high performing estuaries have 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 was collected during the fall 2021 sampling event for all estuaries. This was done to standardize the timeframe when data are collected which would decrease variability in data due to the time of year and increase or ability to detect a difference in condition.

Native Plant Species Cover (Subindex 1)

Native Plant Cover Condition was interpreted using data to characterized Relative Invasive Abundance, Invasive Cover, and Invasive Plant Ecological Severity.

Relative Invasive Abundance Metric: Percent cover data from the 2021 EMPA sampling event were used to plot the relative abundance of native, non-native, and invasive plants at each estuary (Figure 7). 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. the condition tertials 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.

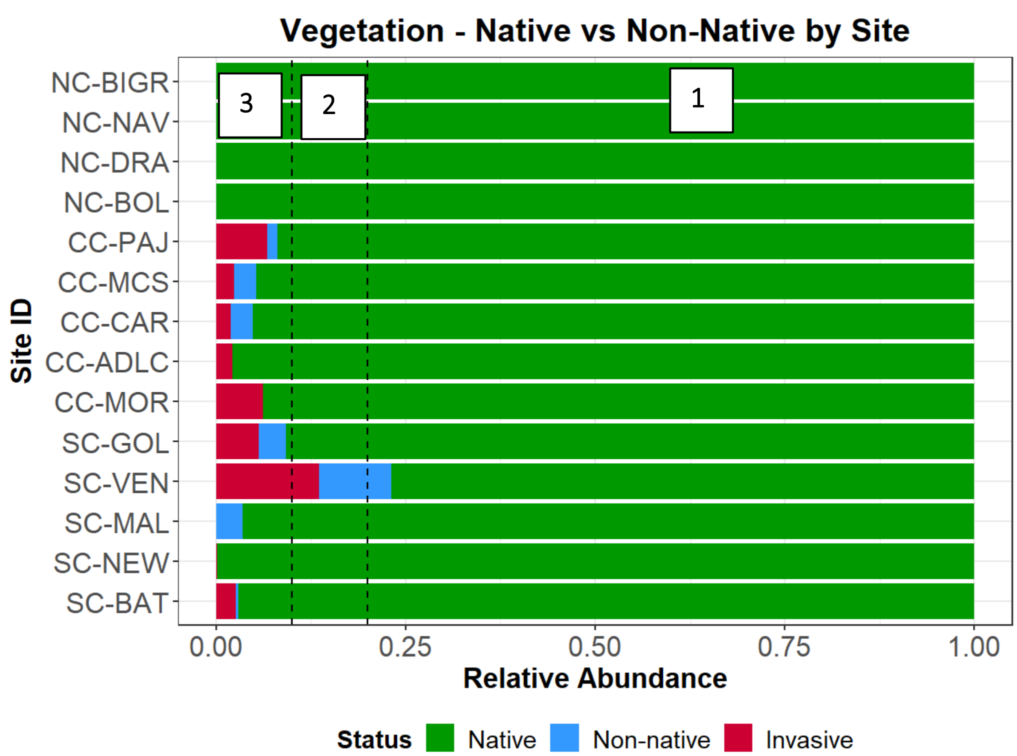


Figure 7. Plot of abundance of native, non-native, and invasive plants at each estuary. Relative Invasive abundance metric cores of 3,2, and 1 were given to estuaries that had combined invasive and non-native cover below 10%, 10-20%, or above 20%, respectively

Invasive Cover Metric: The invasive plant cover metric scores were calculated using the Daubenmire midpoint (Daubenmire 1959) cover class code (Figure 8). The invasive cover value associated with each cover class code was averaged for each site (N=15) and estuary (N=1-3). Average invasive cover value was plotted against the site's CRAM biotic attribute score to estimate the ecological significance of invasive species cover on estuary condition. The maximum invasive cover value measured during this monitoring effort (15%) was used to set the upper percent cover value for this analysis. The range of percent cover values was split into thirds (0-5%, 5-10%, 10-15%) and each estuary was given a score for this metric (lowest third = 3, middle third = 2, highest third = 1).

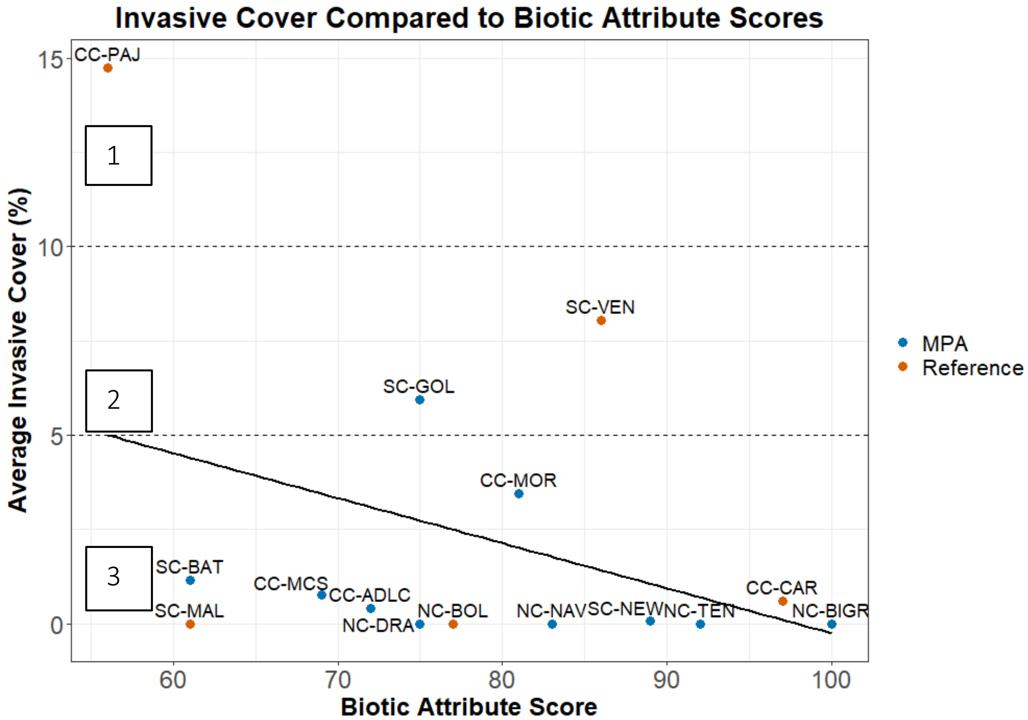


Figure 8. Plot of amount of invasive cover per vegetation plot compared to the CRAM biotic attribute score for each estuary. This analysis deemphasized low Biotic Attribute scores that do not have a correspondingly high associated invasive cover score.

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)[10] rating levels. The ecological severity of each invasive species was determined (undetermined, limited, moderate or high) and each estuary was scored based on the greatest ecological severity of species found there (Table 7). Estuaries with "high severity" rated species received a score of 1, and estuaries with invasive species classified as moderate or limited received a score of 2. Estuaries with no documented invasive species would receive a score of 3 but none of our 15 estuaries met this classification.

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

Table 7. 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
CC-ADLC	*Brassica sp.*	Mustard	Invasive	Undetermined	2	2
	Raphanus sativus	Radish	Invasive	Limited		
CC-CAR	*Rumex crispus*	Curly dock	Invasive	Limited	4	2
	Geranium dissectum	Cutleaf geranium	Invasive	Limited		
	Carduus pycnocephalus	Italian thistle	Invasive	Moderate		
	Polypogon monspeliensis	Rabbit's foot grass	Invasive	Limited		
CC-MCS	*Brassica nigra*	Black mustard	Invasive	Moderate	4	2
	Rumex crispus	Curly dock	Invasive	Limited		
	Geranium dissectum	Cutleaf geranium	Invasive	Limited		
	Brassica sp.	Mustard	Invasive	Undetermined		
CC-MOR	*Atriplex semibaccata*	Creeping saltbush	Invasive	Moderate	3	1
	Cakile maritima	European sea rocket	Invasive	Limited		
	Carpobrotus edulis	Iceplant	Invasive	High		
CC-PAJ	*Ammophila arenaria*	European beachgrass	Invasive	High	2	1
	Carpobrotus edulis	Iceplant	Invasive	High		
SC-BAT	*Brassica sp.*	Mustard	Invasive	Undetermined	2	2
	Bromus diandrus	Ripgut grass	Invasive	Moderate		
SC-GOL	*Cakile maritima*	European sea rocket	Invasive	Limited	4	1
	Carpobrotus edulis	Iceplant	Invasive	High		
	Brassica sp.	Mustard	Invasive	Undetermined		
	Salsola sp.	Russian thistle	Invasive	Undetermined		
SC-NEW	*Limonium ramosissimum*	Algerian sea lavender	Invasive	Limited	1	2
SC-VEN	*Rumex crispus*	Curly dock	Invasive	Limited	4	2
	Cakile maritima	European sea rocket	Invasive	Limited		
	Salsola sp.	Russian thistle	Invasive	Undetermined		
	Tamarix sp.	Tamarisk	Invasive	Undetermined		

Native Plant Cover Subindex score was calculated for each estuary by calculating the average of the Relative Invasive Abundance Metric, Invasive Cover Metric, and Invasive Plant Ecological Severity Metric (Table 8).

Table 8. Native Plant Species Cover (Subindex 1) score for each estuary.

Site	Region	Abundance	% Cover	Invasive Severity	Subindex 1 Score
Ten Mile River	North	NA	3	NA	3.00
Big River	North	3	3	3	3.00
Navarro River	North	3	3	3	3.00
Drakes Estero	North	3	3	3	3.00
Bolinas Lagoon	North	3	3	3	3.00
Pajaro River	Central	3	1	1	1.67
Moro Cojo Slough	Central	3	3	2	2.67
Carmel River	Central	3	3	2	2.67
Arroyo de la Cruz	Central	3	3	2	2.67
Morro Bay	Central	3	3	1	2.33
Goleta Slough	South	3	2	1	2.00
Ventura River	South	1	2	2	1.67
Malibu Lagoon	South	3	3	3	3.00
Newport Bay	South	3	3	2	2.67
Batiquitos Lagoon	South	3	3	2	2.67

Scores for this submetric range from 1.67 to 3.00. Sites in intensive agricultural landscapes (Pajaro, Ventura) scored the lowest while more remote north coast estuaries scored the highest.

Overall Vegetation Cover (Subindex 2)

The Overall Vegetation Cover Subindex was interpreted using data to characterized Species Diversity, Bare Ground (open ground), and Maximum Vegetation Height.

Species Diversity Metric: Species Diversity data collected for every quadrat of every estuary graphed to generate a cumulative frequency distribution of all Shannon-Weiner scores describing the overall range of plant diversity within the 15 estuaries (N = 717) (Figure 9). Each site's averaged diversity score was placed on the curve as a point to generate a diversity ranking. Similar to the CRAM score condition statement, CFD tertials were designated at 33% and 66% of all diversity scores. The estuary average diversity score was characterized as a score of 1, 2, or 3 If the average score fell between 0-33%, 34-66%, or 67-100% respectively.

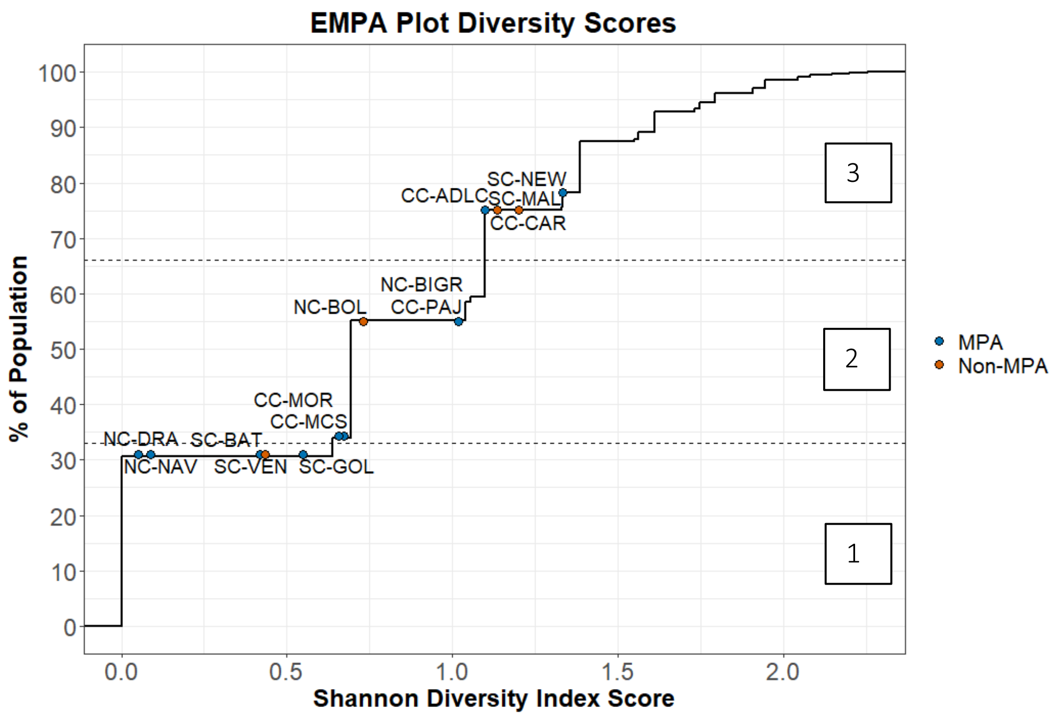


Figure 9. Average Shannon-Weiner plant diversity score for each estuary plotted on a CFD of individual vegetation plot scores for all stations at all sites. Sites are grouped into tertials of the percent population.

Open Cover (bare ground) Metric: Relative Open Cover (bare ground) cover class was estimated using data for all vegetation plots within the mid and high marsh habitat vegetation zones of each estuary (Figure 10). Box plots document the range of scores, along with the mean and median cover. Low marsh was excluded from this analysis because low marsh habitat will naturally have a high percent open cover. The average open cover was split into tertials 0-33%, 34-66%, and 67-100%, with the open cover metric score receiving a 3, 2, and 1, respectively. Each estuary received a score for both the mid and high marsh which were then averaged for the final score for this portion of the condition statement.

