Estuarine & Wetland Ecosystems: the first steps in developing an approach to leveraging existing monitoring programs

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About this Document

The goal of this document is to characterize existing and emerging capacity and resources for monitoring conditions and trends of estuarine and wetland ecosystems (including both ecological and physical metrics), inside and outside of California MPAs. This project was completed in coordination with the author, California Ocean Science Trust, California Ocean Protection Council, and the California Department of Fish and Wildlife. We thank the following people for helpful comments and discussion during the preparation of this report: Mark Carr, David Gill, Frank Shaughnessy, Jeff Crooks, and all of the other scientists and managers who provided useful information.

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Definitions and acronyms used in this report:

CAERS: California Estuarine Research Society
CDFW: California Department of Fish and Wildlife
CEDEN: California Environmental Exchange Network
CMECS: Coastal and Marine Ecological Classification Standard
DO: Dissolved oxygen
MLPA: Marine Life Protection Act
MPA: Marine Protected Area
NERR: National Estuarine Research Reserve
NEP: National Estuary Program
NPS: National Park Service
NT: No-Take Reserve
OPC: Ocean Protection Council
OST: Ocean Science Trust
PISCO: Partnership for Interdisciplinary Studies of Coastal Oceans
PMEP: Pacific Marine and Estuarine Fish Habitat Partnership
SCP: Scientific Collection Pertmit
SMCA: State Marine Conservation Area
SMR: State Marine Reserve
SMRMA: State Marine Recreational Management Area
SONGS: San Onofre Nuclear Generating Station Mitigation Monitoring Program
SWQCB: State Water Quality Control Board
TNC: The Nature Conservancy

Summary

A key first step in evaluating the performance goals of Marine Protected Areas (MPA) is establishing baseline-monitoring programs. The establishment of California Marine Life Protection Act (MLPA) established 23 estuarine MPAs. These MPAs were subdivided into 5 regions, each with its own target metrics to evaluate their performance in meeting MPA goals. The purpose of this report was to determine the existing monitoring programs in California estuaries that could provide leverage to monitoring as outlined in the MLPA. To do this we aimed to develop a comprehensive list of monitoring programs within the 23 estuarine MPAs, identify estuaries outside of the MPA network that would serve as good reference sites, and determine the important gaps that exist for estuarine monitoring within the MLPA framework. Working with partners from UC Santa Cruz, the California Ocean Science Trust (OST), the Ocean Protection Council (OPC), and California Department of Fish and Wildlife (CDFW), we developed a database of existing long-term (committed to greater than 4 years of monitoring) for target metrics in estuaries across the state. Together we identified 176 monitoring projects for the various target metrics across California estuaries. Despite this seemingly high number of monitoring programs most were limited to certain estuaries (e.g., Elkhorn Slough and Humboldt Bay) or programs (e.g., National Estuarine Research Reserve or San Onofre Nuclear Generating Station Mitigation Monitoring Program) or were limited to certain metrics (Dissolved Oxygen, pH, and eelgrass). We identified where many of the existing monitoring gaps occurred and discussed how future efforts could fill these gaps. These strategies include: establishing a network of researchers across the state to coordinate monitoring efforts, establishing other target monitoring metrics that could readily support MLPA goals, and using a regional conference to establish a network of researchers to take on monitoring of target metrics.

Introduction

Leveraging ecological monitoring to support the CA MPA program

Marine protected areas (MPAs) are a modern solution to managing and conserving ocean resources. Recent advances in theory on MPA design have determined that traditional MPAs, usually developed on small site-specific scales, can have little effect to maintaining the diversity and abundance of ocean resources over larger regional scales (Gaines et al. 2010). Since many anthropogenic disturbances and threats (e.g., climate change and over-fishing) to marine ecosystems occur over larger scales there is a high demand for developing networks of MPAs that can aid in mitigating harmful stressors.

An essential feature of determining the effectiveness of MPAs is the development of monitoring protocols that document conditions before and after implementation, and inside and outside of MPAs to monitor changes in target populations (e.g., fishery species), species assemblages, environmental conditions, and other factors necessary for impact evaluation (Ahmadia et al. 2015, Gill et al. 2017). In California, the 1999 Marine Life Protection Act (MLPA) called for the redesign of existing MPAs and the establishment of a statewide network. The MLPA also requires monitoring inside and outside of this network to assess conditions and evaluate MPA performance.

One of the eight coastal and nearshore ecosystems in California MPAs is estuaries. The establishment of the MPA network and the MLPA's monitoring requirement, created the need for monitoring inside and outside 20 estuaries that fall within MPAs across four regions: North Coast, North Central Coast, Central Coast, and South Coast (Figure 1). There are pre-existing monitoring programs within individual estuaries or across multiple that could help to achieve this task, such as those led by: state agencies (e.g., California Department of Fish and Wildlife - CDFW, State Water Quality Control Board - SWQCB), federal agencies (e.g., National Estuarine Research Reserve - NERR, National Estuary Program - NEP, National Park Service NPS), academic institutions, non-profit organizations, and citizen science programs (e.g., Elkhorn Slough Volunteer Water Quality Monitoring Program[1], Sea Otter Savvy[2], and Bay Net[3]. However, a grand challenge is determining whether or not these programs are collecting data and information at spatial, temporal, and taxonomic scales that are relevant to evaluating MPA performance, and more specifically, whether the metrics being monitored by existing programs align with those identified as top priorities for MPA monitoring.

The objectives of this project were to: 1) identify estuarine and wetland MPA and reference sites across the state of California, 2) identify the existing programs and program managers, 3) identify the metrics being sampled by each program, 4) determine if these programs are planning to be long-term (>4 years), so as to inform the effectiveness of established MPAs.

For this project we (Brent Hughes in collaboration with the Ocean Science Trust (OST), California Ocean Protection Council (COPC), and CDFW) aimed at bridging the gap between researchers who are engaged in long-term monitoring and the science needs of the MPA Monitoring Program, by doing the following: 1) develop a database that catalogues estuarine and wetland monitoring programs in California, including documentation of biological and water quality metrics, data management, accessibility to existing information, and program/project duration (MLPA-Partnership 2016, Hughes et al. 2017), and 2) document common metrics among existing estuarine monitoring programs and MPA monitoring metrics for estuaries and wetland ecosystems, as identified in the regional MPA Monitoring Plans.

[1] http://www.elkhornslough.org/research/waterquality_volunteer.htm
[2] http://www.seaottersavvy.org/volunteer
[3] http://montereybay.noaa.gov/getinvolved/volunteer/baynet.html

