Development of a Statewide Estuary Monitoring Program to Evaluate California's Estuarine Marine Protected Areas

Estuary Marine Protected Area Program Overview

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EMPA Monitoring Program

OCEAN PROTECTION COUNCIL

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Introduction

In 2018, the California Ocean Protection Council (OPC) and California Department of Fish and Wildlife (CDFW) released the Marine Protected Area (MPA) Monitoring Action Plan (Action Plan), which proposes a monitoring framework to assess MPA effectiveness, track ecological and socioeconomic change in MPAs over time, and inform adaptive management needs. The Action Plan highlighted the unique monitoring needs of the state's 23 estuarine MPAs (EMPAs) and proposed a monitoring framework built around key biotic and abiotic indicators that largely leveraged existing monitoring programs throughout the California coast.

This document describes development of a broadly applicable monitoring framework that can address fundamental information needs that are shared among most of the state's estuaries, and their many stakeholders. The framework can be used to help answer critical management questions about both MPA and non-MPA estuaries statewide. The products include an integrated estuarine monitoring framework, sampling design, standard protocols, and data management tools to facilitate collection, integration, and dissemination of biotic and abiotic data in a consistent and accessible manner. A monitoring manual (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/monitoring_manual.pdf) 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 a data report (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/data_summary_and_report.pdf) to illustrate how data collected through the monitoring program can be used to answer scientific and management questions about estuary health and stressors, and how that information can inform management decisions. Finally, the team produced an implementation blueprint (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/implementation_blueprint.pdf) that lays out a strategy for ongoing management and implementation of the program to collect data over time that will be necessary to fully address priority management questions. These documents are available via the EMPA web portal: https://empa.sccwrp.org/.

Overview of Need and Key Management Questions

The MPA program was established to protect important marine and coastal ecosystems for the benefit of fisheries and other ecosystem services. However, over the past decade, the bulk of MPA management and monitoring effort has focused on non-estuarine marine ecosystems, making it difficult to complete an assessment of estuarine MPAs during the first decadal MPA management review in 2022, as called for by the MPA Monitoring Action Plan. This project aimed to leverage the resources of multiple geographically representative institutions to create and pilot a sustainable estuary monitoring program to help achieve the following objectives:

1. Assess the conditions (key species abundance, diversity, structure, function, and integrity) of estuarine ecosystems in EMPAs, with a focus on how EMPAs:
    - Provide effective nursery habitat for focal fisheries

- Support biodiversity of California marine ecosystems
- Are degraded by post-European activities, incorporating traditional ecological knowledge
- Represent the range of estuarine habitat types historically present along the coast
- Are resilient to climate change

2. Compare the conditions and anthropogenic stressors present in EMPAs to those in non-EMPA estuaries,
3. Relate the conditions in EMPAs to conditions in nearby offshore MPAs (using summary reports from other monitoring programs),
4. Build on previous efforts to identify key threats to estuarine conditions in EMPAs and non-EMPA estuaries,
5. Inform strategies for future management and conservation actions in EMPAs, and
6. Document Marine Life Protection Act (MLPA) performance in Estuary MPAs

The coordinated Statewide Estuarine Monitoring Program includes the compilation and analysis of select, currently available data sets, a focused field data collection effort to fill data gaps through implementation of standard protocols (abiotic, biotic, habitat, and stressor parameters), quantification of the current benefits of MPA status, and the development of long-term monitoring and management recommendations to expand the benefits of EMPA designation and document changes through time. This program aimed to:

1. Develop a key set of priority management and monitoring questions, metrics, and indicators of estuarine condition by convening a technical advisory committee (TAC) of experts in estuarine ecology, biogeochemistry, and monitoring.
2. Establish a strategic approach for evaluation of estuarine MPA condition and MLPA performance based on a standardized set of data collection protocols and monitoring tools (building off the performance evaluation questions laid out in the Action Plan combined with unique performance questions for estuaries).
3. Determine data collection, quality control, and management protocols for the metrics and indicators identified.
4. Pilot test priority indicators and data collection protocols at a subset of estuaries to demonstrate how they can be applied and how the resultant data can be used to address MLPA goals
5. Complete a baseline assessment (including analysis and reporting) of selected estuarine MPA/non-MPA sites using existing and collected data.
6. Develop the structure and approach for ongoing coordination of estuary monitoring.

Working with a Management Advisory Committee (MAC) comprised of federal and state agency staff, academic researchers, tribal representatives, and local conservancies, the project team identified a series of priority management questions (endpoints) that should be addressed through estuary monitoring program (Table 1).