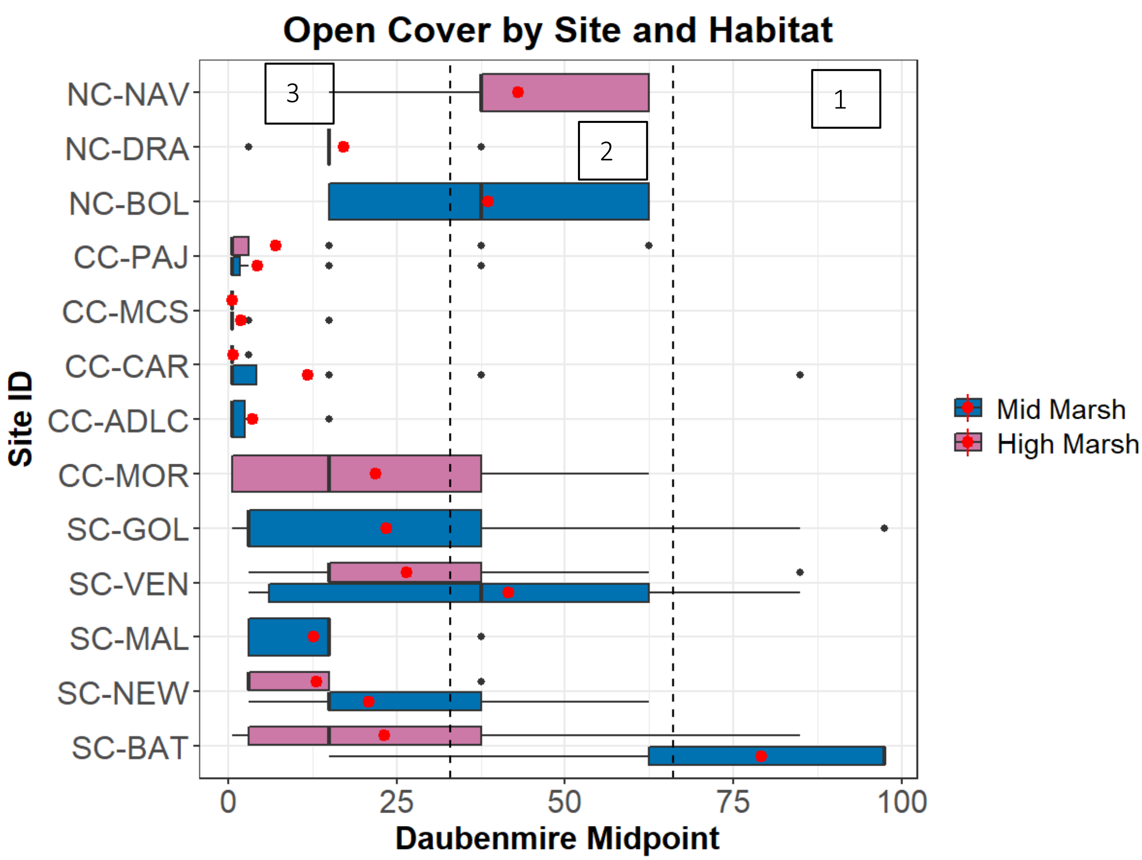


Figure 10. Box plot of the Open Cover (bare ground) cover class for all vegetation plots in the mid and high marsh habitat vegetation zones for each estuary.

Maximum Vegetation Height Metric: The range of maximum plant height found in each plant quadrat was plotted to document the spread of plant heights within each estuary (Figure 11). Estuaries with higher variability in maximum plant heights are likely have higher variability in plant zonation and complexity. The inner quartile range (IQR) of the low, mid and high marsh plain areas of each estuary was averaged and tertial bins were calculated for the range of IQR value. Higher IQRs received a 3, middle IQRs received a 2, and lower IQRs received a 1.

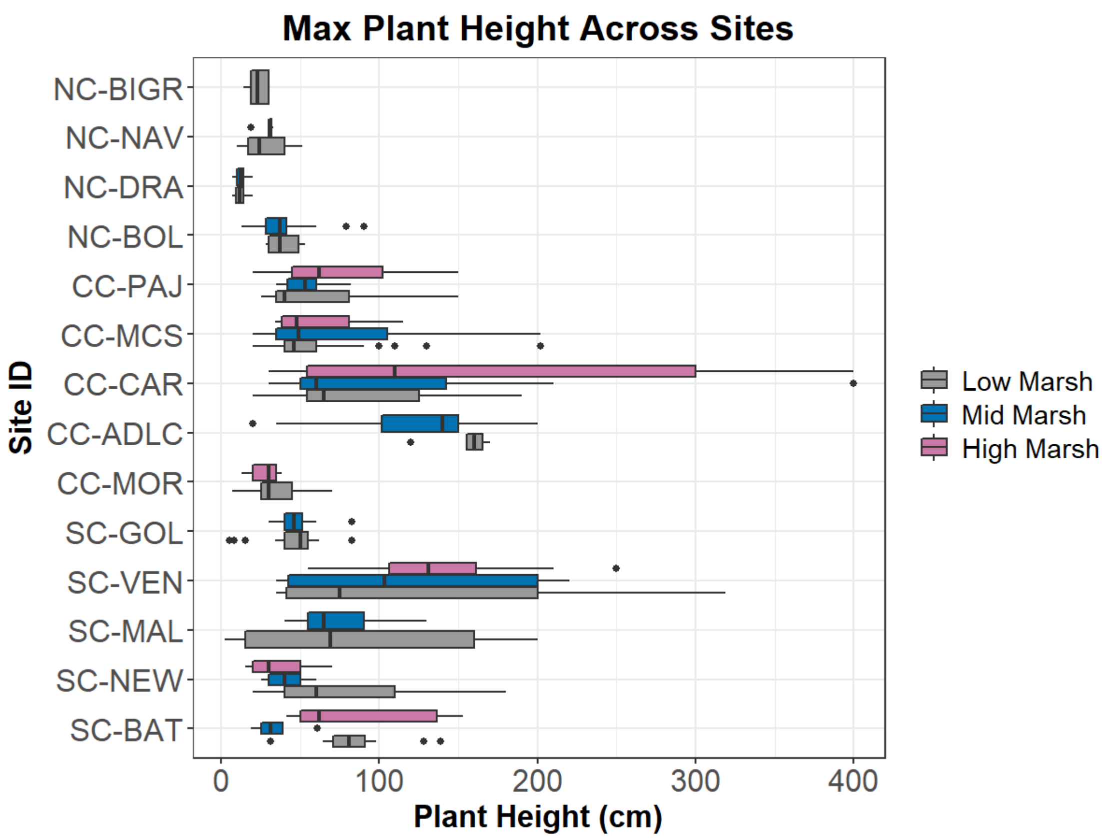


Figure 11. Boxplot of maximum plant height found in each quadrat of the high, medium, and low marsh plain transects at each estuary.

The Vegetation Cover Subindex Score for each estuary is the average of the three metric scores (diversity, open ground, plant height) described above (Table 9).

Table 9. Vegetation Cover (Subindex 2) for each estuary.

Site	Region	Diversity	Open Cover			Plant Height	Subindex 2 Score
			Mid Marsh	High Marsh	Avg. Open		
Ten Mile River	North	NA	NA	NA	NA	NA	NA
Big River	North	2	NA	NA	NA	1	1.50
Navarro River	North	1	NA	2	2	1	1.33
Drakes Estero	North	1	3	NA	3	1	1.67
Bolinas Lagoon	North	2	2	NA	2	1	1.67
Pajaro RiverMoro Cojo Slough	Central	2	3	3	3	1	2.00
Carmel River	Central	3	3	3	3	3	3.00
Arroyo de la Cruz	Central	3	3	NA	3	1	2.33
Morro Bay	Central	2	NA	3	3	1	2.00
Goleta Slough	South	1	3	NA	3	1	1.67
Ventura River	South	1	2	3	2.5	3	2.17
Malibu Lagoon	South	3	3	NA	3	1	2.33
Newport Bay	South	3	3	3	3	1	2.33
Batiquitos Lagoon	South	1	1	3	2	1	1.33

Marsh Vegetation Distribution and Diversity Condition Scores

The final Marsh Vegetation Distribution and Diversity Condition score was the average of the native plant species score (subindex 1) and overall vegetation cover score (subindex 2) (Table 10).

Table 10. Marsh Vegetation Distribution and Diversity Condition score for each estuary.

Site	Marsh Vegetation Distribution & Diversity		
	Native Plant Cover (Subindex 1)	Vegetation Cover (Subindex 2)	Plant Condition Indicator Score
Ten Mile River	3.00	NA	3.00
Big River	3.00	1.50	2.25
Navarro River	3.00	1.33	2.17
Drakes Estero	3.00	1.67	2.33
Bolinas Lagoon	3.00	1.67	2.33
Pajaro River	1.67	2.00	1.83
Moro Cojo Slough	2.67	2.00	2.33
Carmel River	2.67	3.00	2.83
Arroyo de la Cruz	2.67	2.33	2.50
Morro Bay	2.33	2.00	2.17
Goleta Slough	2.00	1.67	1.83
Ventura River	1.67	2.17	1.92
Malibu Lagoon	3.00	2.33	2.67
Newport Bay	2.67	2.33	2.50
Batiquitos Lagoon	2.67	1.33	2.00

Scores ranged from 1.83 to 3.0 for the Marsh Vegetation Distribution and Diversity Condition. Two bar-built estuaries (Carmel and Malibu) scored the highest. These two estuaries have a wide variety of native plant species and good plant coverage. The lowest scoring sites were Pajaro and Goleta slough where the marsh plains are mostly covered with pickleweed with invasive species along the upland edge.

Condition Indicator 3: Marsh Plain Elevation

To estimate Marsh Plain Elevation variability needed to support a diverse plant community, GIS topographic data of the marsh plain were analyzed to quantify the relative amount of marsh plain topographic variability (levels of rugosity).

The footprint boundaries for each estuary were downloaded as shapefiles from the [Pacific Marine & Estuarine Fish Habitat Partnership (PMEP)][11] database and mapped in ArcGIS Pro (ESRI 2022). A digital elevation model (DEM) was downloaded from the NOAA Digital Coast Data Access Viewer, (the same DEM NOAA uses for their sea level rise projections), mapped in ArcGIS Pro, and clipped to the estuary footprint (Figure 12). The Terrain Ruggedness Index tool 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 marsh plains relative to all landforms (mountains, hills, valleys) the EMPA estuaries ruggedness scores all fell in the smallest bin (0-80m) 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 11).

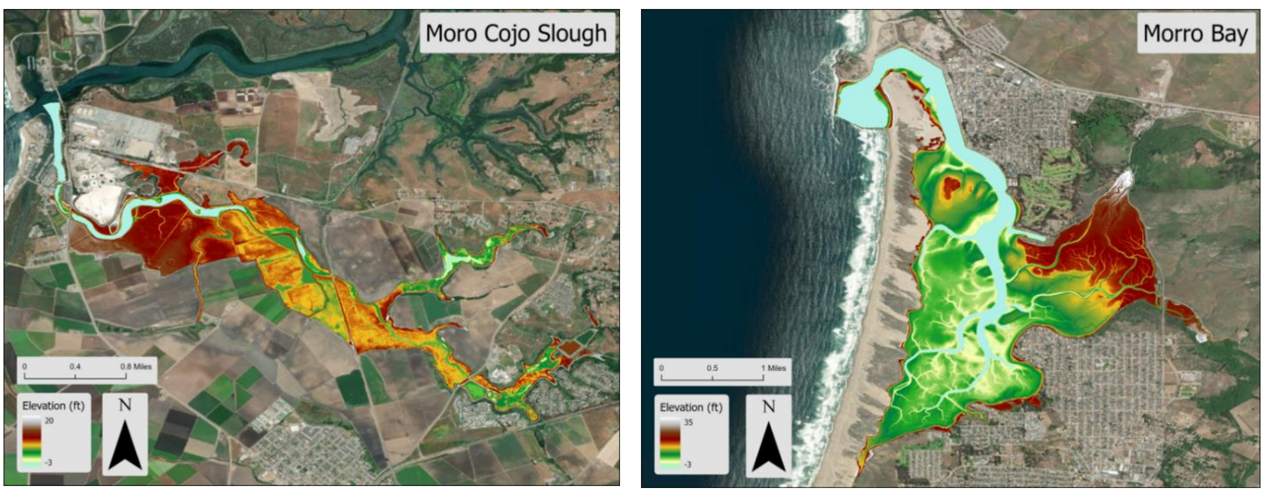


Figure 12. Example DEMs that were analyzed using the Terrain Ruggedness Index tool in the Arc Hydro toolbox in ArcGIS Pro to calculate the ruggedness index of each estuary.

[11] https://www.pacificfishhabitat.org

Table 11. 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.

Site	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 Lagoon	South	17	2
Newport Bay	South	21	3
Batiquitos Lagoon	South	16	2

In general, bar-built estuaries in confined river valleys scored highest for variability in marsh plain elevation, while larger perennial estuaries scored lower.

Condition Indicator 4: Sediment supply to the marsh plain supports vascular plants

This condition statement will use marsh plain accretion rate and sediment grainsize analysis to estimate the sediment quantity and quality available to support marsh plain accretion. Because accretion rates require several years between marker deployment and first sampling, this analysis has not yet been performed.

Ross Clark deploying feldspar in the Moro Cojo

Condition Indicator 5: Relative marsh plain inundation from main channel

Using water depth loggers deployed at a number of estuaries, we created a time series of water elevation data to document marsh plain flooding events. Currently only three locations on the Central Coast have been linked to an elevation datum, needed to complete our analysis (Figure 13). For the three estuaries, we noted the three marsh plain elevation classes thresholds (dotted lines) (low, mid, and high marsh elevation values) to determine how frequently water flooded each marsh plain elevation zone. For the estuaries where we did not have water elevation data tied to a vertical datum, this analysis was not performed. Once water elevation data are georeferenced to a vertical datum for all the estuaries, a relative inundation analysis will be possible.