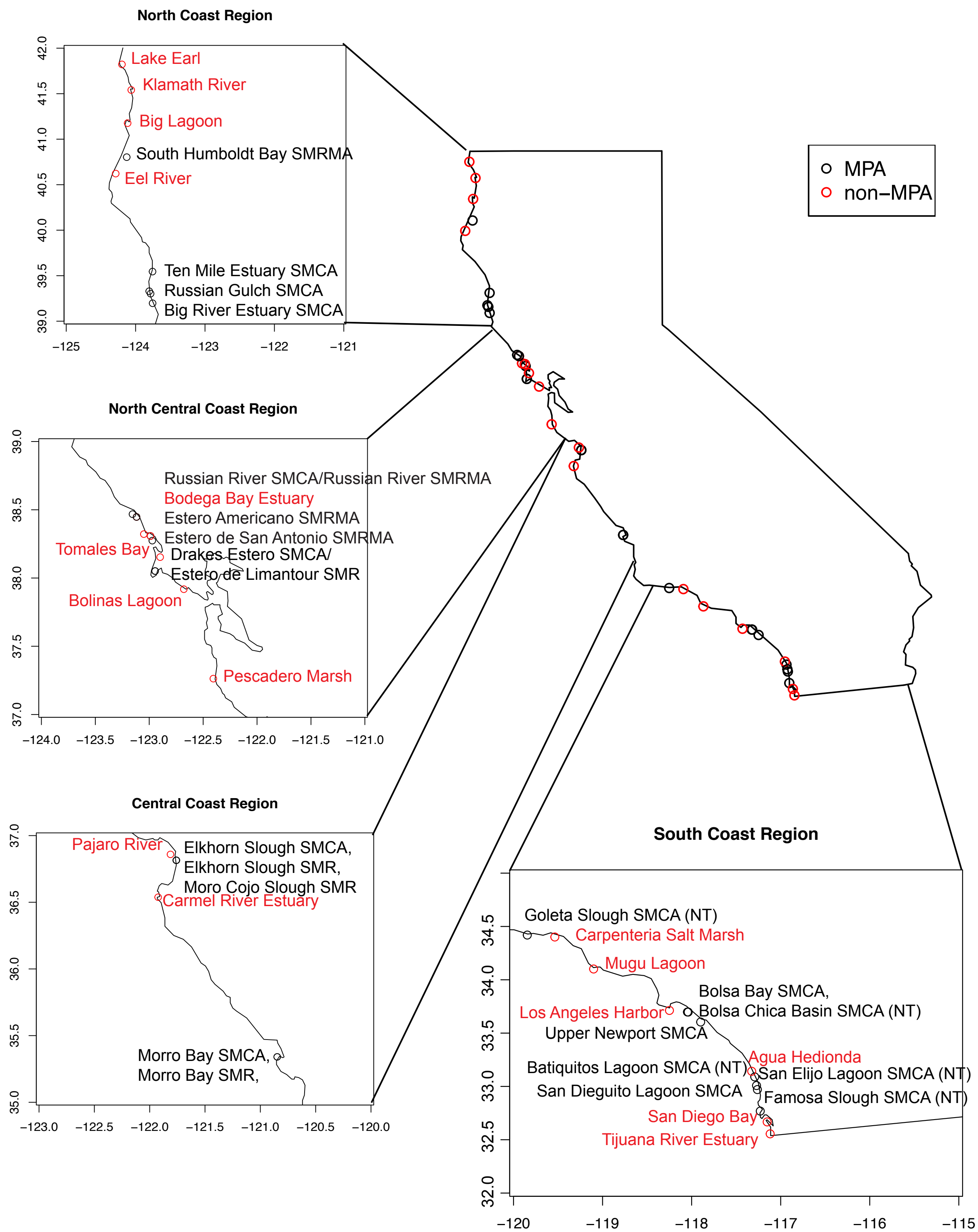

Figure 1. Distribution of estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California. The MLPA defined a fifth region in California, San Francisco Bay, but to-date the MLPA MPA siting process has not begun in that region. NT = No-Take MPA.

Methods

Identification of MPA and reference sites: a crosswalk with previous efforts

We started with a preliminary list of 23 potential estuarine MPAs provided by OST and CDFW. Not all of these MPAs turned out to be estuaries, mainly because, while the name implies estuary, the MPA is actually offshore (e.g., Tijuana River Mouth State Marine Conservation Area - SMCA). We aimed to identity a proportional number of "control" estuaries to compare with MPAs across all four coastal regions. A recent study done by The Nature Conservancy (TNC) and Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) identified 184 estuaries in California that range in size from <1 ha to >10,000 ha (i.e., San Francisco Bay) (Hughes et al. 2014). This database encompassed all estuarine MPAs in California and served as a baseline to identify:

- Estuaries that have known fish and invertebrate monitoring.
- Potential non-MPA (control) estuaries based on the following attributes:
    - Regional representation (among the 4 MPA regions)
    - Estuary type, i.e., lagoon, riverine, bar built, etc.
    - Estuary acreage to ensure that MPAs and control sites are of comparable size.
    - Existing monitoring programs as outlined by the regional MPA monitoring target metrics.

After MPA sites and candidate reference sites were determined (Appendix 1, Table 1), we gathered all target monitoring metrics from regional MPA monitoring plans (MPA Monitoring Enterprise 2010, 2011, 2014) (Appendix 1, Table 2). Each metric was tabulated and compared across the four regions to determine overlap and/or lack of overlap among regions. These metrics were used to evaluate alignment of monitoring efforts in California estuaries with the regional MPA monitoring plans.

Developing the estuarine and wetland monitoring database

After the preliminary list of estuaries was assembled, we developed key attributes for each monitoring program among the candidate list of MPA and control sites. This information aimed to identity the key attributes for each target metric that has known monitoring. To avoid including shorter-term sampling or experimental programs that had no guarantee of commitment to long-term monitoring we set a definition of "long-term monitoring programs". We used the recent definition of long-term monitoring being greater than four years commitment to monitoring (Hughes et al. 2017). By using this strict definition we were able to identify monitoring programs that are likely to extend into the future and worthy of assessing effects from MPAs.

Elkhorn Slough was the first site included in the database – it is a well-studied estuary with many known monitoring programs, and has some of the richest monitoring programs[1] among California estuaries outside of San Francisco Bay. Being part of the NERR system, the statewide MPA network, and a central location for researchers in Monterey Bay made this the ideal first site for this project.

While populating the database for Elkhorn Slough monitoring programs, we generated a list of researchers with potentially relevant monitoring programs and started contacting key researchers and managers. This list was generated using an exhaustive search, which included:

- A list of known fish monitoring in estuaries from the recent TNC and PMEP effort (Hughes et al. 2014).

[1] http://www.elkhornslough.org/research-program/

- Professional contacts of the contractor.
- Suggestions from project partners.
- A list of all researchers conducting estuarine research according to the CDFW scientific collecting permit (SCP) database.
- Leads produced by contacts.

In total this effort produced contacts of 52 researchers and managers across California estuaries (List available upon request)[1].

Populating the MPA monitoring database, a multi-tiered approach

Once contact was established with targeted researchers, we reached out to request information on relevant monitoring programs (see Appendix 2 for form letter requests). This approach began with an email introducing this project and major collaborators, followed with a few short questions:

- Do you monitor any of the following metrics (Table 1)?
- Is this monitoring program committed to the next five years or more?
- Can you provide me specific details about the monitoring program to populate the database?

Table 1. List of target metrics for estuarine monitoring listed for the MLPA monitoring process across all 4 regions (Figure 1).

Acipenser spp.	Marine mammal density
Anas spp.	Native oyster bed areal extent/abundance
Anthya spp.	*Oncorhyncus* spp.
Arthropod biomass	Pacific gaper clam abundance
Bat ray abundance	Parasite diversity
Black Brandt	pH/Carbonate chemistry
Black seaperch density & size structure	Pickleweed areal extent
CA halibut abundance & size frequency	Pile surfperch density & size structure
Cancer magister density	Piscivorous bird richness & abundance
Clam adundance and size frequency	Pleuronectidae
Common littleneck clam abundnce	Scolopacidae
Croaker abundance & size frequency	Shorebird richness & abundance
Diamond turbot density $ size structure	Spotted sand bass density & size structure
DO (dissolved oxygen)	Spp diversity (invert and fish functional groups)
Eelgrass areal extent	Spp richness (inverts and fishes)
Eelgrass density & % cover	Starry flounder abundance & size frequency
Fat innkeeper worm	Surfperch abundance & size frequency (any spp.)
Ghost and/or mud shrimp abundance	Topsmelt denisty & size structure
Gobies density & size structure	*Ulva* areal extent
Harbor porpoise	Washington clam abundance
Leopard shark density & size structure/abundance	Western Gull
Marine bird richness & abundance	

[1]Contact Erin Meyer (erin.meyer@oceansciencetrust.org) for access to the complete list of contacts.