Table 1. Priority questions identified by the Management Advisory Committee

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

These questions relate back to overarching questions that are important for the MPA program in general:

- Do indicator species inside of MPAs differ in size and abundance relative to non-MPA sites?
- Do California MPA Monitoring Program indicator species, including those of economic importance, experience positive population level benefits in response to MPA implementation?
- How are the frequency of non-consumptive use, knowledge, attitudes, and perceptions regarding the MPAs changing over time?
- Have federally and state listed endangered/threatened species, culturally significant species, and commercially important species recognized with Essential Fish Habitat (EFH) under the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and culturally significant species benefited from the presence of California's MPAs?
- How has the level of compliance with MPA restrictions changed over time since the MPAs were first implemented and what factors influence variation in compliance within and among MPAs?
- How do other stressors impact the performance of MPAs over time (e.g., water quality, oil spills, desalination plants, ocean acidification, sea level rise, removal of large dams)?

Framework and Approach

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

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

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

2. Comparability: Characterizing systems by geomorphic features

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

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

To capture seasonal and interannual variation among and within estuaries, sampling protocols concentrate multiple measurements around sampling zones. Users establish several permanent sampling zones within their sites in order to concentrate multiple sampling methods (i.e., cluster sampling) in a given area and have the ability to resample the selected areas. Concentrating multiple measures within an area will enhance our ability to interpret data.

4. Practicality: Accomplishing sampling within three days

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

Given the ecological and hydrological complexity of estuaries, there are a vast number of potential indicators one could use to evaluate the health and condition of estuaries. Eleven priority ecological functions of estuaries were identified by the EMPA technical team (see EMPA Technical Memo: https://empa.sccwrp.org/pages/technical-reports-and-memos). The underlying principle is that all estuaries should provide a variety of ecological functions at some ideal rate in the absence of anthropogenic disturbance and alteration. Priority ecological functions were selected to present a mix of true ecological functions (processes with limited direct society value) as well as ecosystem services (processes with direct, often commodifiable, society value; Table 2).

Table 2. Priority estuarine ecological functions with a brief definition of each function

Function	Definition
Nekton Habitat	Support for a variety of resident and transitory fishes and crustacean by providing structure that serves as shelter from predation and providing benthic or water column food sources.
Primary Production	Production of organic material from carbon input to the system that supports development of diverse microbial, algal, and macrophyte (plant) communities.
Secondary Production	Transformation of allochthonous and autochthonous organic matter into meiofauna and macrofauna, which in turn are consumed by the resident nekton of the estuary or are exported out to the nearshore coastal zone.
Protected Species Support	Provision of the appropriate subtidal, intertidal, and marsh habitat to support one or more life stages of species that are protected by federal, state, or local regulations. Includes physical structure and water quality conditions (salinity, oxygen, pH, etc.) to support these organisms.
Nutrient Cycling	Processing of nitrogen, phosphorous, and carbon from their elemental or detrital forms to support primary production by algae and vascular plants. Nutrient cycling is often high in estuaries because of high inputs, density/tidally driven estuarine circulation patterns, and geomorphology.
Sea Level Rise Amelioration and Resiliency	Capacity to absorb and protect adjacent uplands from increasing sea level 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 growth and transgression.
Bird Habitat	Provision of physical and biological structure for resident and migratory birds to support predator evasion or nesting (via their associated wetlands) and abundant food (via high secondary and tertiary (nekton) productivity).
Shellfish Support	Provision of habitat for establishment and growth of shellfish. Estuaries are obligate habitats for a variety of societally, economically, and ecologically important shellfish species that rely on the basin morphology, mesohaline/oligohaline salinities, and large amounts of primary production only available in estuaries.

Function	Definition
Nursery Habitat	Provision of habitat for spawning and nursery support for marine or anadromous species based on the structural complexity and high primary/secondary productivity found in estuaries.
Support of Vascular Plant Communities	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 and elevation, salinity gradient, and submergent condition.
Wildlife Support	Support for different life stages and access to movement corridors for a variety of marine- and land-based fauna that rely on estuaries to fulfil a portion of their life history need.

To support implementation of the monitoring framework and program, the project team produced a monitoring manual (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/monitoring_manual.pdf) that includes 14 sets of standard operating procedures (SOPs) to ensure consistent data collection. The SOPs are supported by a data portal (https://empa.sccwrp.org/) that includes standard data templates, automated quality control routines, and data query capabilities.

Each function can be evaluated by one or more indicators providing flexibility to use indicators appropriate for the specific estuary, while still allowing the standard set of functions to be evaluated (Figure 1: Matrix relating field indicators to the functions they are used to assess. Shaded boxes indicate which indicators correspond to each function. The matrix indicates that each indicator can support multiple functions and each function can be assessed by a combination of indicators).