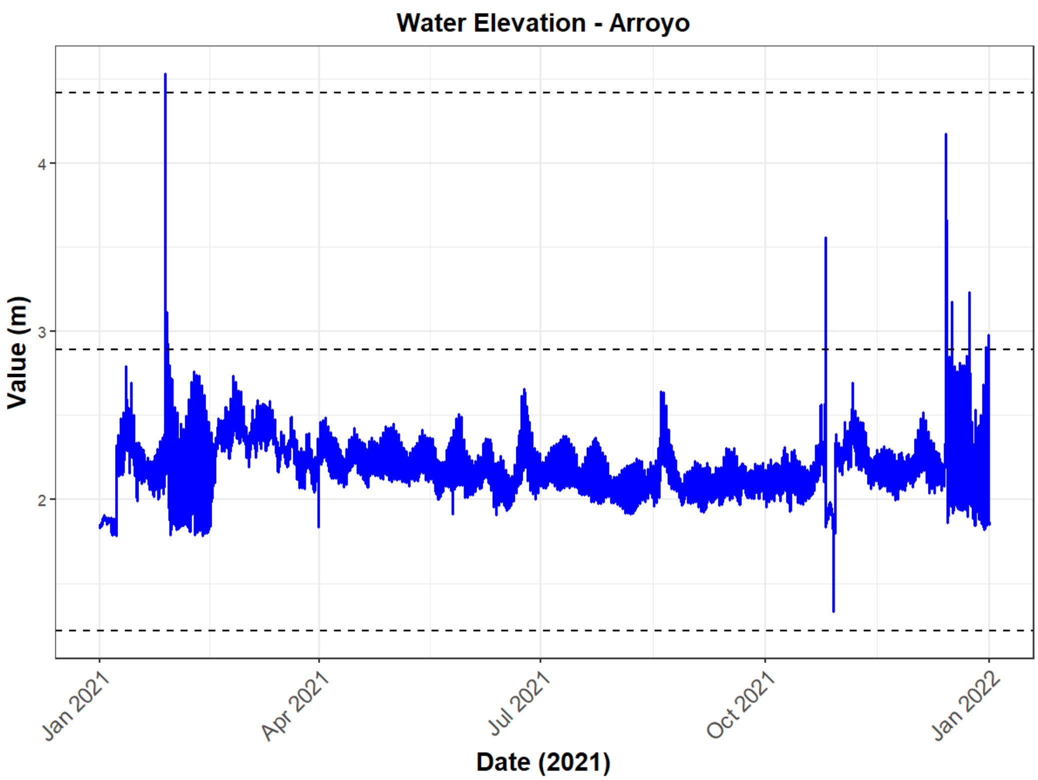


Figure 13. Graph of water elevation in Arroyo de la Cruz estuary from January through December, 2021. Three marsh plain elevation classes thresholds (dotted lines) (low, mid, and high marsh elevation values) are noted.

Condition Indicator 6: Low presence of floating algae in the main channel

The average percent cover of floating algae of the three monitoring stations at each estuary were quantified (Figure 14). For sites with 0-25%, 25-50%, or 50-100% average floating algal cover, the estuary received a score of 3, 2, or 1, respectively. More refined tertial demarcations will be developed as additional data are collected.

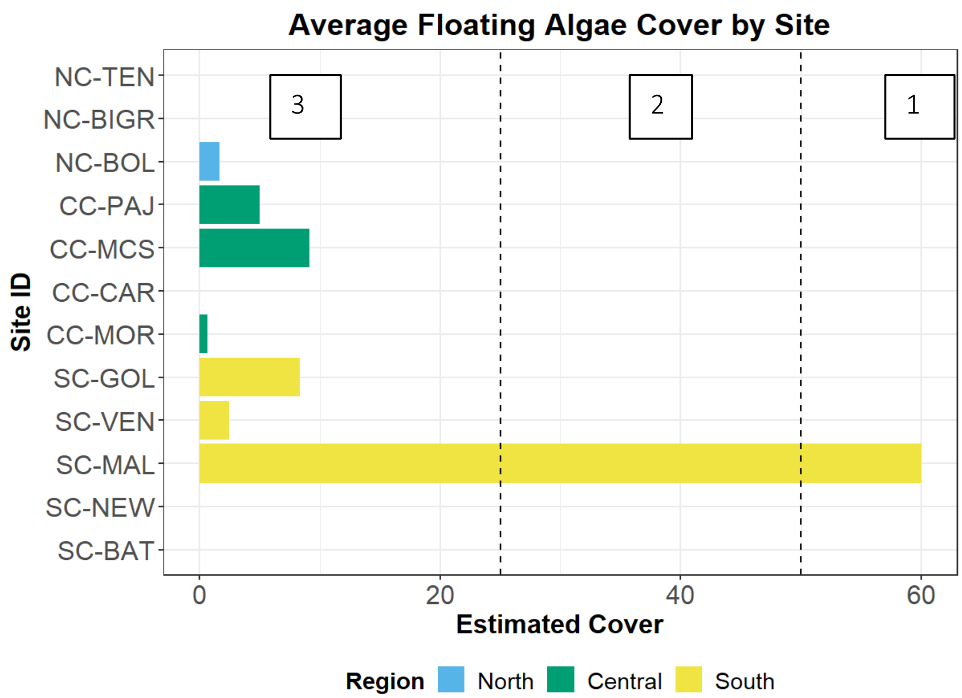


Figure 14. Plot of the average percent cover of floating algae of the three monitoring stations at each estuary.

Summary of Results for Vegetation Support

The Vegetation Support function-based assessment, averaged the scores for condition statements to generate a function analysis score for each estuary ranging from 1 to 3. Final Vegetation Support Scores were color ranked and placed into three tertials, describing the range of scores found within this field investigation: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good). Table 12 compiles the results for each condition statement for each estuary. The estuary with the highest score for support for vascular plant communities was Ten Mile River Estuary, while the lowest scoring estuaries were Pajaro River Lagoon and Moro Cojo Slough (Table 12).

Table 12. Vascular plant support function scoring results for each condition statement for all 15 EMPA sites.

Site Name	General habitat condition	Marsh vegetation distribution & diversity		Marsh plain elevation		Sediment accretion rates	SAV/ macroalgae distribution	Final Score
	High CRAM Index, physical, and biotic attribute scores	*Native plant cover*	*Vegetation Cover*	*Varied marsh plain topography*	*Appropriate amount of inundation*	*Sediment supply*	*Low presence of floating algae*	
Ten Mile River	3.00	3.00	NA	3.00	NA	NA	3.00	3.00
Big River	3.00	3.00	1.50	3.00	NA	NA	3.00	2.70
Navarro River	3.00	3.00	1.33	3.00	NA	NA	NA	2.58
Drakes Estero	3.00	3.00	1.67	3.00	NA	NA	NA	2.67
Bolinas Lagoon	3.00	3.00	1.67	2.00	NA	NA	3.00	2.53
Pajaro River	1.33	1.67	2.00	2.00	NA	NA	3.00	2.00
Moro Cojo Slough	1.33	2.67	2.00	1.00	NA	NA	3.00	2.00
Carmel River	2.67	2.67	3.00	3.00	NA	NA	3.00	2.87
Arroyo de la Cruz	2.67	2.67	2.33	2.00	NA	NA	NA	2.42
Morro Bay	2.67	2.33	2.00	2.00	NA	NA	3.00	2.40
Goleta Slough	2.00	2.00	1.67	2.00	NA	NA	3.00	2.13
Ventura River	2.67	1.67	2.17	2.00	NA	NA	3.00	2.30
Malibu Lagoon	2.00	3.00	2.33	2.00	NA	NA	2.00	2.27
Newport Bay	3.00	2.67	2.33	3.00	NA	NA	3.00	2.80
Batiquitos Lagoon	1.67	2.67	1.33	2.00	NA	NA	3.00	2.13

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.*

This function has been given six condition statements to help analyze the ability of an estuary to adapt with sea level rise. Each condition statement was analyzed separately and the resulting scores were then averaged to give each estuary an overall score for the function. Because good condition vegetation communities are critical to sea level rise resiliency, some analysis of condition statements for Sea Level Rise Resiliency are similar or identical to those of the Vascular Plant Functional Analysis. For those identical condition statements, the data analysis is referred to in the section above and only the final scores are presented.

Six condition statements have been drafted to help direct data analysis to quantify the level of Sea Level Rise Amelioration and Resiliency provided by each estuary. Sea Level Rise Resiliency in high performing estuary have:

- Dense vegetation cover in each marsh elevation habitat (low and high marsh)
- Varied marsh plain macro-topography
- Sedimentation rates support accretion and foreshore resiliency
- High California Rapid Assessment Method (CRAM) scores (Index)
- Sufficient upland migration area to respond to SLR
- Mouth conditions allowing for proper sediment transport

Each condition statement was analyzed separately and the resulting scores were averaged to give each estuary a final score for this function.

Our SLR Amelioration and Resilience equation states that high performing systems will have higher average scores for: **General Habitat Condition Score + Vegetation Cover + Marsh Plain Elevation Score + Mouth Dynamics Score / divided by N (the number of condition statements evaluated).** As additional data are collected and analyzed, the water quality and sediment accretion rate indicators will be added to this analysis.

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

Condition Indicator 1: General Habitat Condition Score using California Rapid Assessment Method Index scores

For this Condition analysis the CRAM Index scores were plotted as a cumulative frequency distribution plot and then the 15 monitoring sites for this project were plotted along the curve as points based on their most recent average CRAM score (Figure 4). Results are shown in Table 13.

Table 13. Condition Indicator 1: California Rapid Assessment Method (CRAM) condition indicator scores

Site	Region	CRAM Condition Indicator Score
Ten Mile River	North	3
Big River	North	3
Navarro River	North	3
Drakes Estero	North	3
Bolinas Lagoon	North	3
Pajaro River	Central	1
Moro Cojo Slough	Central	1
Carmel River	Central	2
Arroyo de la Cruz	Central	3
Morro Bay	Central	2
Goleta Slough	South	1
Ventura River	South	2
Malibu Lagoon	South	2
Newport Bay	South	3
Batiquitos Lagoon	South	1

Results showed that larger and/or more remote estuaries (Big River, Arroyo de la Cruz, Bolinas) scored higher than estuaries that are managed open and/or in close proximity to stressors (Moro Cojo Slough, Batiquitos, Goleta Slough). Also, north coast estuaries scored higher than central and south coast estuaries, most likely due to increased stressors, adjacent development (urban and ag), and mouth management.

Condition Indicator 2: Vegetation Cover

As completed for Vascular Plan Functional Assessment, Vegetation Cover Condition was interpreted using data to characterized Species Diversity, Bare Ground (open ground) and Maximum Vegetation Height (Table 14).

Table 14. *Vegetation Cover Condition for each estuary.*

Site	Region	Diversity	Open Cover			Plant Height	Condition Score
			Mid	High	Avg Open		
Ten Mile River	North	NA	NA	NA	NA	NA	NA
Big River	North	2	NA	NA	NA	1	1.50
Navarro River	North	1	NA	2	2	1	1.33
Drakes Estero	North	1	3	NA	3	1	1.67
Bolinas Lagoon	North	2	2	NA	2	1	1.67
Pajaro River	Central	2	3	3	3	1	2.00
Moro Cojo Slough	Central	2	3	3	3	1	2.00
Carmel River	Central	3	3	3	3	3	3.00
Arroyo de la Cruz	Central	3	3	NA	3	1	2.33
Morro Bay	Central	2	NA	3	3	1	2.00
Goleta Slough	South	1	3	NA	3	1	1.67
Ventura River	South	1	2	3	2.5	3	2.17
Malibu Lagoon	South	3	3	NA	3	1	2.33
Newport Bay	South	3	3	3	3	1	2.33
Batiquitos Lagoon	South	1	1	3	2	1	1.33

Scores ranged from 1.33 to 3.0 for the Marsh Vegetation Cover Condition. Carmel River Lagoon scored the highest having high scores for all indicators. The lowest scoring sites were in estuaries with short and less diverse plant communities like Drakes Estero and Batiquitos.

Condition Indicator 3: Marsh Plain Resiliency to Sea Level Rise

The Marsh Plain Resiliency condition was interpreted using data to characterized Marsh Plain Macro-topography, Sediment Accretion Rates and Upland Migration Capacity.

Varied Marsh Plain Macro-Topography Metric

The NOAA DEMs used in the vegetation function analysis were reclassified into five elevation classes (associated with different marsh plain elevations), using the natural breaks method (Figure 15). This uses an algorithm to group values in classes that are separated by distinct break points and keeps values that are similar together (ESRI 2022). The five classes being represented were water, low marsh, mid marsh, high marsh, and upland. The number of pixels were calculated in each class to determine their relative abundance in the estuary. For analysis results, the upland habitat was excluded since it could potentially extend beyond the estuary footprint and would not be fully captured in the analysis. The relative abundance of each habitat in each estuary was plotted (Figure 16). 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. Results are shown in Table 15.

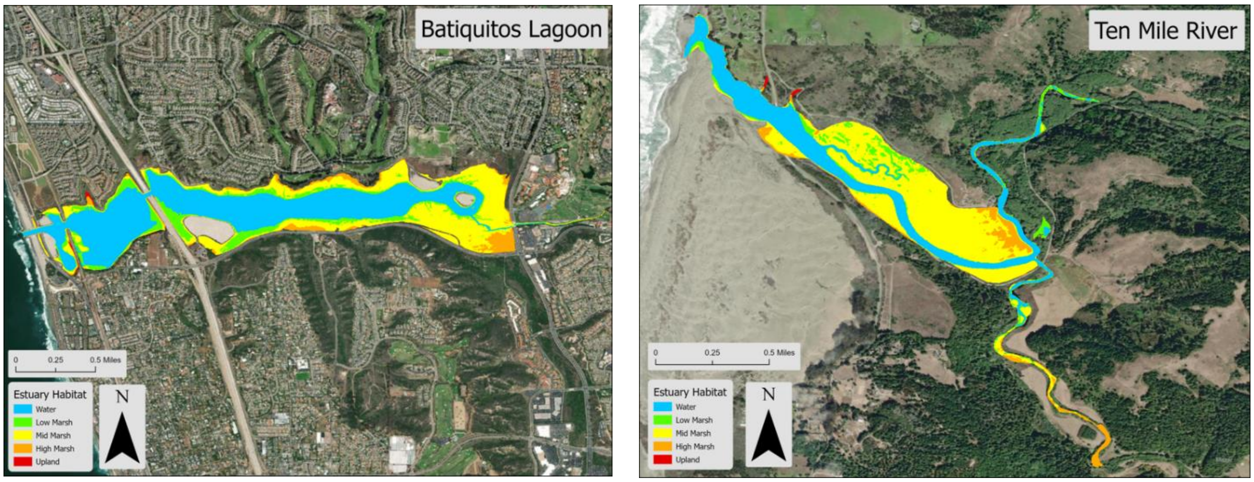


Figure 15. *Example DEMs that were reclassified into five classes using the natural breaks method (water, low marsh, mid marsh, high marsh, and upland.*

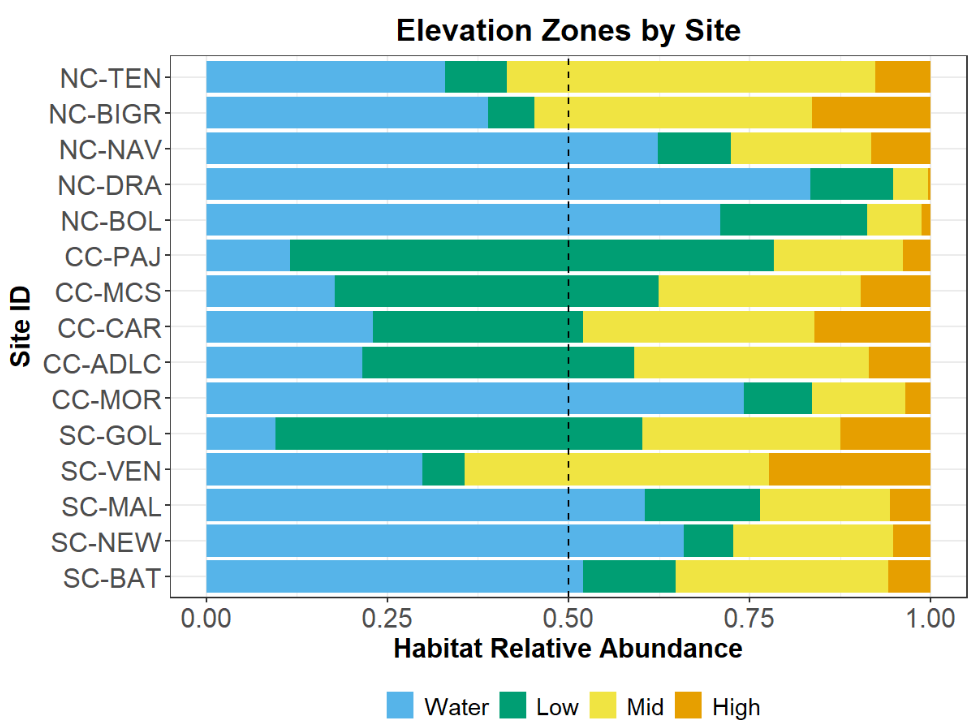


Figure 16. *The relative abundance of each habitat in each estuary.*

Sedimentation Rates Support Accretion Metric

This condition statement will utilize marsh plain accretion rates as a surrogate for sediment supply to the marsh plain. This analysis will be completed when initial accretion rates are quantified (year 2 or 3).