For some of the lesser-known programs on the list and to further investigate potential programs, we performed online searches to find monitoring programs across the state, which included the following databases:

- California Environmental Exchange Network (CEDEN)
- CDFW
- NERR
- NEP
- San Onofre Nuclear Generating Station Mitigation Monitoring Program (SONGS)

These databases were checked for monitoring metrics and long-term commitment to monitoring. When applicable, researchers from each program were contacted to verify if monitoring was planned as long-term (> 4 years).

In addition, CDFW provided a list of all known research efforts in California estuaries based on their SCP database. We contacted all researchers in this database to ask them the multi-tiered questions as described above and limited any follow-up research (Appendix 2) to those programs/projects committed to long-term monitoring.

Analysis and Results

Using our MPA monitoring database[1], we generated summary figures of the following:

- Map of locations with known monitoring programs, coded as MPA v. non-MPAs (Figure 1).
- Assessment of target metrics across the coast (Table 1) to address the following questions:
  - What metrics are most common across MPAs?
  - What are the biggest gaps in target metrics?

Figures 2-18 show the distribution of monitoring programs where more than one site has monitoring of a given target metric.

What metrics are most common across MPAs?

Out of all of the target metrics for the 23 MPA and 15 reference sites, dissolved oxygen (n = 7 MPAs, n = 6 reference sites), pH (n = 5 MPAs, n = 6 reference sites), and eelgrass areal extent (n = 6 MPAs, n = 4 reference sites) has the greatest number of long-term monitoring sites (Figures 2-3, Table 2). Each of the four regions has some monitoring of pH and DO, but only the North Coast lacks a reference site. For eelgrass, all regions except for the North Central Coast have monitoring, and the North Coast only has one MPA site.

What are the biggest gaps in target metrics, MPAs vs. Reference sites, and regions?

For this assessment of the 23 MPAs and 15 non-MPA reference sites (N = 38 sites), there appears to be a general lack of monitoring of estuaries (MPA or non-MPA) across the state of California. Other than DO, pH, and eelgrass areal extent, there are no other metrics monitored at ten or more monitoring sites (Table 2). However, it should be noted that most metrics are region-specific making it challenging to assess monitoring target metrics across the state.

[1]Contact Erin Meyer (erin.meyer@oceansciencetrust.org) for access to the monitoring database.

Over the entire state of California, monitoring programs are proportionally distributed among MPA sites (n = 77) and non-MPA reference sites (n = 64). However, at finer regional scales, these proportions are not consistent. For example, in the North Coast, only Humboldt Bay has representative monitoring programs, compared to only one non-MPA reference site, Eel River Estuary, where sturgeon is monitored. The Central Coast has good representation of monitoring in MPAs, but has no monitoring in non-MPA reference sites. This is partly due to the lack of estuaries in the region because of geological factors, and that the four MPAs (Elkhorn Slough SMR/ State Marine Conservation Area - SMCA, Moro Cojo Slough SMR, and Morro Bay State Marine Recreational Management Area - SMRMA) are monitored as part of two federal programs: NERR and NEP. The region with the most representation of monitoring programs is the South Coast (Table 2). This is expected because of the greater abundance of estuaries compared to the other regions (Hughes et al. 2014). However, certain programs exist, such as SONGS, which has long-term mitigation monitoring programs established at four estuaries (1 MPA, 3 non-MPA) in the region.

Table 2. Collated target monitoring metrics across the four coastal MPA regions. NA signifies that the metric is not a target metric for the region.

REGION, **M** = MPA (N = 23), **R** = Reference (N = 15)

	North		***N. Central***		***Central***		***South***		**TOTAL**	
Target Metric	**M**	**R**	**M**	**R**	**M**	**R**	**M**	**R**	**M**	**R**
Acipenser *spp.*	0	1	NA	NA	NA	NA	NA	NA	**0**	**1**
Anas *spp.*	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Anthya *spp.*	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Arthropod biomass	0	0	NA	NA	NA	NA	1	3	**1**	**3**
Bat ray abundance	0	0	0	0	NA	NA	NA	NA	**0**	**0**
Black Brandt	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Black seaperch density & size structure	NA	NA	NA	NA	0	0	NA	NA	**0**	**0**
CA halibut abundance & size frequency	1	0	0	0	NA	NA	1	3	**2**	**3**
Cancer magister density	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Clam abundance and size frequency	0	0	0	0	3	0	1	3	**4**	**3**
Common littleneck clam abundance	0	0	0	0	NA	NA	1	3	**1**	**3**
Croaker abundance & size frequency	NA	NA	NA	NA	NA	NA	1	3	**1**	**3**
Diamond turbot density & size structure	NA	NA	NA	NA	0	0	NA	NA	**0**	**0**
DO (dissolved oxygen)	1	0	0	2	5	0	1	4	**7**	**6**
Eelgrass areal extent	1	0	0	0	4	0	1	4	**6**	**4**
Eelgrass density & % cover	0	0	0	0	1	0	0	0	**1**	**0**
Fat innkeeper worm	0	0	0	0	1	0	NA	NA	**1**	**0**
Ghost and/or mud shrimp abundance	0	0	0	0	0	0	1	3	**1**	**3**
Gobies density & size structure	1	0	NA	NA	NA	NA	1	3	**2**	**3**
Harbor porpoise	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Leopard shark density & size/abundance	1	0	0	0	NA	NA	1	3	**2**	**3**
Marine bird richness & abundance	0	0	2	0	5	0	0	0	**7**	**0**
Marine mammal density	0	0	2	0	5	0	0	0	**7**	**0**
Native oyster bed areal extent/abundance	0	0	0	0	2	0	NA	NA	**2**	**0**
Oncorhyncus *spp.*	1	0	NA	NA	NA	NA	NA	NA	**1**	**0**
Pacific gaper clam abundance	0	0	0	0	1	0	0	3	**1**	**3**
Parasite diversity	NA	NA	NA	NA	NA	NA	0	0	**0**	**0**
pH/Carbonate chemistry	1	0	0	2	3	0	1	4	**5**	**6**
Pickleweed areal extent	NA	NA	0	0	NA	NA	1	4	**1**	**4**
Pile surfperch density & size structure	NA	NA	NA	NA	0	0	NA	NA	**0**	**0**
Piscivorous bird richness & abundance	0	0	NA	NA	5	0	0	0	**5**	**0**
Pleuronectidae	1	0	NA	NA	NA	NA	NA	NA	**1**	**0**
Scolopacidae	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Shorebird richness & abundance	0	0	NA	NA	5	0	0	0	**5**	**0**
Spotted sand bass density & size structure	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
Spp diversity (invert and fish functional groups)	NA	NA	0	0	NA	NA	3	3	**3**	**3**
Spp richness (inverts and fishes)	NA	NA	0	0	NA	NA	3	3	**3**	**3**
Starry flounder abundance & size frequency	1	0	0	0	NA	NA	NA	NA	**1**	**0**
Surfperch abundance & size frequency	0	0	NA	NA	0	0	NA	NA	**0**	**0**
Topsmelt denisty & size structure	NA	NA	NA	NA	0	0	1	3	**1**	**3**
Ulva *areal extent*	0	0	0	0	3	0	NA	NA	**3**	**0**
Washington clam abundance	NA	NA	NA	NA	NA	NA	1	3	**1**	**3**
Western Gull	0	0	NA	NA	NA	NA	NA	NA	**0**	**0**
TOTAL	**9**	**1**	**8**	**4**	**43**	**0**	**21**	**59**	***77***	***64***