		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	Marshplain elevation	Sediment accretion rates	Mouth dynamics	General habitat condition
Ecosystem Functions	Nekton Habitat	x	x				x	x	x					
	Primary Production			x	x		x			x	x	x		x
	Secondary Production					x	x			x				
	Protected Species Support	x		x			x	x	x	x	x		x	x
	Nutrient Cycling		x		x	x	x			x		x	x	
	SLR Amelioration						x			x	x	x		x
	Bird Habitat					x	x	x	x	x	x		x	x
	Shellfish Support	x	x	x	x	x	x							
	Nursery Habitat					x	x	x	x				x	
	Support Vascular Plants	x			x		x			x	x	x		x
	Wildlife Support	x	x	x			x			x	x			x

Figure 1. A function-based assessment will be used to assess the condition of each estuary, where multiple indicators can be used to assess a given ecological function. The figure shows the relationship between indicators and the functions they assess. Green squares marked with X represent the indicators that can be used to evaluate each function.

Pilot Implementation

In 2021, the EMPA Team conducted a pilot implementation of the Monitoring Framework. The state was broken up into three regions (North, Central, South) with regionally based field teams implementing the framework at 15 estuaries. The sites sampled included 10 MPA estuaries and 5 non-EMPA estuaries. The 15 selected sites represent a wide range of estuary types, sizes, and level of protection in California (Table 3). The project team successfully completed sampling in spring and fall of 2021. Each assessment took about three days to complete with a team of 4 to 6 people. The results of the pilot implementation are presented in the Project Summary and Data Analysis Report (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/data_summary_and_report.pdf)

Table 3. Estuaries included in the pilot implementation

Estuary Name	MPA type	Size (acres)	Classification	Region	Within 3 miles of offshore MPA
Ten Mile River	SMCA	212	Lagoonal	North Coast	Yes, Ten Mile Beach
Big River	SMCA	314	Riverine	North Coast	No
Navarro River	non-MPA	185	Lagoonal	North Coast	No
Drakes Estero	SMCA and SMR	2692	Embayment	North Coast	Yes, Point Reyes
Bolinas Lagoon	non-MPA	1261	Embayment	North Coast	No
Pajaro River	non-MPA	793	Lagoonal	Central Coast	No
Moro Cojo Slough	SMR	975	Embayment	Central Coast	No
Carmel River	non-MPA	93	Lagoonal	Central Coast	Yes, Carmel Bay
Arroyo de la Cruz	SMR	23	Lagoonal	Central Coast	Yes, Piedras Blancas
Morro Bay	SMR and SMRMA	2586	Embayment	Central Coast	No
Goleta Slough	SMCA (no take	325	Lagoonal	South Coast	Yes, Campus Point
Ventura River	non-MPA	38	Lagoonal	South Coast	No
Malibu Creek	non-MPA	34	Lagoonal	South Coast	No
Newport Bay	SMCA	1760	Embayment	South Coast	Yes, Crystal Cove
Batiquitos Lagoon	SMCA (no take)	538	Embayment	South Coast	Yes, Swami’s

Using the results of the pilot assessment, we were able to demonstrate how the framework can be used for three select functions: Support of Vascular Plant Communities, Sea Level Rise Amelioration and Resiliency, and Nekton Support. Assessment of other functions will be possible following additional data collection.

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, elevation, salinity gradient, and submergent conditions.

This function has been given seven condition statements (grouped into five indicator groups) that help analyze the ability of an estuary to support vascular plants. Each condition statement was analyzed separately, and the resulting scores were then averaged to give each estuary an final score for the function (Table 4, right column). Each indicator was evaluated independent of other indicators and scored based on the range of the respective data type. The function-based assessment linked to condition statements resulted in a final score for each estuary ranging from 1 to 3. 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. Final Scores were then color-coded based on tertials of possible scores: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good) (Table 4). Please see the EMPA Data Analysis Report for a complete description of the analysis and results for the vascular plant support and other functions.

The estuary function for sea level rise amelioration has been defined as:

Capacity to absorb and protect adjacent uplands from increasing sea level 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 growth and transgression.

This function has been given six condition statements (grouped into five indicator groups) 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.

The function-based assessment linked to condition statements resulted in a score for each estuary ranging from 1 to 3. The estuary with the highest score for support for SLR Amelioration was Ten Mile River Estuary, while the lowest scoring estuary was Batiquitos Lagoon. Final Scores were then color-coded based on tertials of possible scores: 1-1.66=red (poor), 1.67-2.33=yellow (fair), 2.34-3=green (good) (Table 5).

Table 4. Summary results for evaluation of Support for Vascular Plant Communities function. Green shading indicates good function, yellow indicates fair/moderate function, and red indicates poor function. 'NA' indicates data was not available at the time of report publication. Missing values were excluded from the final score calculation.

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*	*Overall 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

Table 5. Summary results for evaluation of the Sea Level Rise Amelioration function. Green shading indicates good function, yellow indicates fair/moderate function, and red indicates poor function. A dash indicates data was not available for that estuary.