Sufficient Upland Migration Area to Respond to SLR Metric

Following the methods described by Robinson (2017), we used the head of tide level as the upper limit for determining the transition zone in each estuary. In ArcGIS Pro, we created a 50 m buffer using the Buffer tool around each estuary footprint, ending at the transition zone, and overlayed the 2019 National Land Cover Dataset (MRLC 2022). We clipped the land cover layer to the 50 m buffer and reclassified the land cover classes into three new classes: open, developed, and agricultural land cover (Figure 17). We calculated the percentage of each cover class in the buffer and if an estuary had 0-33%, 34-66%, or 67-100% open cover in its buffer it received a 1, 2, or 3, respectively (Table 15).

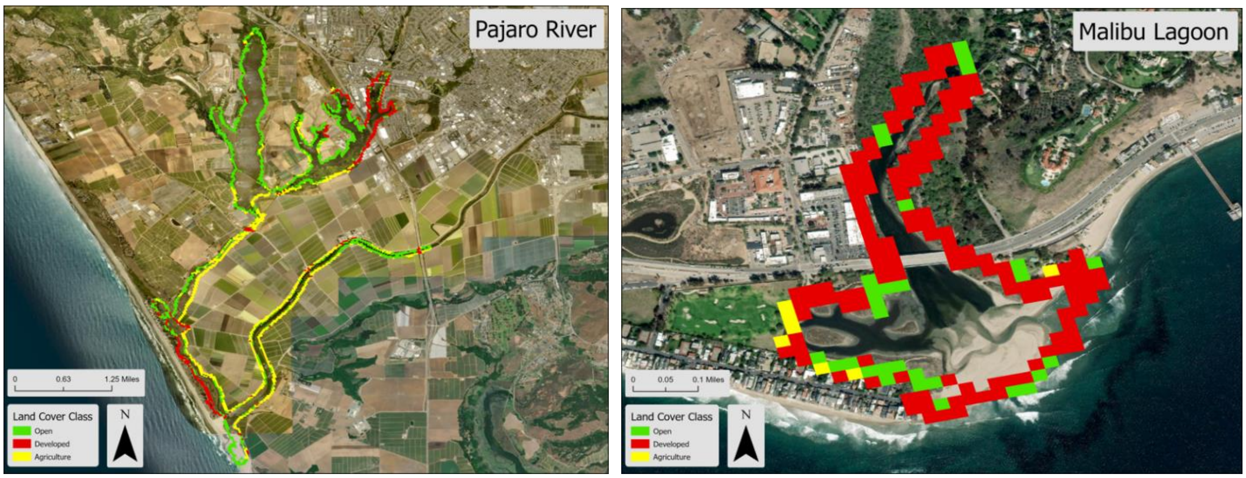


Figure 17. Example outputs for determining the transition zone and associated land use in each estuary. The NLCD land cover layer was clipped to the 50 m buffer and reclassified into three new groups: open, developed, and agricultural land cover.

Table 15. Marsh plain resiliency to sea level rise condition score for each estuary

Site	Landcover Type			Score
	Open	*Developed*	*Ag*	
Ten Mile River	59	35	5	2
Big River	76	24	0	3
Navarro River	58	42	0	2
Drakes Estero	96	3	1	3
Bolinas Lagoon	35	65	0	2
Pajaro River	50	17	34	2
Moro Cojo Slough	53	24	24	2
Carmel River	42	58	0	2
Arroyo de la Cruz	95	5	0	3
Morro Bay	58	42	0	2
Goleta Slough	31	66	3	1
Ventura River	50	49	1	2
Malibu Lagoon	18	78	4	1
Newport Bay	18	82	0	1
Batiquitos Lagoon	12	88	0	1

Condition Indicator 4: Mouth condition

The Marine Connectivity metric score from the California Rapid Assessment Method (CRAM) (CWMW 2013) was utilized for each estuary to establish a mouth condition score (Figure 18). Estuaries that scored an A rating received a 3, sites that scored a B received a 2, and sites that scored a C or D received a 1. Results are shown in Table 16 .

Rating	Alternative States
A	There are no signs of altered sediment supply or marine connectivity on the beach up-coast and down-coast 500 m.
B	Less than 500m up-coast and down-coast has evidence of altered sediment supply AND/OR marine connectivity
C	500-900m of the transect up-coast and down-coast has evidence of altered sediment supply OR marine connectivity
D	More than 500 meters of the transect up-coast and down-coast has evidence of altered sediment supply AND marine connectivity OR more than 900 meters up-coast and down-coast has evidence of altered sediment supply OR marine connectivity

Figure 18. Marine Connectivity metric scoring descriptions from the California Rapid Assessment Method (CRAM)

Table 16. Marine Connectivity metric score for each estuary from the California Rapid Assessment Method (CRAM)

Site	Mouth Condition Score
Ten Mile River	3
Big River	3
Navarro River	3
Drakes Estero	3
Bolinas Lagoon	3
Pajaro River	2
Moro Cojo Slough	1
Carmel River	2
Arroyo de la Cruz	3
Morro Bay	1
Goleta Slough	2
Ventura River	2
Malibu Lagoon	2
Newport Bay	1
Batiquitos Lagoon	1

Higher scoring sites included north and central coast estuaries that lack mouth management and restrictions to the lateral movement of sediment along the coastline. Lower scoring sites included central and south coast estuaries with mouth management and feature at the mouth or along the beach which restrict sediment transport.

Summary of Results for SLR Amelioration

The function-based assessment linked to condition statements resulted in a score for each estuary ranging from 1 to 3. A final score was then calculated as the average of the condition statement scores. Final Scores were color coded base on tertials of possible scores: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good). Table 17 shows the results for each condition statement for each estuary. The estuary with the highest score for support for SLR Amelioration was Ten Mile River Estuary, while the lowest scoring estuary was Batiquitos Lagoon.

Table 17. SLR Amelioration and Resiliency function scoring results for each condition statement for all 15 EMPA sites.

Site	General Habitat Condition	Marsh vegetation distribution & diversity	Marsh Plain Elevation			Mouth Dynamics	Final Score
	High CRAM Index score	*Vegetation Cover*	*Varied marsh topography with multiple elevation zones*	*Sufficient upland migration area to respond to SLR*	*Sedimentation supports accretion and foreshore resiliency*	*Mouth condition*	
Ten Mile River	3	1	3	2	NA	3	2.75
Big River	3	NA	3	3	NA	3	2.7
Navarro River	3	1.50	1	2	NA	3	2.07
Drakes Estero	3	1.33	1	3	NA	3	2.33
Bolinas Lagoon	3	1.67	1	2	NA	3	2.13
Pajaro River	1	1.67	2	2	NA	2	1.8
Moro Cojo Slough	1	2.00	2	2	NA	1	1.6
Carmel River	2	2.00	2	2	NA	2	2.2
Arroyo de la Cruz	3	3.00	2	3	NA	3	2.67
Morro Bay	2	2.33	1	2	NA	1	1.6
Goleta Slough	1	2.00	2	1	NA	2	1.53
Ventura River	2	1.67	3	2	NA	2	2.23
Malibu Lagoon	2	2.17	1	1	NA	2	1.67
Newport Bay	3	2.33	1	1	NA	1	1.67
Batiquitos Lagoon	1	2.33	1	1	NA	1	1.07

Functional Analysis 3: Nekton Habitat and Nursery Support

High functioning **Nekton Habitat** has been defined as: *Supporting a variety of resident and transitory fishes and crustacean by providing structure that serves as shelter from predation and benthic or water column food sources.*

High functioning **Nursery Support** has been defined as: *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.*

Data limitations currently restrict our ability to quantify many of the variables listed above. For this initial analysis, we have focused on species diversity and abundance and water chemistry data collected during the first year of sampling. As additional data are compiled and analyzed, additional condition statements will be tested and compared among estuaries.

Condition Indicator 1: Better performing estuaries have higher native fish abundance and greater native species richness.

Fish species abundance (Figure 19) and species composition (Figure 20) varied by MPA designation and estuary type. Over 30 different fish species were observed in MPAs and non-MPA sites. The three most common species were the three-spine stickleback (in northern and central sites, not present in the south), topsmelt silverside (in all regions), and Pacific staghorn sculpin (in all regions). Many different species of goby (Figure 20) were also documented.

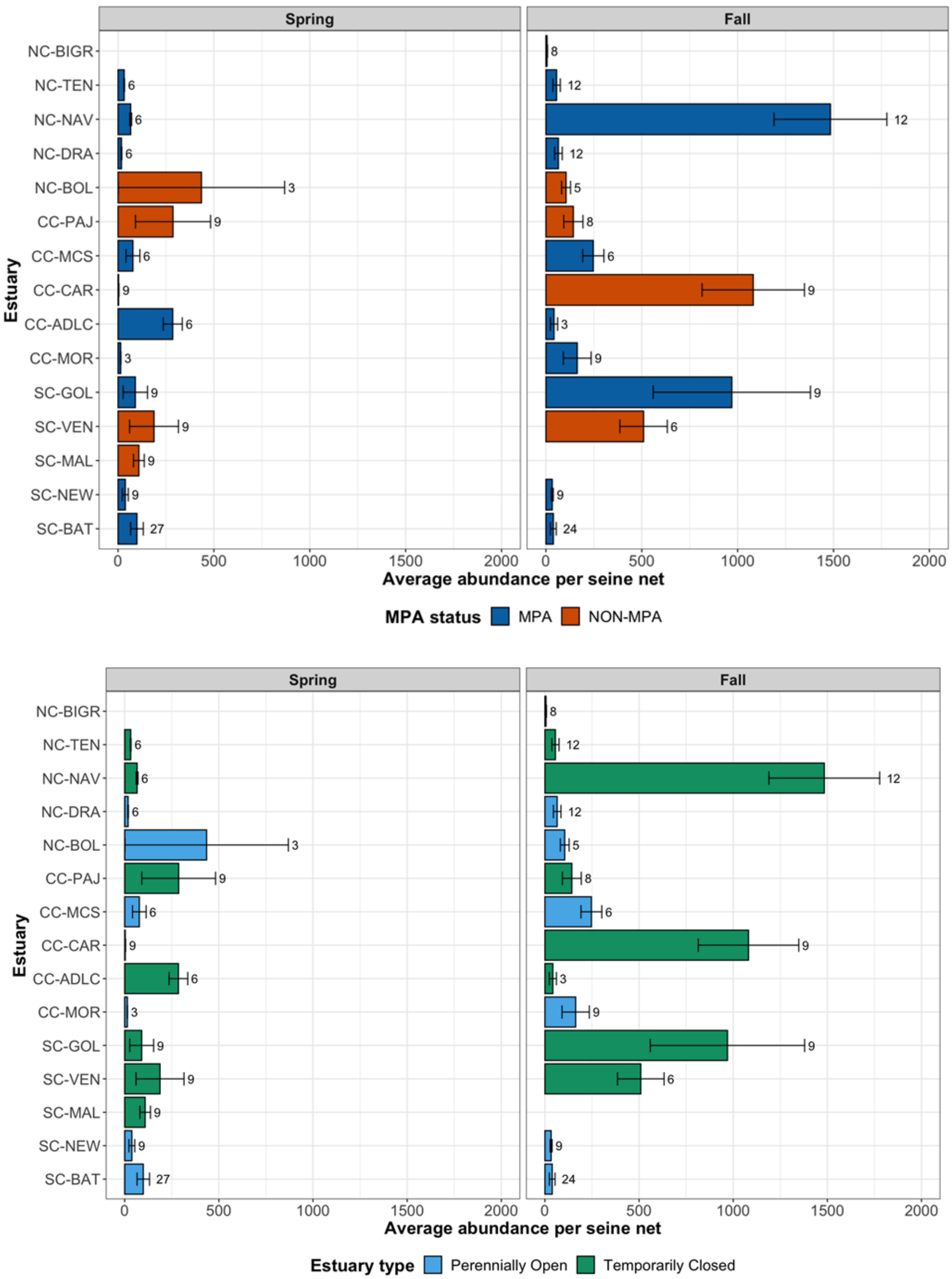


Figure 19. (A) MPA designation (MPA [blue] and Non-MPA [orange]) and (B) estuary type (perennially open [blue] and temporarily closed [green]). Number of seines conducted total for that estuary are shown as the number next to standard error bars. NC-DRA: Drakes Estero, NC-BOL: Bolinas Lagoon, CC-MCS: Moro Cojo Slough, SC-NEW: Newport Bay, SC-BAT: Batiquitos Lagoon, NC-BIGR: Big River, NC-TEN: Ten Mile River, NC-NAV: Navarro River, CC-PAJ: Pajaro River, CC-CAR: Carmel River, CC-ADLC: Arroyo de la Cruz, SC-GOL: Goleta Slough, SC-VEN: Ventura River, SC-MAL: Malibu Lagoon.