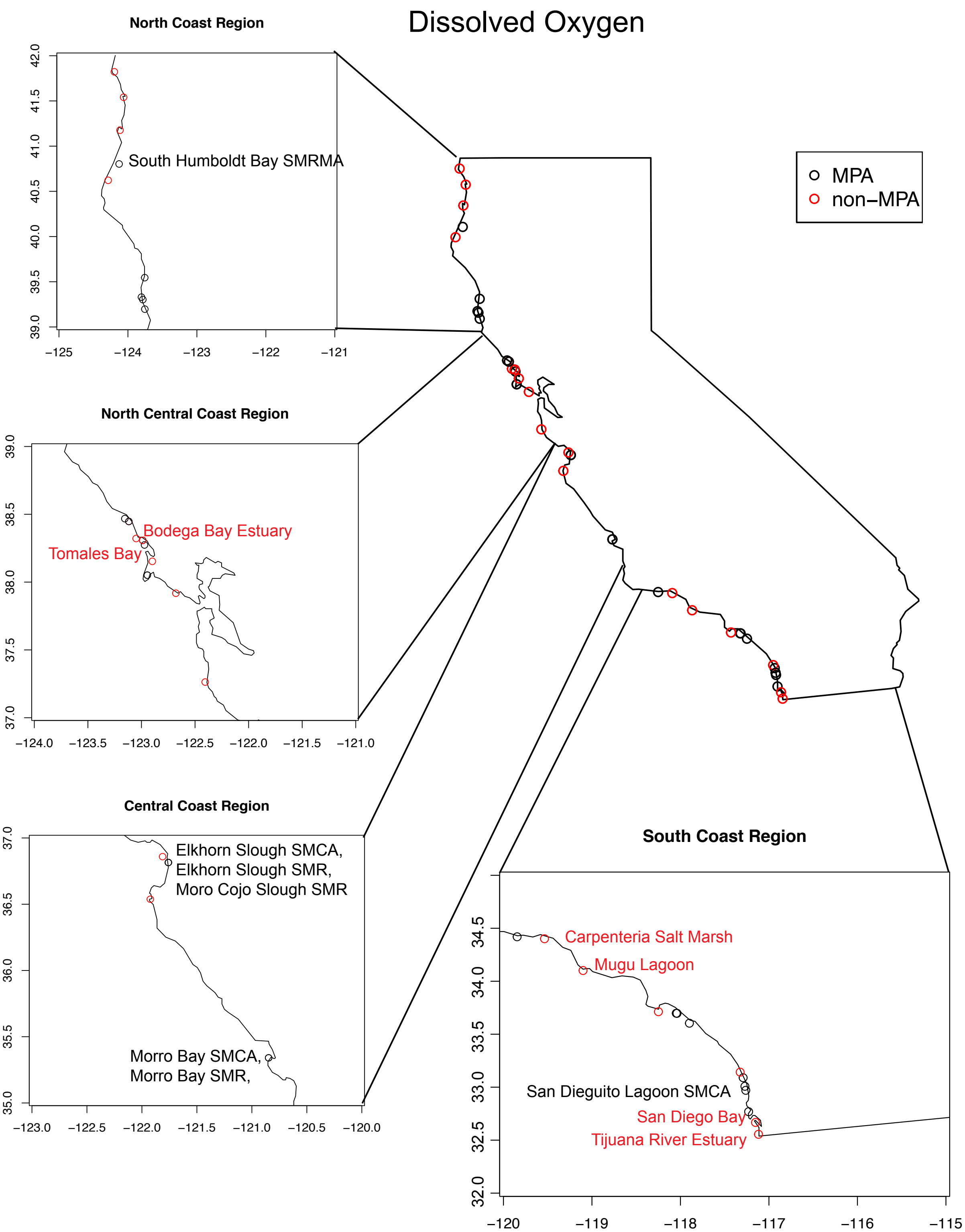

Figure 2. Distribution of dissolved oxygen monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

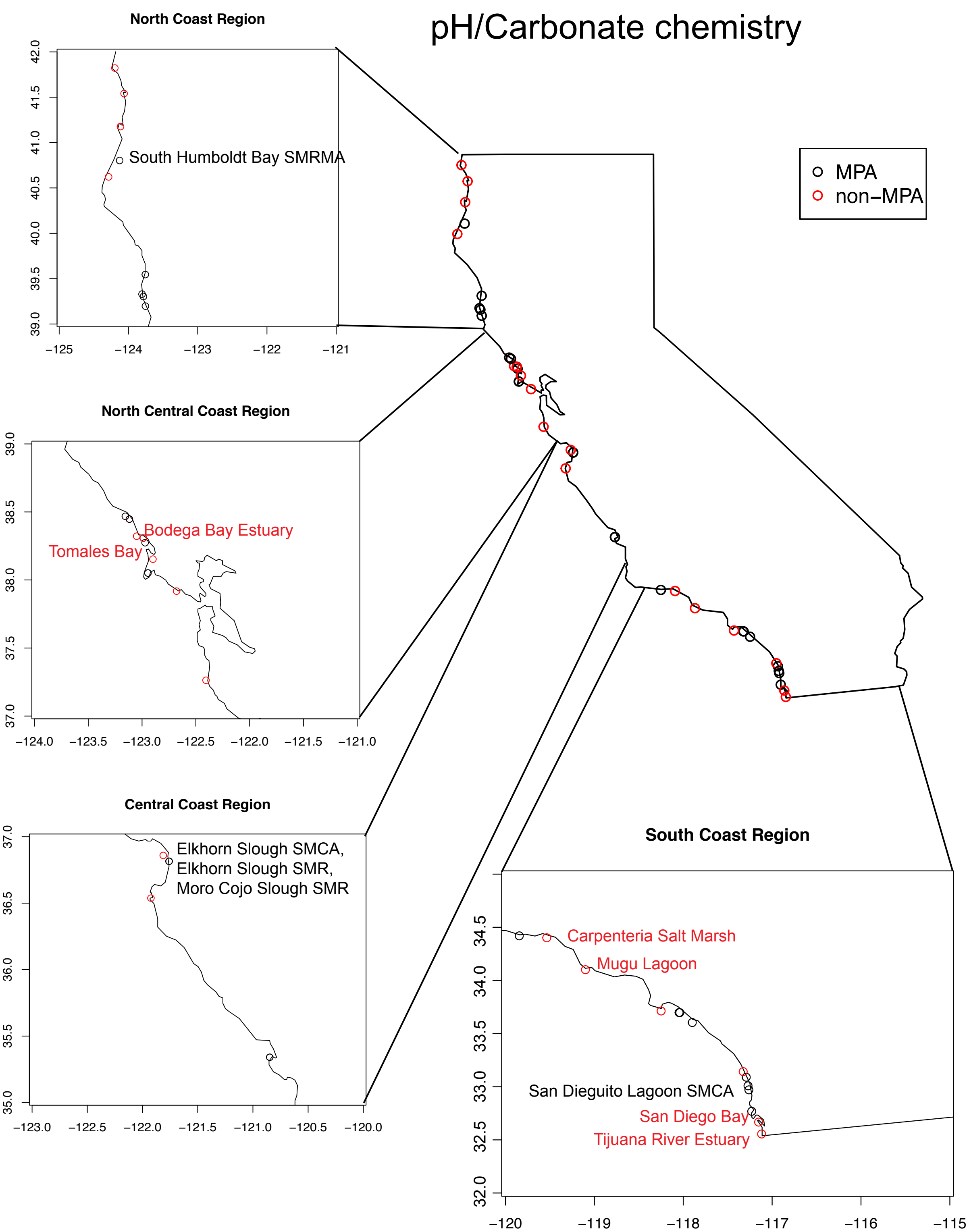

Figure 3. Distribution of pH monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