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

Moving Toward Implementation

Long-term implementation of the EMPA monitoring program will require a program structure that can facilitate and manage all implementation aspects, coordinate with other relevant state, regional, and local monitoring programs, act as fiduciary to solicit and manage funding for the program, lead outreach and information dissemination, and take responsibility for any reporting requirements. The project team developed an implementation blueprint (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/implementation_blueprint.pdf) that transcends the assessment framework and serves as a roadmap for long-term program implementation. The blueprint asserts that implementation should occur through four primary program elements: program governance, program management, science management, and data management.

The program structure should provide opportunities for all interested parties (e.g., regulators, resource managers, funders, practitioners, community organizations) to participate in some aspect of the monitoring program. The proposed tiered structure would allocate responsibilities and provide participation opportunities at multiple scales. The tiered structure would require mechanisms for ongoing coordination between the different levels (Figure 2: Organizational diagram showing the relationship of workgroups at the state, regional and local level. The program management, data management and governance groups support regional implementation, which in turn support local implementation). We recommend that overall program management be assumed by an existing organization whose mission and expertise involve implementing regional or statewide monitoring programs.

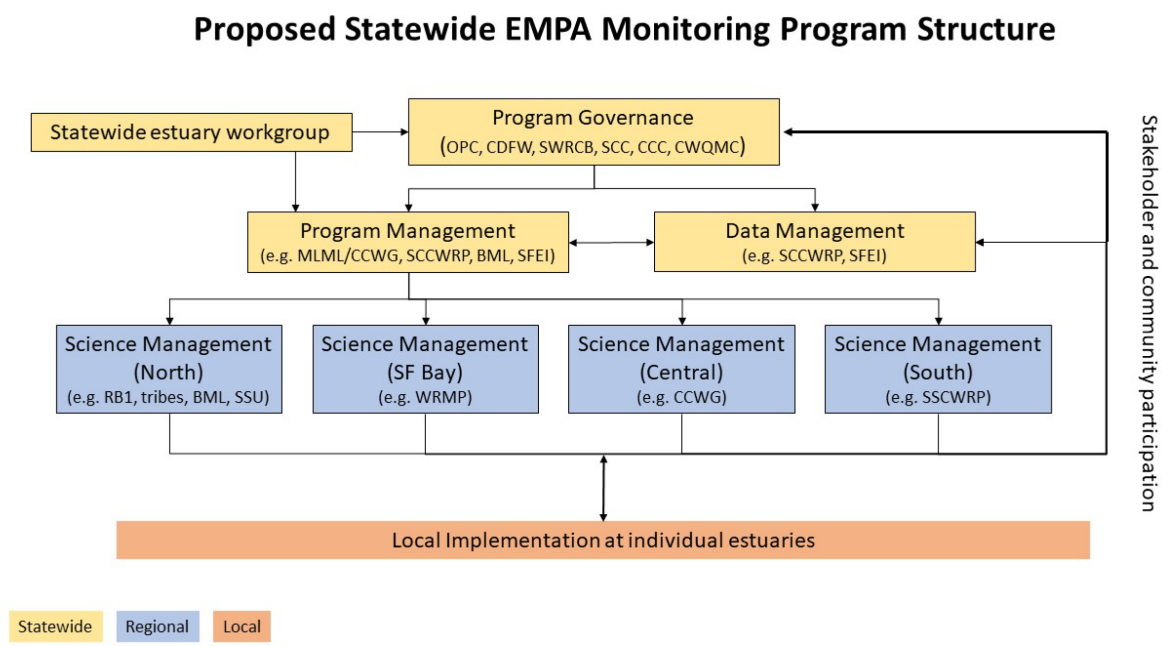

Figure 2. Tiered program structure showing how the key elements of a statewide EMPA Monitoring Program relate to each other with opportunities for stakeholder and community participation at all levels. Yellow cells are statewide, blue cells are regional, and orange cells are local.

Long-term implementation will also require development and maintenance of an integrated data management system based on electronic data flow from collection through dissemination. Finally, a sustained, committed, and diversified funding strategy will be necessary to support program management, data management, data analysis, and communication and outreach activities. Detailed recommendations for program implementation are provided in the Implementation Blueprint document (https://ftp.sccwrp.org/pub/download/PROJECTS/EMPA/deliverables/implementation_blueprint.pdf)

Recommendations

The EMPA Monitoring Framework should be seen as an iterative program with room for refinement and enhancement. Moving forward, we recommend the following:

1. Extend collection of baseline data
2. Add indicators measuring the effects of climate change and coastal resilience to the Monitoring Manual
3. Develop a standard template for a report card of estuary health for each MPA and non MPA site
4. Engage local communities through participatory protocols
5. Leverage other data sets and/or additional funding to help answer broader questions