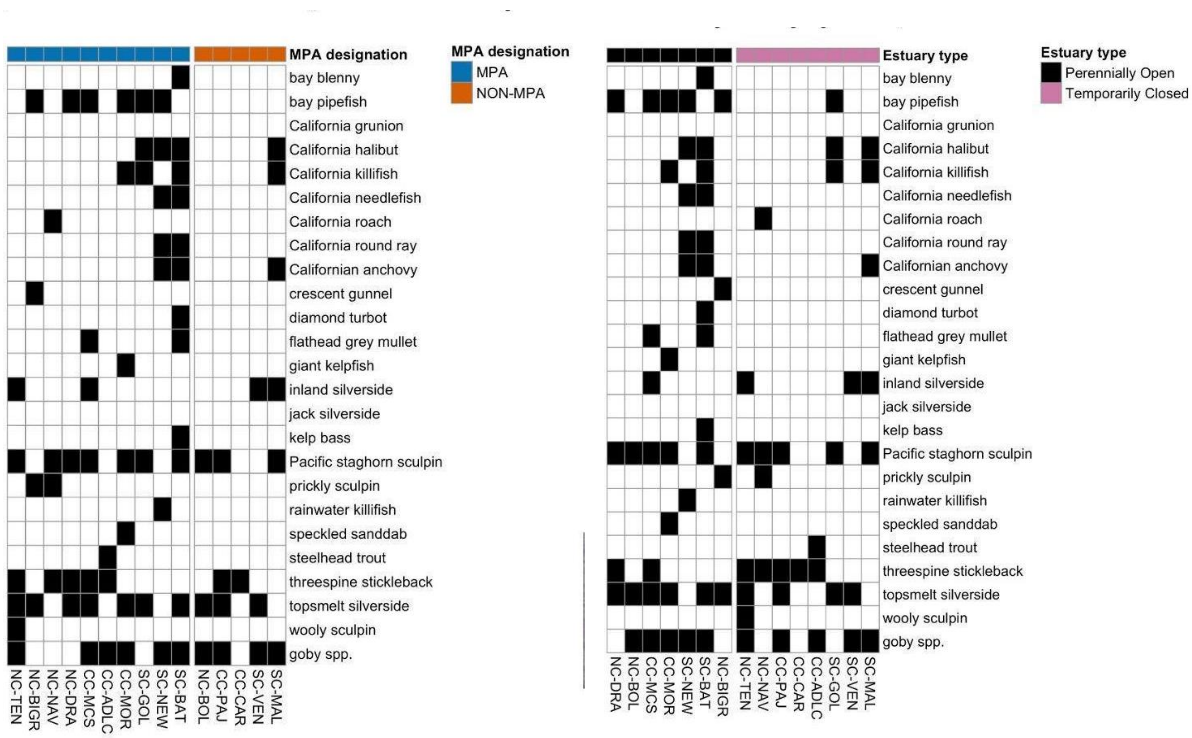


Figure 20. Heatmaps showing species presence/absence by species in each sampled estuary for spring and fall 2021. Black squares indicate the presence of the species in the estuary (arranged along the x axis from north to south, left to right) while open (white) squares indicate absence of the species in sampling. A shows the sampled estuaries grouped by MPA designation (MPA [blue] and Non-MPA [orange]) while B shows the sampled estuaries grouped by estuary type (perennially open [Black] and temporarily closed [pink]). NC-DRA: Drakes Estero, NC-BOL: Bolinas Lagoon, CC-MCS: Moro Cojo Slough, SC-NEW: Newport Bay, SC-BAT: Batiquitos Lagoon, NC-BIGR: Big River, NC-TEN: Ten Mile River, NC-NAV: Navarro River, CC-PAJ: Pajaro River, CC-CAR: Carmel River, CC-ADLC: Arroyo de la Cruz, SC-GOL: Goleta Slough, SC-VEN: Ventura River, SC-MAL: Malibu Lagoon.

Condition Indicator 2: Better performing estuaries have water quality within a range of healthy conditions (typically not hypoxic or anoxic, have average daily water temperature below 28 °C (varies with latitude)), and supports SAV beds[12].

Physical metrics, such as temperature and salinity, vary within and across regions, types of estuaries, and seasons (Figure 21). We hypothesized that higher fish abundance and species richness are typically associated with systems that are generally not hypoxic or anoxic and with average daily water temperature generally below 28 °C (although this varies with latitude). For the purposes of this study, we have defined hypoxic waters to have dissolved oxygen concentrations of less than 2-3 mg/L (typical EPA standards). The causes of hypoxia likely varied by estuary and were not specifically measured in this sampling metric but include excess nutrients, primarily nitrogen and phosphorus. Throughout the year most estuaries had some days of hypoxic conditions, but these were more frequent in temporarily closing

[12] Note: In this current sampling time period, we have not mapped SAV beds in all estuaries so those data are not represented in this section of the data report.

estuaries (Figure 21). Few estuaries exceed the hypothesized temperature range although GLM data (discussed below) indicate that temperature (both range and maximum) correlates with fish abundance with higher temperatures having fewer fish. These data are heavily influenced by several large fish catches at lower temperature sites.

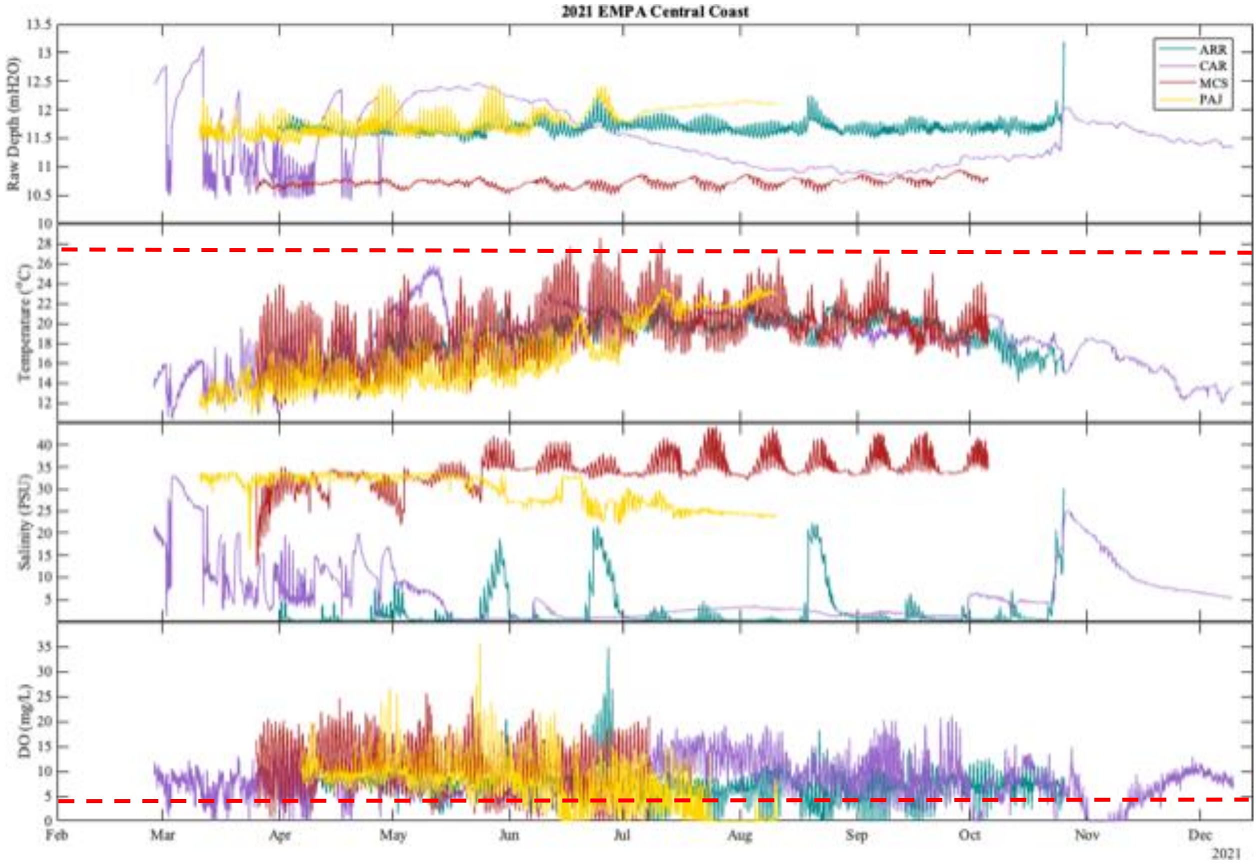


Figure 21. Time series of water quality metrics for Central Coast estuary sites. Red dashed lines on Temp and DO represent biological tolerances associated with fish communities.

Factors Driving Fish Populations Within EMPAs

Rather than ranking highly variable fish populations and fluctuating water chemistry (from a single year of data), we investigated relationships between water chemistry and fish species among all sites to determine what factors are found to drive fish population dynamics. These relationships will aid our selection of sampling techniques in future years and help understand how fish populations relate to natural and anthropogenically driven variability within and among estuaries.

Multivariate analysis (GLMs). To identify the variables (shown in Figure 22 and in full model outputs in Table 18) that are potentially affecting the fish abundance, data were compiled and analyzed using random forest models with the randomForest function in the 'randomForest' R package (Liaw and Weiner 2002) for R statistical software. These random forest models were built through a multi-step process. A bootstrap sample population was first selected from the data and a classification tree was built. Each node within the tree was constructed by selecting a random subset of the environmental variables and determining which variable combination yields the most effective split for maximizing purity in the two resultant groups. Nodes are continuously added to the tree until there is one plot per leaf. This process is repeated until the desired number of trees has been built (1000 in this analysis). To obtain a prediction from the forest of classification trees, each tree is allowed one‗vote' for the model prediction. Whichever model receives the most‗votes' from all of the trees in the random forest becomes the model prediction. From the variables selected in the random forest modeling, we built a generalized linear model (GLM) for all of the studied sites in both seasons (spring 2021, fall 2021). GLM full models, including all covariates, were dredged using the MuMin package (Barton 2022) in R to generate all possible models, ranked from lowest to highest AIC score, and all best models with an AIC score within 2 delta are shown in Table 18. Each covariate was assessed for its contribution to the variation in abundance from seines. Future data reports will contain similar GLMs for MaxN from baited remote underwater videos (BRUVs) and species richness from seines.

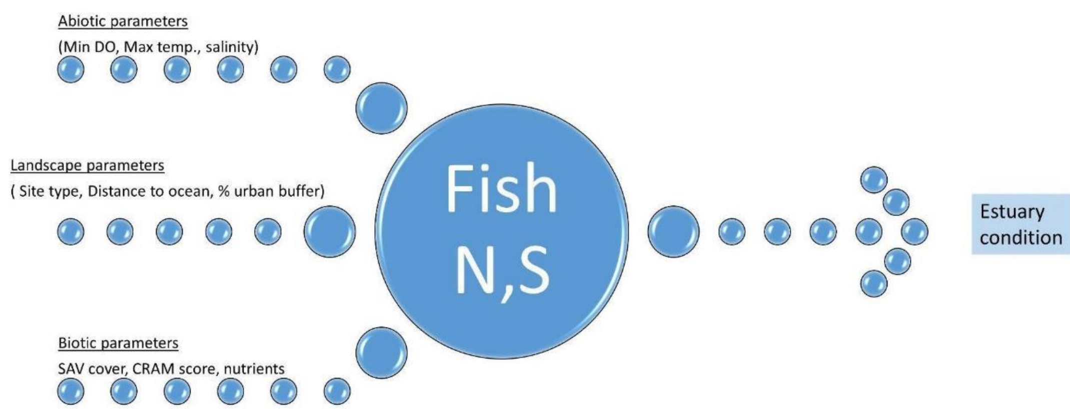


Figure 22. Schematic showing the full model options used to predict abundance (N) and species richness (S, for future data reports) that are indicative of estuary condition (as specified in the condition statement).

Table 18. GLM results for all sites. Full model is included as well as best models that resolved with an AIC within 2 delta of the best model.

Models	Inputs												df	AIC	Delta
Full Model	Ammonia	Avg conductivity	Min DO	Estuary Type	MPA Status	Nitrite	Nitrogen	Region	Season	Max T	T range	MPA Status x Region	16	545.92	3.998
Best Model 1	Ammonia	Avg conductivity		Estuary Type	MPA Status	Nitrite		Region	Season	Max T	T range	MPA Status x Region	14	541.92	0
Best Model 2	Ammonia	Avg conductivity		Estuary Type	MPA Status	Nitrite	Nitrogen	Region	Season	Max T	T range	MPA Status x Region	15	543.66	1.741

There were 2 models that fit best for seine abundance. The model that best fits the data includes the variables ammonia + average conductivity + estuary type (temporarily closed/permanently open) + MPA status (MPA/non-MPA) + Region (south/central/north) + season (Spring21/Fall21) + maximum temperature + temperature range + interaction of MPA status and region (AIC: 541.92; Delta: 0). The next best fit models in order of declining strength included the same factors plus total nitrogen (AIC:543.66; Delta: 1.741). All models explained some percentage of variation in the data; to illustrate patterns of abiotic parameters with abundance as grouped by key categorical variables, we graphed individual parameters (Figure 23).

While these results are provided to illustrate the necessity of multivariate analysis for predicting fish abundance, these results should not be interpreted as a model for estuarine fish abundance due to lack replicate years and limited data for key parameters, especially SAV cover, in the current dataset. These data are for only two seasons of sampling during one year. This modeling exercise is included within the report to illustrate the type of analysis that can be conducted once more complete datasets are generated.

Not surprisingly, many of the key factors driving fish population diversity and abundance are associated with the estuarine typology (bay or lagoonal), associated salinity gradient, latitude, and season factors. Several anthropogenically driven water chemistry values were also identified as being associated with fish populations. Specifically, ammonia and nitrite concentrations and the maximum and range of temperature were found to be factors in fish populations documented at a station. MPA status was also a factor.