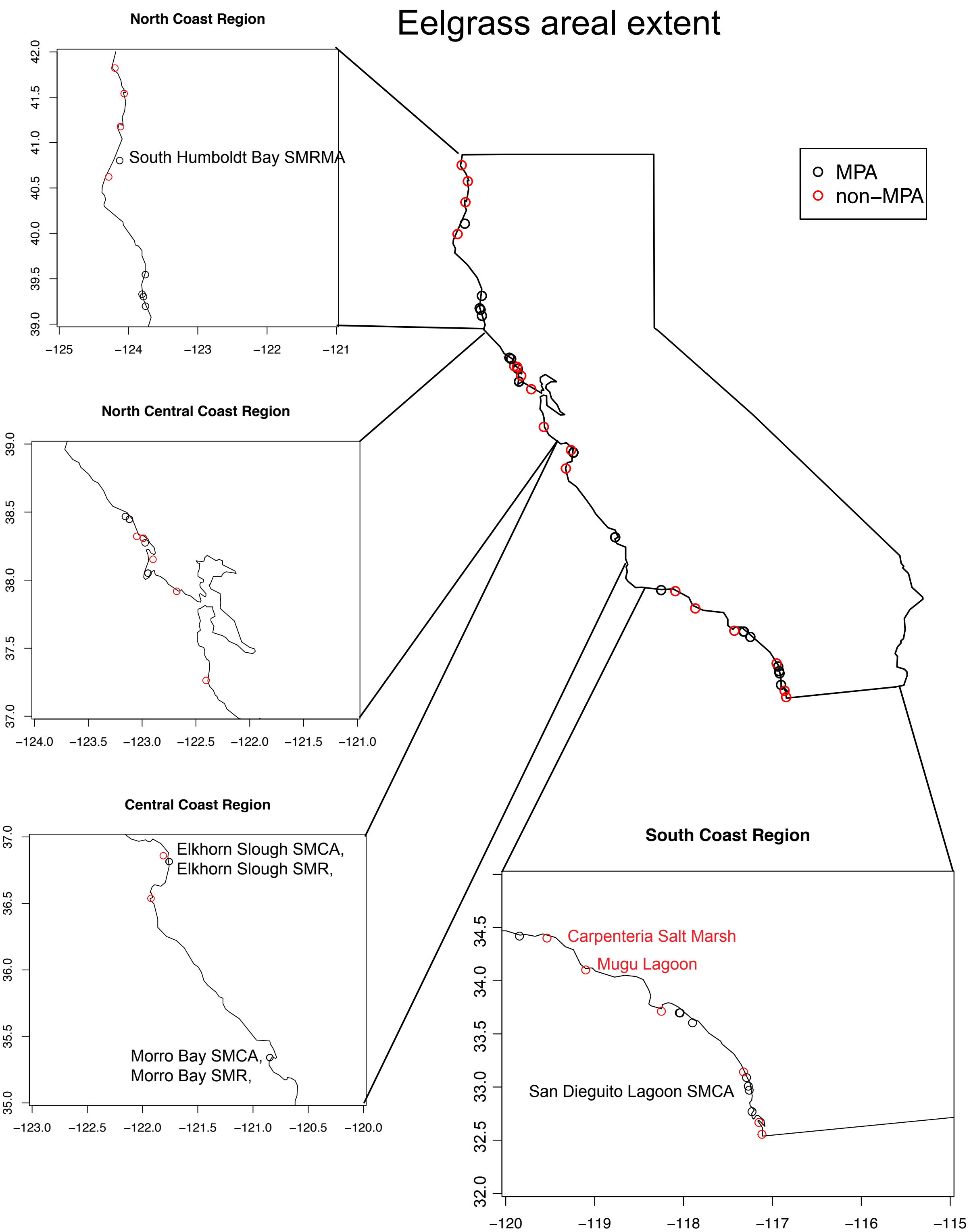

Figure 4. Distribution of eelgrass (*Zostera marina*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

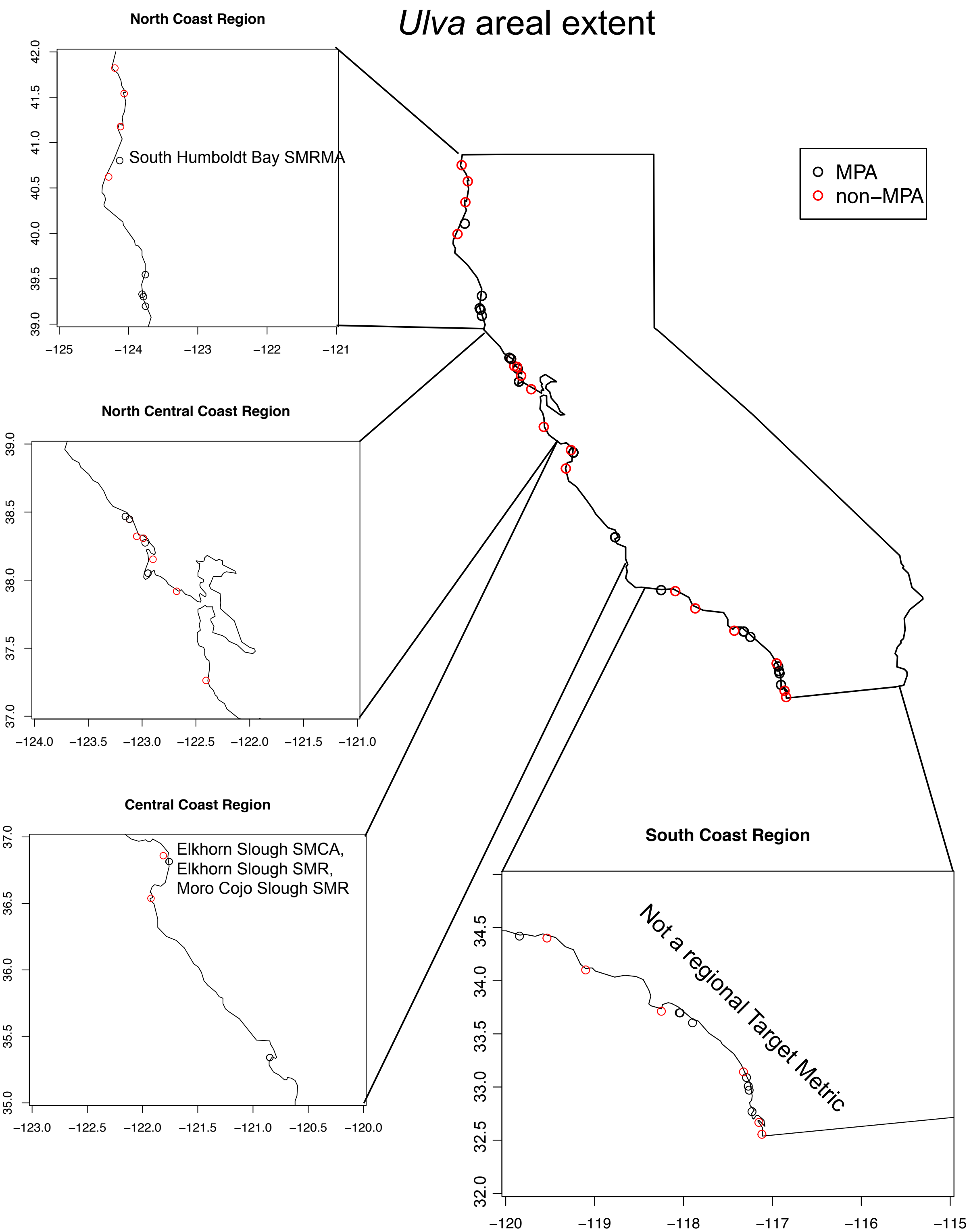

Figure 5. Distribution of green alga *Ulva* spp. monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

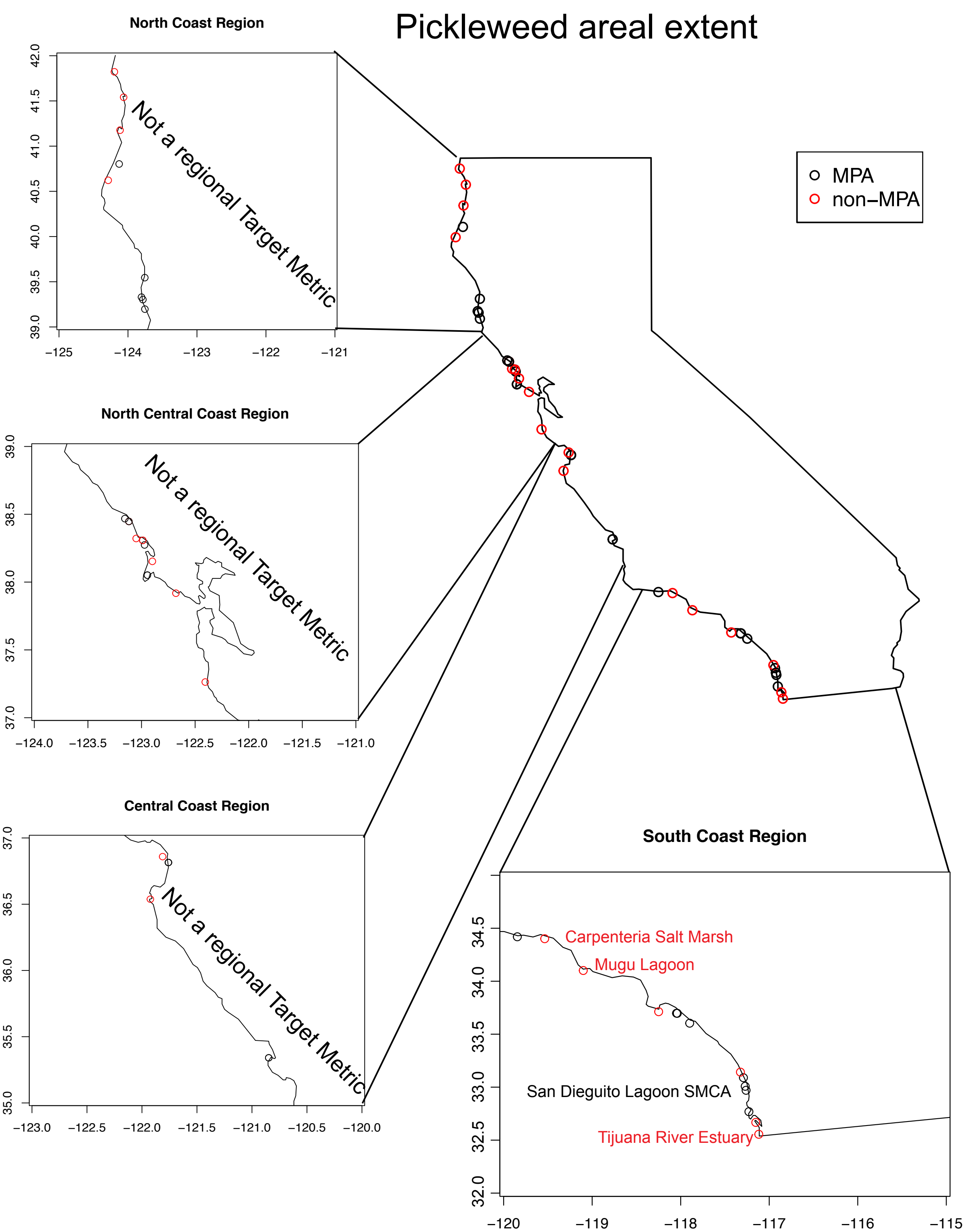

Figure 6. Distribution of pickleweed salt marsh (*Salicornica virginica*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

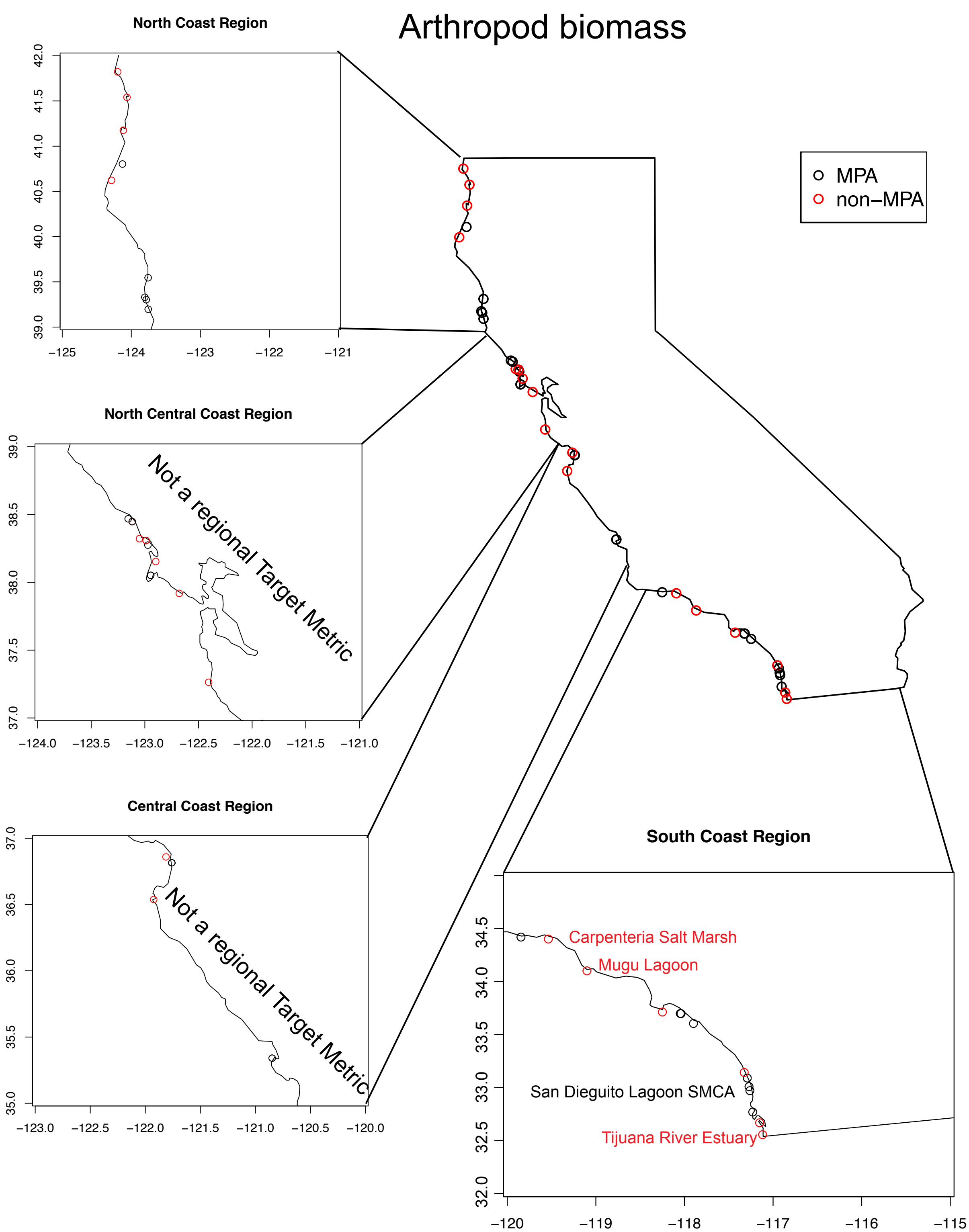

Figure 7. Distribution of arthropod biomass monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