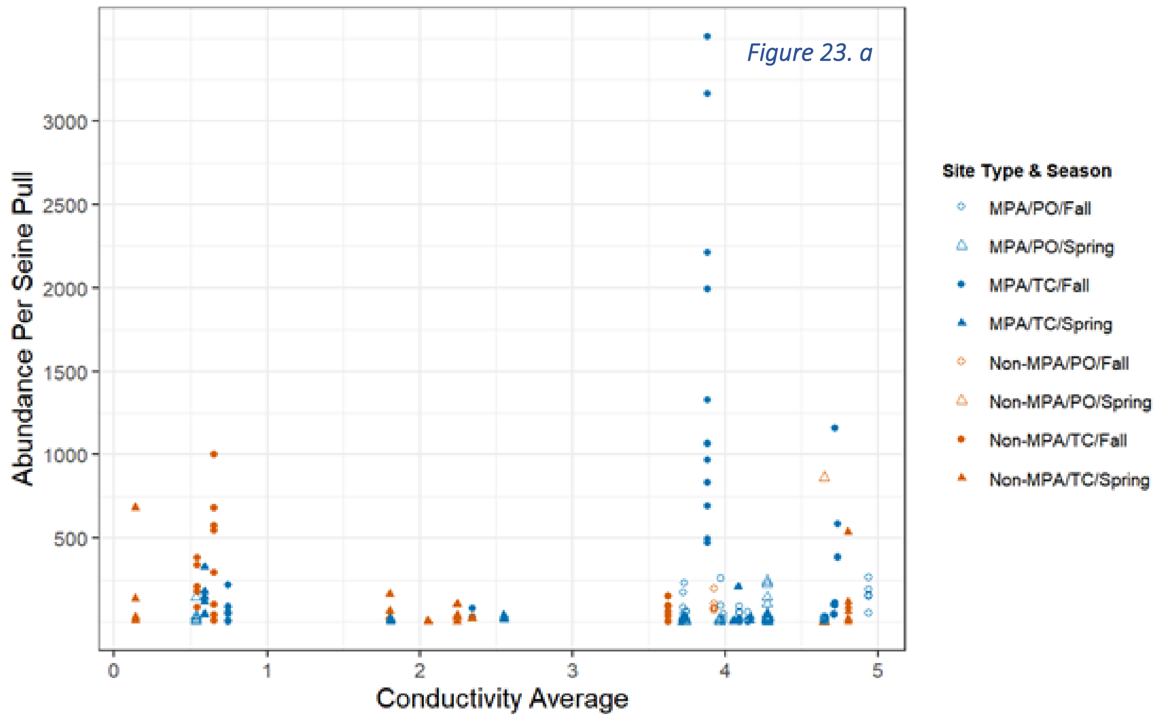


Figure 23. a
Abundance Per Seine Pull
Conductivity Average
Site Type & Season
MPA/PO/Fall
MPA/PO/Spring
MPA/TC/Fall
MPA/TC/Spring
Non-MPA/PO/Fall
Non-MPA/PO/Spring
Non-MPA/TC/Fall
Non-MPA/TC/Spring

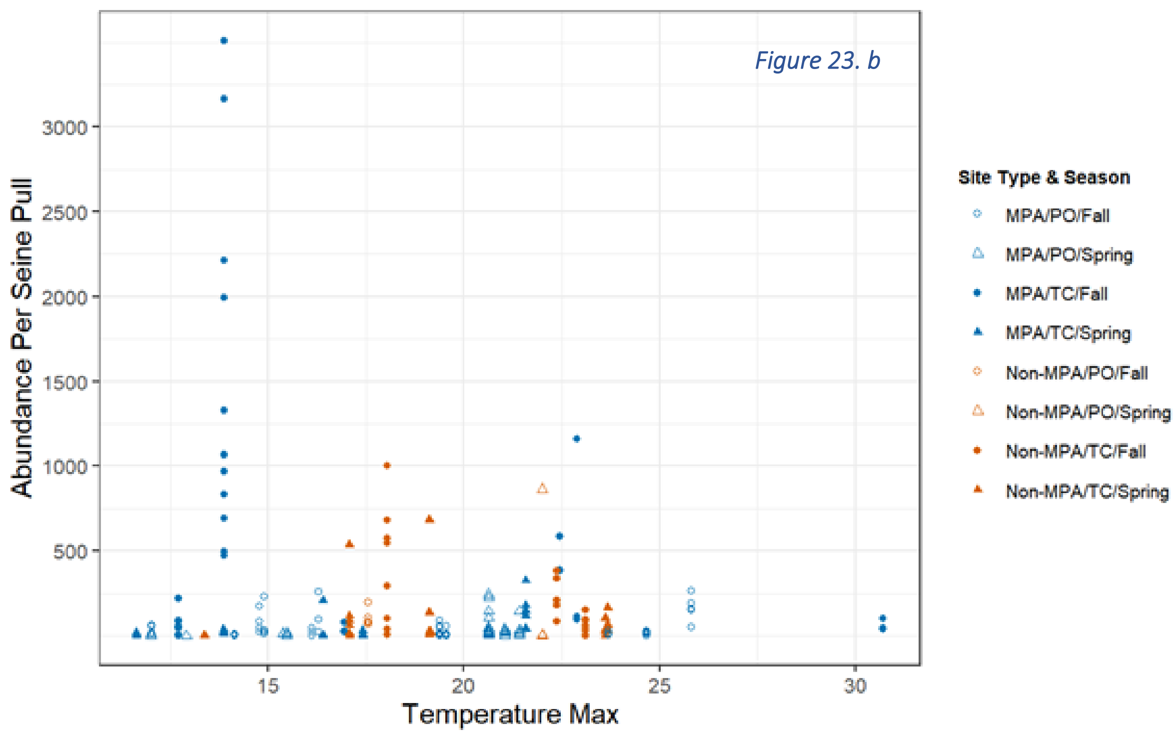
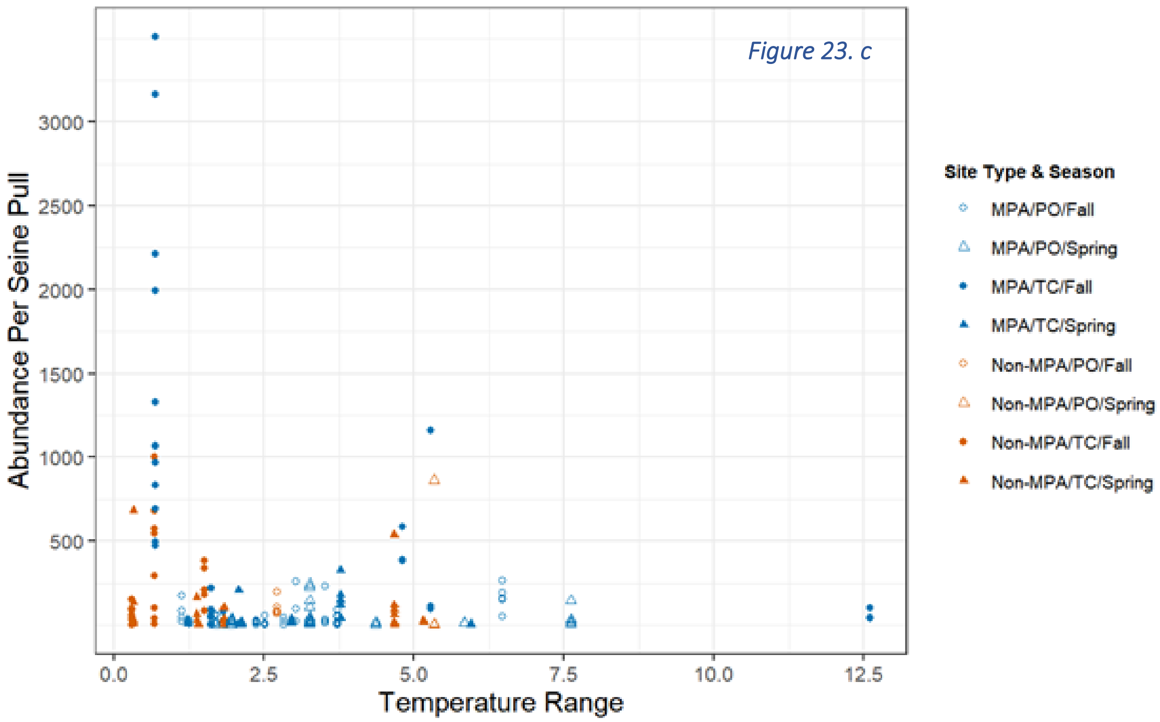


Figure 23. b
Abundance Per Seine Pull
Temperature Max
Site Type & Season
MPA/PO/Fall
MPA/PO/Spring
MPA/TC/Fall
MPA/TC/Spring
Non-MPA/PO/Fall
Non-MPA/PO/Spring
Non-MPA/TC/Fall
Non-MPA/TC/Spring



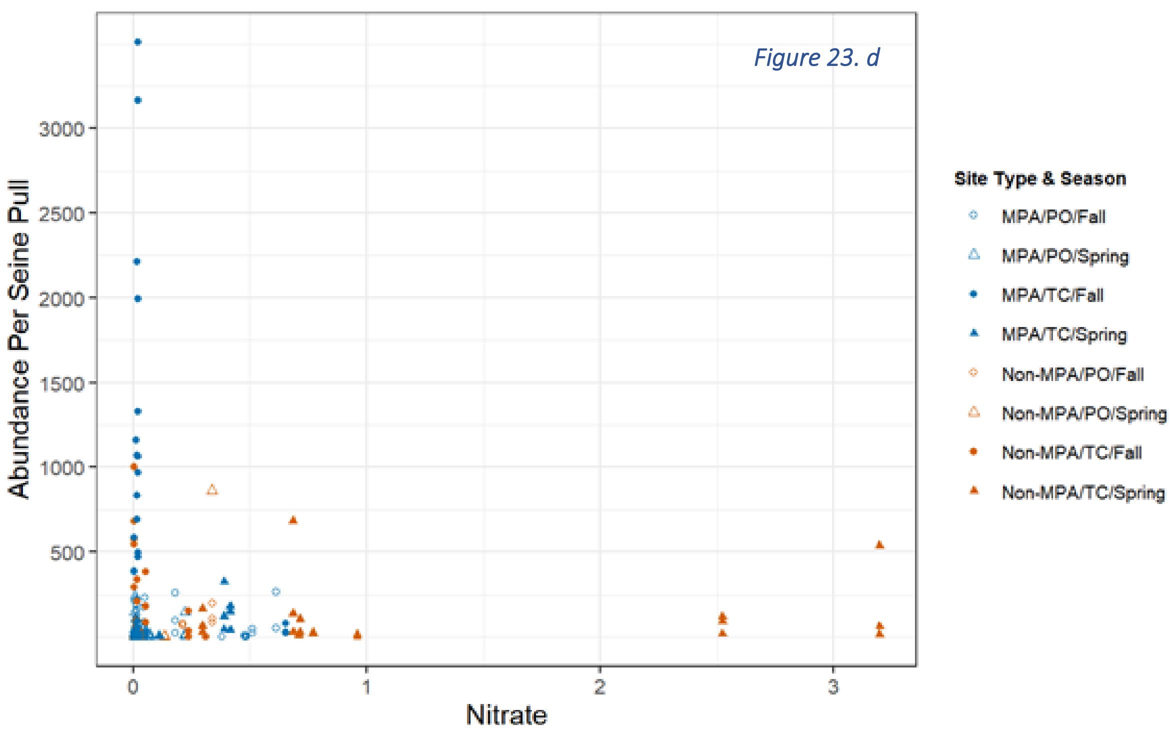


Figure 23. Plots of key parameters from the GLMs explaining variation in fish abundance from seines in spring and fall 2021. Abiotic covariates with largest effects in the best model are on x axes (a - conductivity average, b - average temperature daily maximum, c - average temperature daily range, d- nitrate), and other influential covariates (MPA status, season, estuary type) are represented by variation in color and symbol as indicated in legends.

Additional Example Functions for Future Analysis

Below are draft definitions and potential condition statements for two additional estuarine functions; nutrient cycling and bird habitat. As additional data become available over the course of several years of data collection, the EMPA Team will be able to analyze the results for trends in all functions in the monitoring framework.

Nutrient Cycling

The estuary function for Nutrient Cycling has been defined as: *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 and tidally driven estuarine circulation patterns, and geomorphology*

This function has been given 6 draft condition statements that can be used once additional data are collected and analyzed to determine the ability of an estuary to support nutrient cycling. Each condition statement will be analyzed separately and the resulting scores will then be averaged to give each estuary an overall score for the function.

1) High abundance and diversity of benthic infauna
2) Low sediment anoxia (in subtidal area)
3) Low water column nutrient concentration
4) Presence of marine-derived wrack
5) High abundance and diversity of SAV
6) Coarser grained sediment

Bird Habitat

The estuary function for Bird Habitat has been defined as: *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).*

This function has been given 3 draft condition statements that can be used once additional data are collected to estimate an estuary’s capacity to support bird habitat. Each condition statement will be analyzed separately and the resulting scores will then be averaged to give each estuary an overall score for the function.

1) A marsh plain with a diversity of native plant species and height classes
2) Good habitat condition (CRAM) with numerous habitat sub-types (marsh plain, mud flat, open water, canopy cover, beach, etc.) that support avian feeding, nesting and predator avoidance
3) Available food supply (fish, benthic and mobile invertebrates)

The EMPA Team plans to coordinate future bird data collection in estuaries with the Beach Habitat monitoring team being led by Jenny Dugan at UCSB, which already collects shorebird metrics at a suite of beaches along the coast.

Stressors Acting on Estuaries

The vast majority of the state's 124 MPAs are located in offshore marine waters and help to protect marine life from threats such as overfishing, resource extraction, and related activities. California's estuarine MPAs however are more heavily influenced by watershed land use, coastal infrastructure, water resource management, water quality, and other stressors that are largely regulated outside of the MLPA. Below we demonstrate some analyses which can start to quantify these adjacent stressors and the effect on estuarine condition.

Landscape/Watershed/Land Use Stressors

Generalizations on dominant land cover types and potential stressors within the watersheds of the 15 estuaries can be made from the watershed landcover GIS analysis. Urban and impervious surfaces are highest in the southern California watersheds, while agriculture is highest on the central coast (Figure 24). Within 2km radius of the estuary, the urban land cover on the south coast becomes dominant (Figure 24). The natural land cover of forest cover is greatest in northern watersheds and lowest in southern watersheds of the state. Scrub/shrub coverage is greater in drier southern watersheds. The central coast region is found to have equal coverage of both land forms (Figure 25).