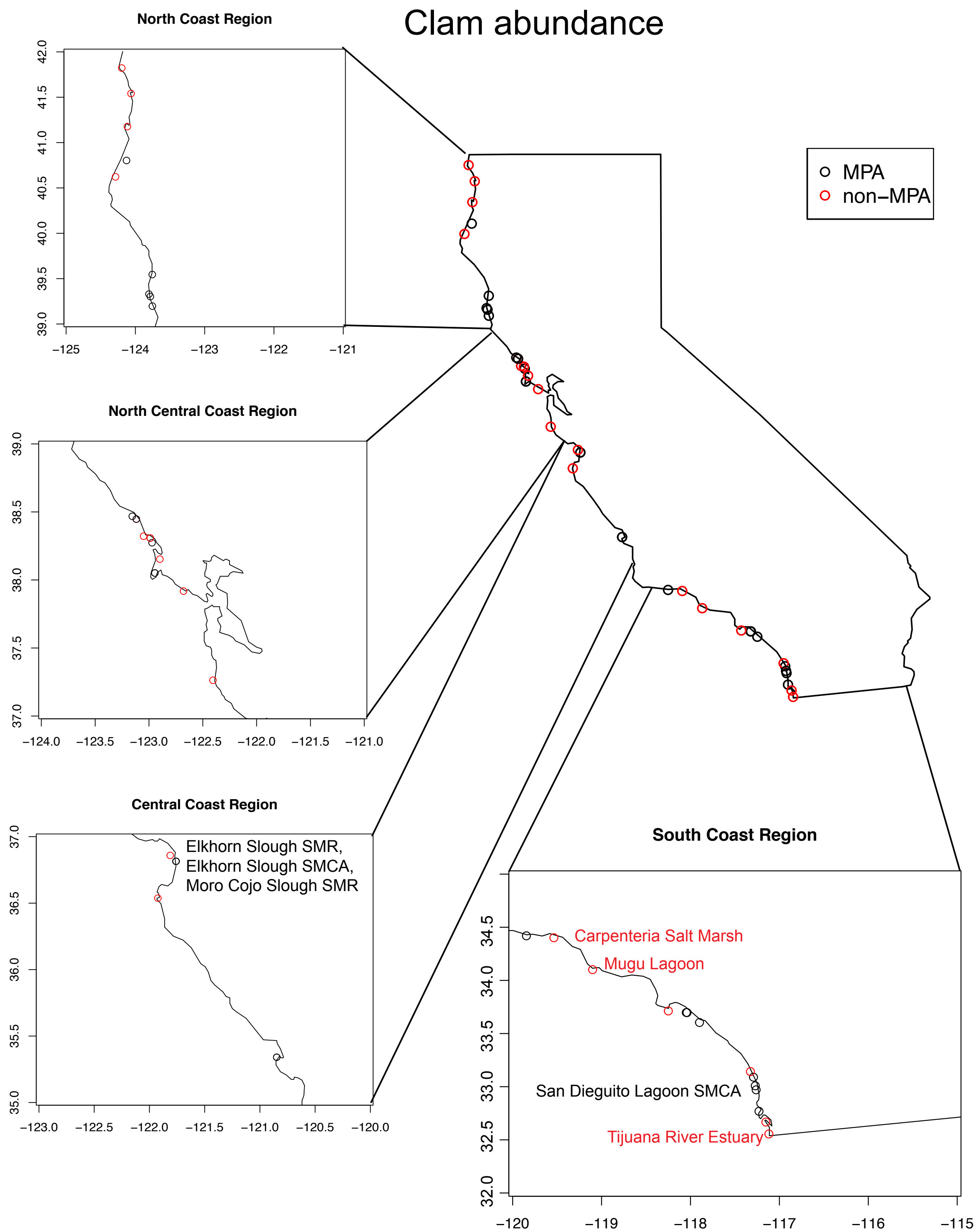

Figure 8. Distribution of clam abundance monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

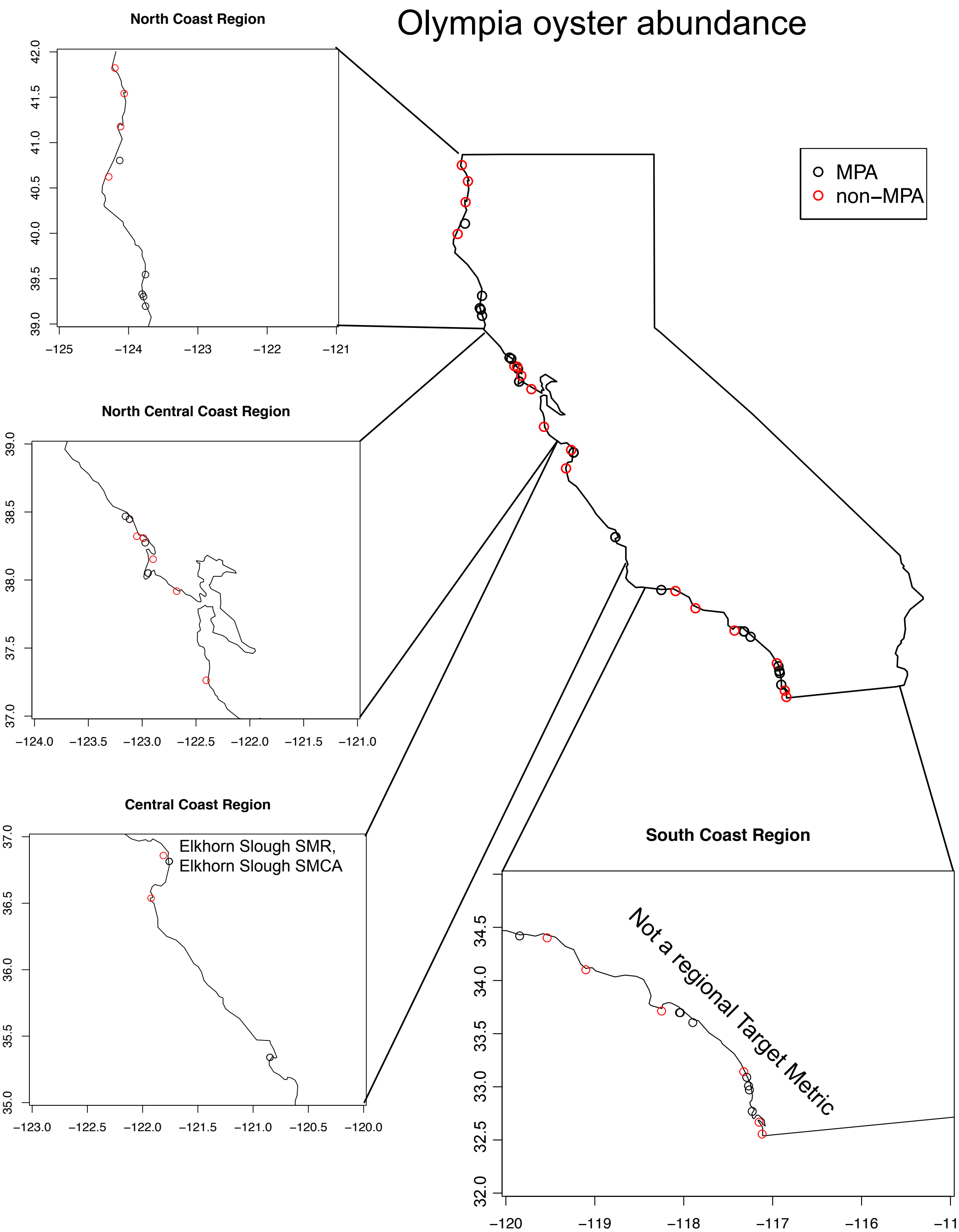

Figure 8. Distribution of Olympia oyster (*Ostrea lurida*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