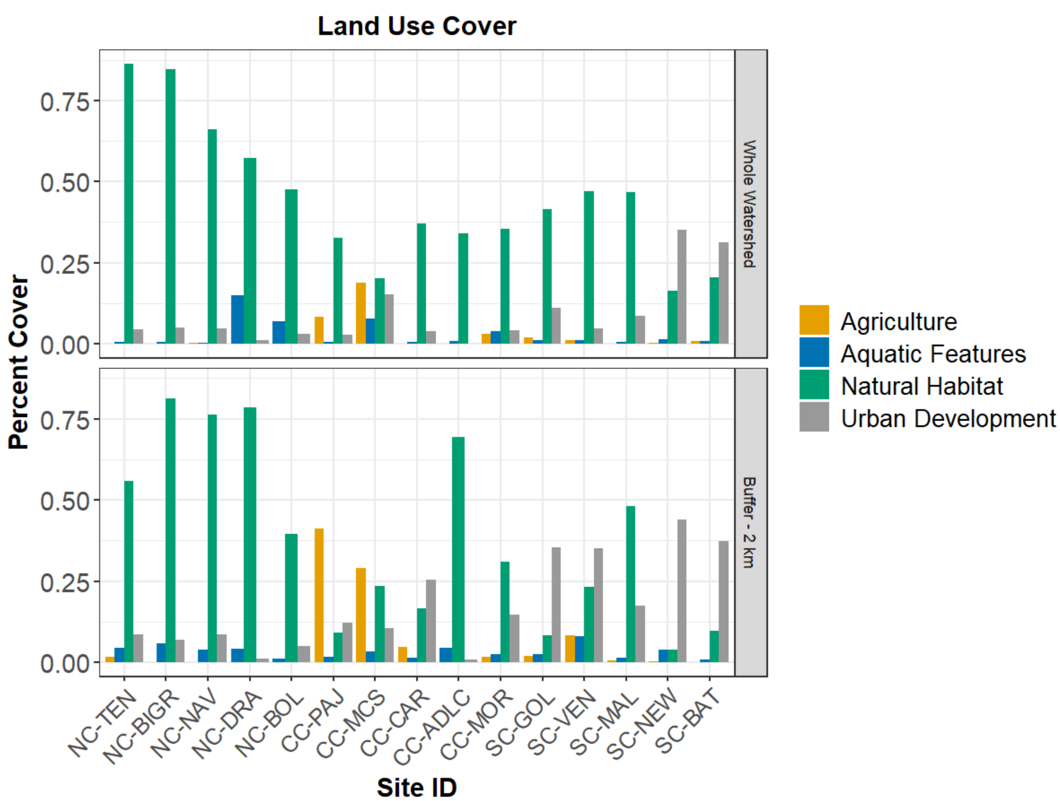


Figure 24. Percent cover of several land cover types in A) the whole watershed and B) within 2 km of each EMPA estuary.

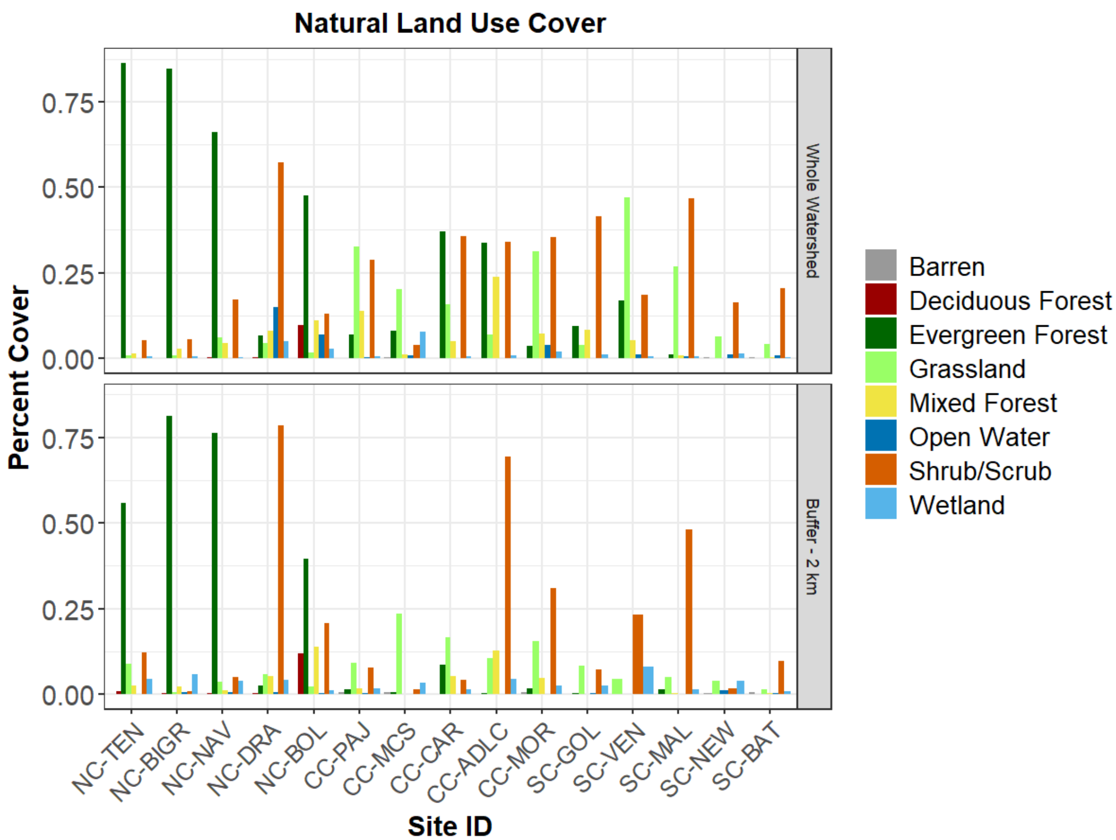


Figure 25. Percent cover of a breakdown of the natural land cover and aquatic feature types in A) the whole watershed and B) within 2 km of each EMPA estuary.

Water Quality

Water quality varied widely amongst the 15 EMPA estuaries (Figure 26). Nutrient samples collected in the spring and fall of 2021 showed higher levels of nitrate in the Pajaro and Ventura estuaries, both dominated by agricultural land use in the upstream watershed. Higher phosphate concentrations were documented in Drakes Estero, Moro Cojo Slough and Malibu Lagoon.

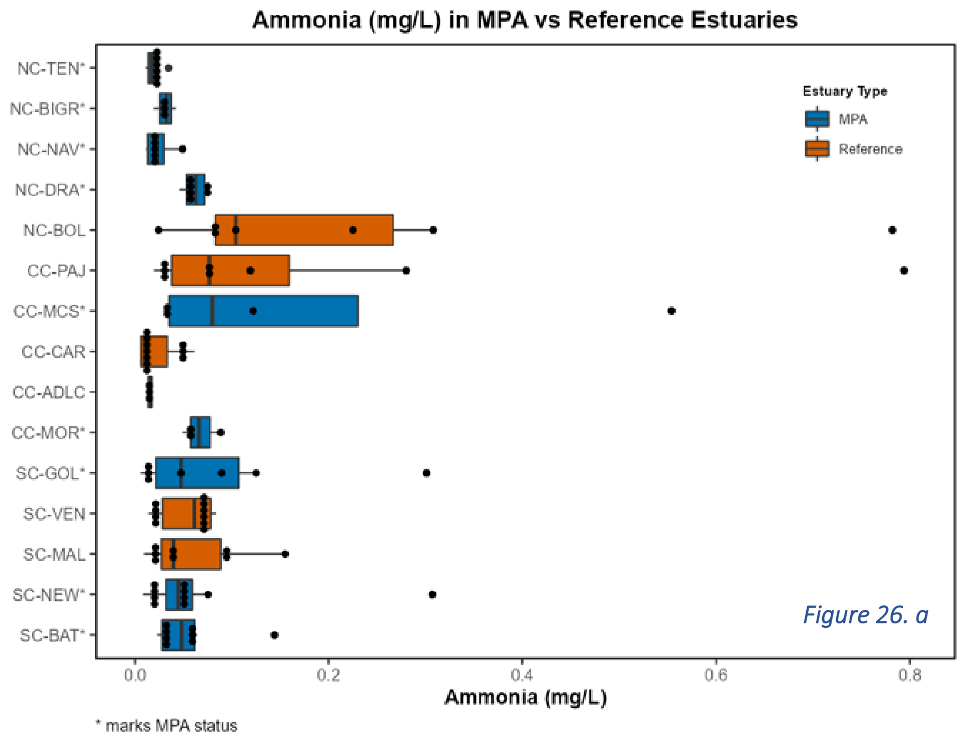


Figure 26. a

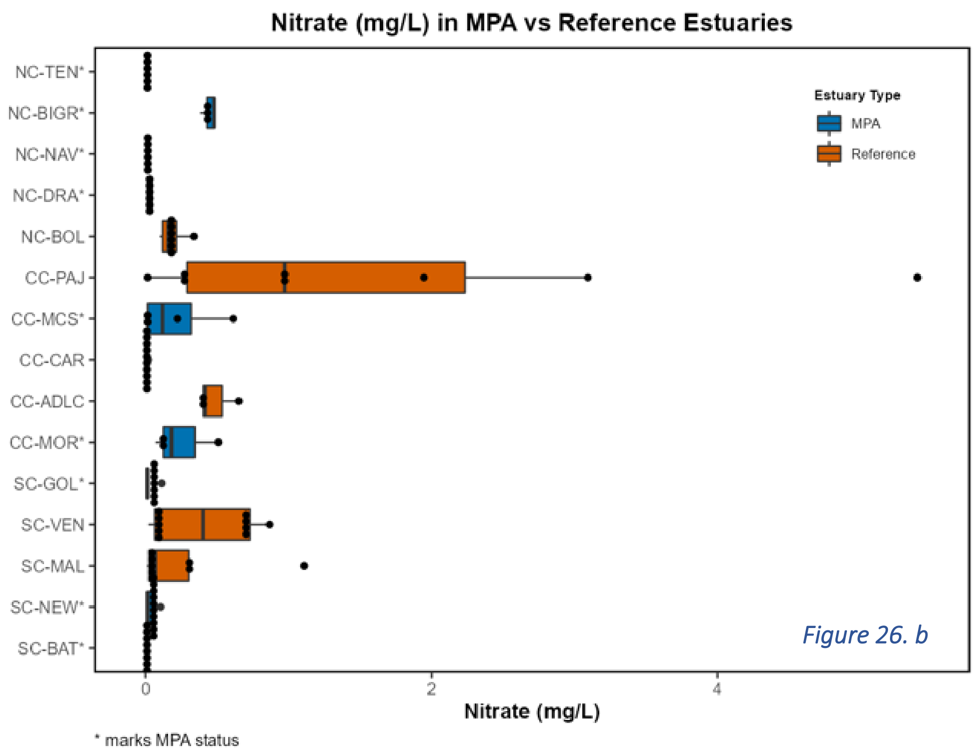


Figure 26. b

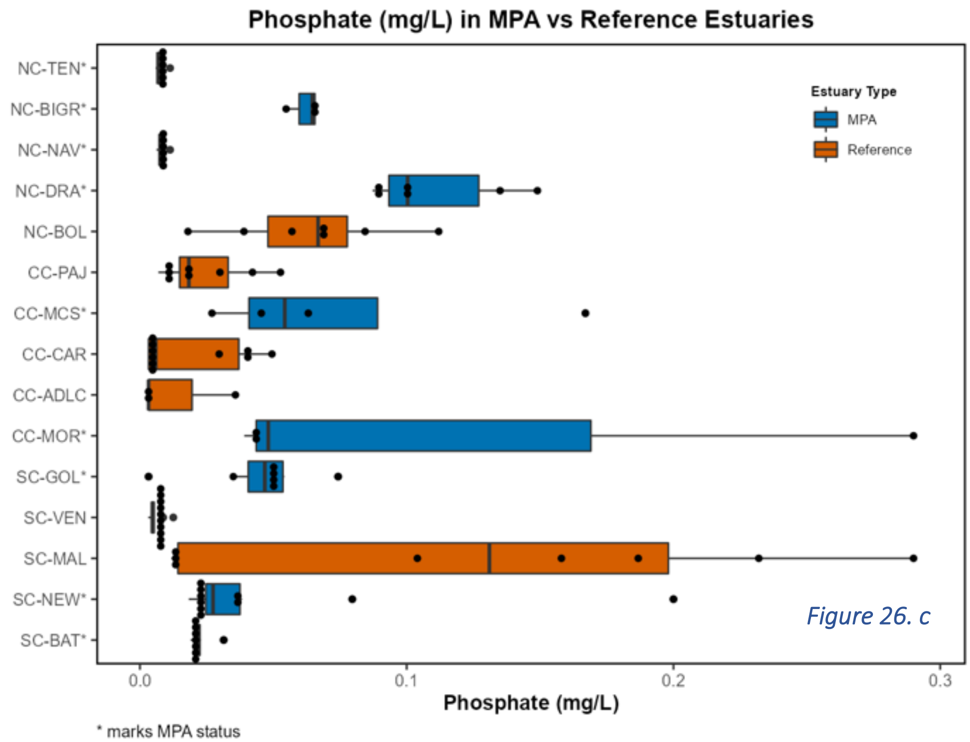


Figure 26. Box plots of water nutrient samples collected in the spring and fall of 2021 at all 15 EMPA sites. (a – ammonia, b - nitrate, c - phosphate).

Estuary Mouth Management

Bar-built estuaries are the dominant estuary type in California, and many of these small estuaries are subject to a sand barrier forming and separating the estuary from the ocean for days to months. In lagoons, water impounded behind the sand barrier, may rise or fall depending on fluvial input and wave overtopping. During these conditions water quality degradation may occur. Poor water quality and the obstruction of fish passage motivate local agencies to breach the sand barrier in many of these systems that can result in undesirable secondary impacts to ecological functions. Proposed sand barrier breaching is frequently aimed at addressing one or more of the following management objectives (Largier et. al. 2018):

- Alleviate or preclude flooding of agricultural lands, urban infrastructure, special status species habitat and recreational resources.
- Eliminate or reduce undesirable water quality conditions (e.g., hypoxia), including biological impacts resulting from water column stratification.
- Alleviate elevated risk to public health from vector borne illness such as West Nile virus from freshwater mosquito species (e.g., *Culex tarsalis*).
- Allow fish passage for anadromous adults and/or juveniles.

The EMPA estuaries were classified as either having no mouth management, experiencing periodic breaching actions, or being fully managed as an open system (Table 19). An analysis was then performed comparing the average CRAM scores amongst the three groups.

The sites classified as managed open and having periodic breaching events received significantly lower average CRAM Index scores as compared to estuaries with no mouth management (Figure 27). There are many factors that contribute to a low CRAM score, mouth management being just one of them.

Table 19. Classification of mouth management for each EMPA site.

Site	Mouth Managed?	Type of Management
Ten Mile River	No	N/A
Big River	No	N/A
Navarro River	Yes	Sometime breached
Drakes Estero	No	N/A
Bolinas Lagoon	No	N/A
Pajaro River	Yes	Sometime breached
Moro Cojo Slough	Yes, managed open	Jetty, dredging, tide gates
Carmel River	Yes	Sometime breached
Arroyo de la Cruz	No	N/A
Morro Bay	Yes	Jetty
Goleta Slough	Yes	Sometime breached
Ventura River	No	N/A
Malibu Lagoon	Sometime breached	Sometime breached
Newport Bay	Yes	Jetty and dredging
Batiquitos Lagoon	Yes	Jetty and dredging

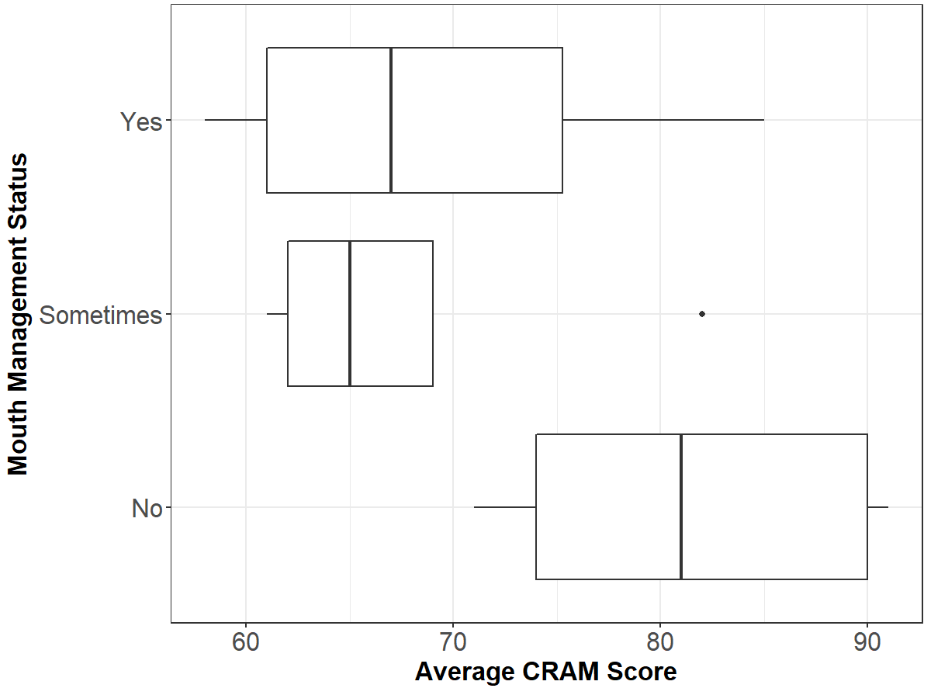


Figure 27. Box plots of average CRAM Index score for each mouth management classification group.

Lessons From Year One of Data Collection

The EMPA team has worked to refine and enhance the EMPA assessment framework, field protocol, and data analysis. After each field season, team members from each regional team met to discuss sampling protocol and sampling challenges and method improvements were documented. Below are a number of lessons learned and recommendations for improvements as the EMPA Program.

Evaluation of Effect of Sampling Effort and Sampling Type for Selected Indicators

As is well documented in the literature, the fish sampling method selected will influence the resulting data describing species composition. To understand how the fish sampling methods selected by the EMPA program may bias fish population data, the southern regional team conducted a sampling methods trial (comparing baited underwater remote videos, angle surveys, cast nets, seines) in spring and fall 2021 and a sampling effort trial in spring 2021. For the sampling effort trials, 9 seines were conducted at each sampling zone in Batiquitos in each season. In spring 2021, three seines per sampling site were sampled in all other estuaries. Based on results of this analysis, sample size was increased to five seines per estuary sampling site for fall 2021.

As predicted, each fishing method captured selective portions of the fish species present. Fish seines and cast nets caught different types of fish (typically smaller, benthic-associated species) than hook-and-line fishing and Baited Remote Underwater Videos (BRUVs) (typically catching larger, more mobile, water column-associated fish) (Figure 28). Sampling effort (measured as the number of seine pulls) was found to influence species richness estimates, with a higher number of species caught as additional seines are sampled (Figure 29). Based on the results of the southern California sample analysis, the EMPA team increased the number of seine pulls from three to five per station to better document site specific fish species diversity. The fall protocol was modified to include three seines in which all fish were counted to estimate abundance and two additional seines were collected to document new fish species (not caught in earlier seines).

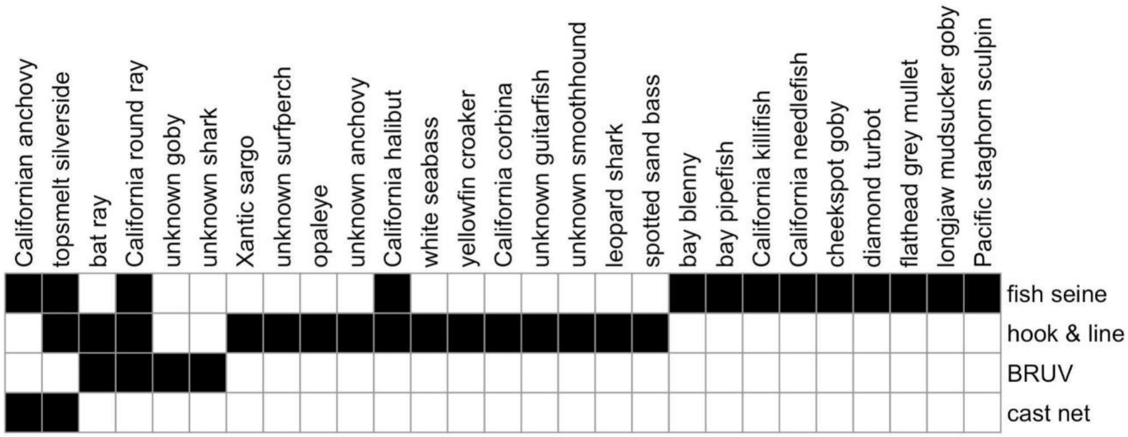


Figure 28. *Fish presence and absence in spring and fall of 2021 for each fishing method: cast net, BRUV (Baited-Remote Underwater Video), hook & line, and fish seine at Batiquitos Lagoon only (where all four methods were conducted). Note: hook and line sampling was from angler observations at Batiquitos.*

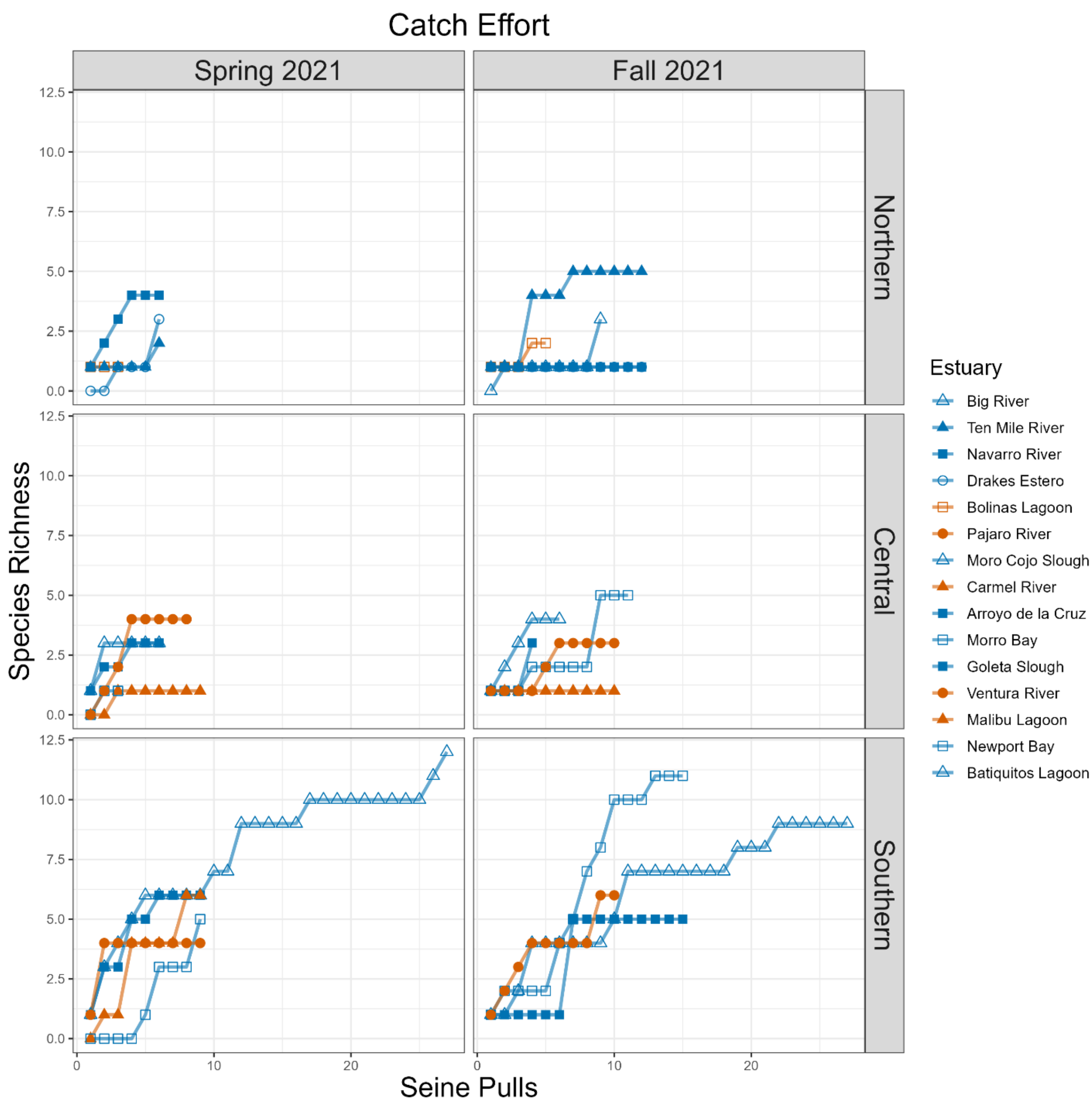


__Figure 29.__ Number of seine pulls in each region divided by season and region versus species richness (as measured by unique species among all pulls within an estuary). MPA sites are indicated by orange while non-MPA sites are indicated in gray.

Recommendations for Refinement or Enhancement of the Monitoring Framework

The EMPA Monitoring Framework describes a consistent, comprehensive approach to statewide monitoring. The framework is intended to be modified and expanded as new systems and new partners are integrated, building an iterative process for method refinement and enhancement. Over the next few years, we recommend the following additions to the framework -

1) Addition of resilience indicators

Resiliency is a commonly stated objective of many coastal wetland restoration projects. However, we currently lack a consistent definition, assessment approach, and tools for evaluating resiliency. We recommend working with the MAC to develop an agreed upon definition and conceptual model of resiliency that is structured around quantifiable elements and functions. The definition will lend itself to both structured measures in the field and management responses/decisions. Measures could include in-situ measures such as accretion rates and inundation frequencies, functional measures such as carbon and biomass accumulation, and landscape features such as accessibility to transition zones. By including resilience metrics within a statewide framework, California will be able to build a “resiliency index” that can be used to evaluate past restoration projects, inform design of future restoration projects, and develop monitoring and performance metrics for future efforts.

2) Addition of climate change indicators

Changing ocean and estuarine conditions due to climate variability and change, including increasing temperature, ocean acidification, and deoxygenation, are impacting marine ecosystems. There is a growing need to develop estuarine MPAs management guidance that protects estuarine resources from climate change. We recommend adapting and enhancing existing EMPA monitoring methods to better document climate change stressors (sea-level rise, temperature, acidification, etc.)

3) Addition of remote sensing tools

In 2021, the project team collaborated with NASA-JPL to build a google earth engine-based interactive, cost effective, user-friendly tool which can be used to classify and assess estuaries along the California coast. The tool uses maps and timeseries satellite data to quantify various water quality metrics including temperature and chlorophyll concentration and mouth condition.

In addition to satellite-based assessments, the EMPA Framework may work to incorporate drone-based assessment techniques, including SAV monitoring and mapping. Drones with high spatial resolution capabilities 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.

4) Development of estuarine report cards

Over the course of the development of the EMPA Program (about 2 years), meetings of the MAC assisted in the identification of key management and monitoring questions to be addressed by the Program and provided review and feedback on priority indicators, metrics, and sampling protocols. A priority request from the MAC was the development of scoring criteria to evaluate the overall condition of estuaries and efficacy of MPAs. We recommend working with the MAC to develop a report card for a estuaries to provide management recommendations for 1) stressor amelioration, 2) restoration actions, and 3) adaptive management.

5) Development of community science protocols

To engage the public and local, regional, and state agencies, we recommend establishing community science program that allows the public to participate in existing data collection, and expands the scale and periodicity of data collection efforts. We recommend:

Establishing photo monitoring locations at each of the selected estuaries (capturing mouth conditions or marsh plain water elevations) to encourage the public to upload standard photos to an online, interactive portal. The crowd-sourced data can then be used to track seasonal and daily changes in estuary features.

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.

6) Leveraging other data sets to help answer questions

There are many estuary specific intensive long-term monitoring efforts, including efforts conducted by the Wetlands Recovery Project Integrated Wetlands Regional Assessment Program (WRP IWRAP) members, the first SMBRA Wetland Program Development Grant, and a 2020 team under the EPA WPDG (Johnston et al. 2020). These regional datasets are extremely valuable and for most indicators, a data crosswalk can be developed to fully integrate many long-term datasets. We recommend continued efforts to crosswalk the EMPA indicators with other regional datasets. Examples include:

1) Morro Bay National Estuary Program: SAV (eelgrass) and water quality monitoring being conducted by the Moro Bay NEP.
2) SONGS: fish monitoring data being collected by the SONGS Program at several southern California estuaries (San Dieguito Lagoon, Point Mugu, Tijuana estuary, Carpinteria)
3) Elkhorn Slough and Tijuana River National Estuarine Research Reserves: multiple biotic and abiotic monitoring parameters being collected by the NERRs in California.

Inherent Variability in Estuaries Influences Ability to Draw Conclusions

Estuaries are inherently dynamic systems. Conditions vary due to tidal, seasonal, interannual, and (in some cases) 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. Because estuaries integrate environmental stress from watersheds and the ocean, it can be difficult to identify primary stressors and document clear stress response relationships.

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 inform management decisions.

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