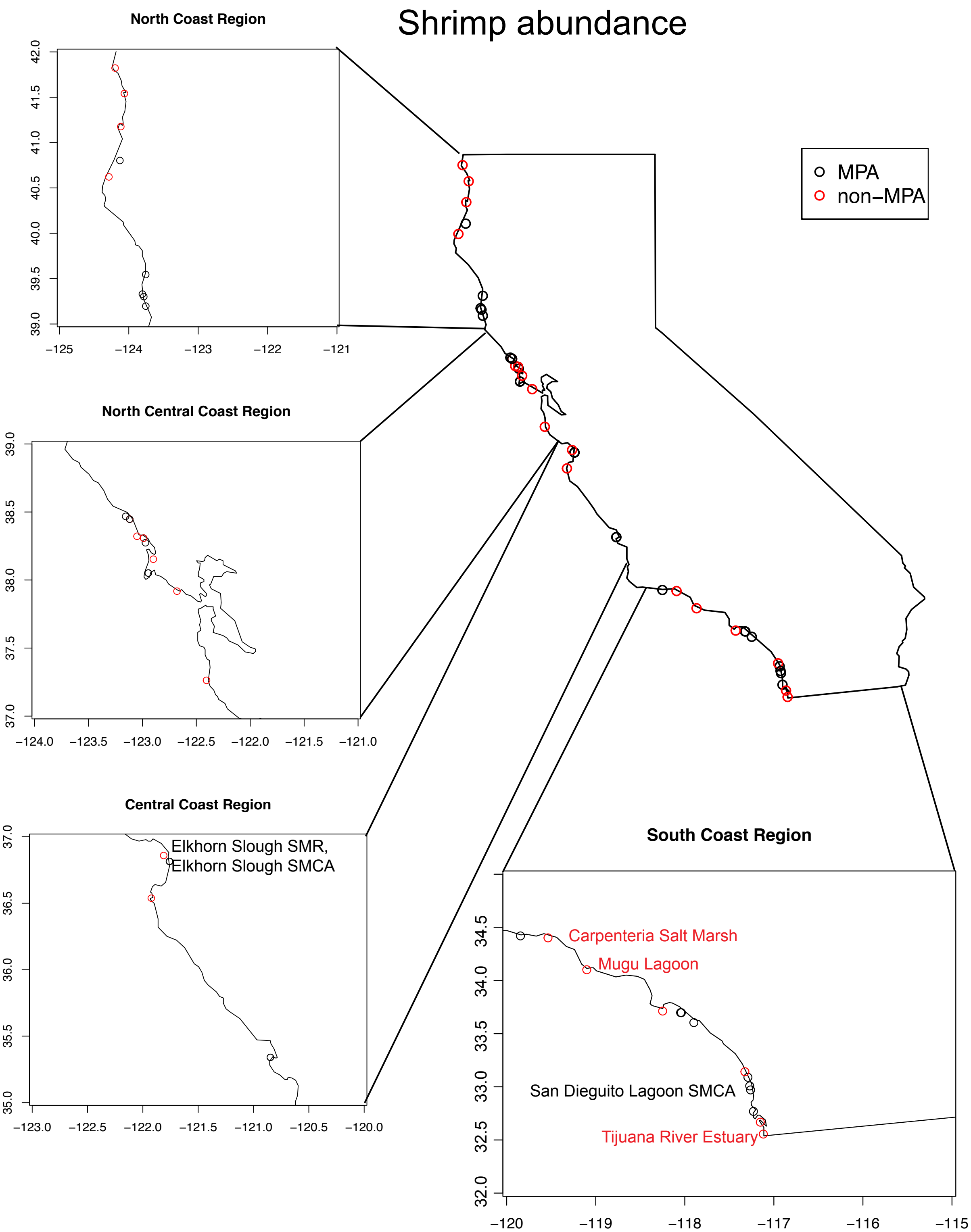

Figure 9. Distribution of shrimp monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

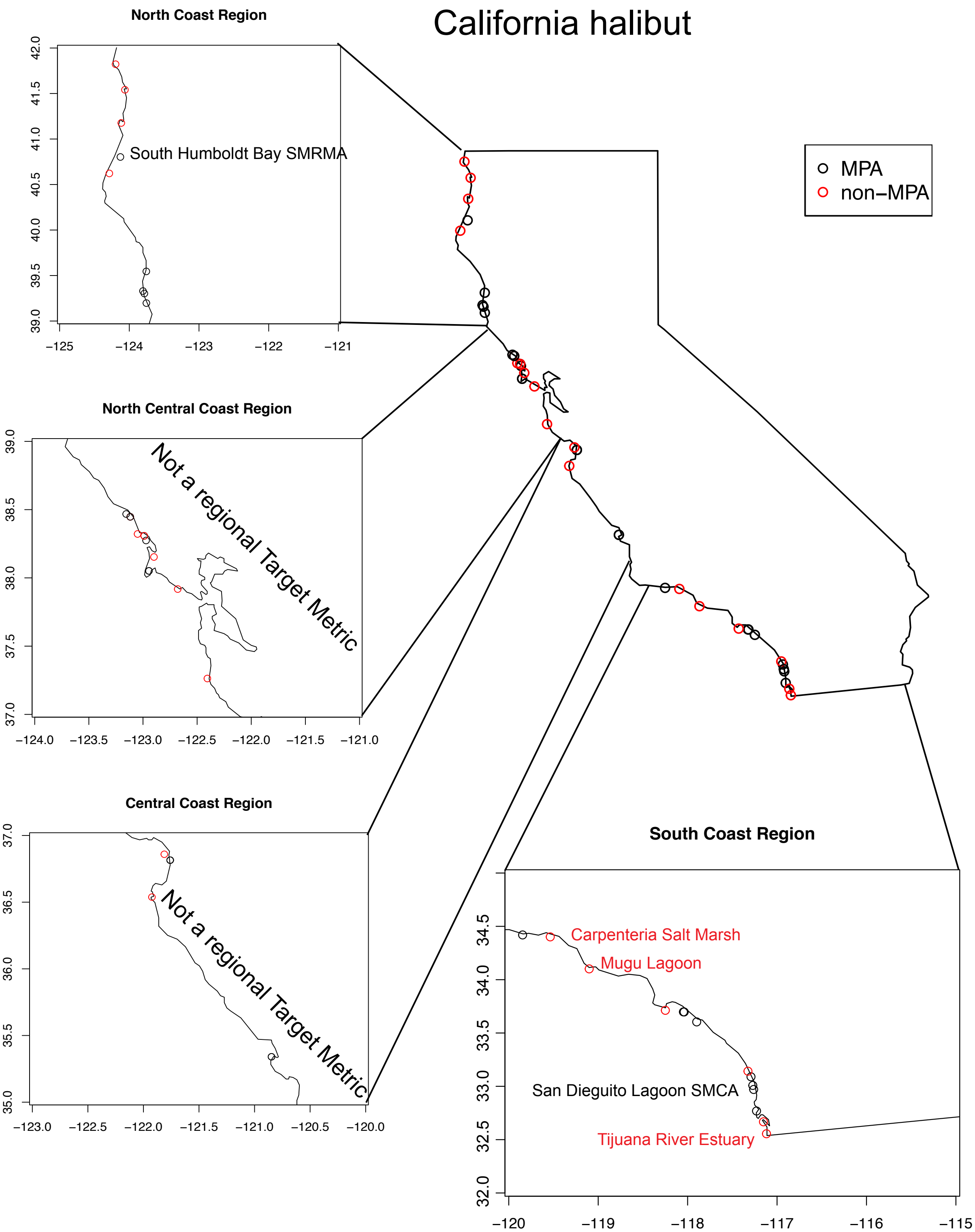

Figure 10. Distribution of California halibut (*Paralichthys californicus*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

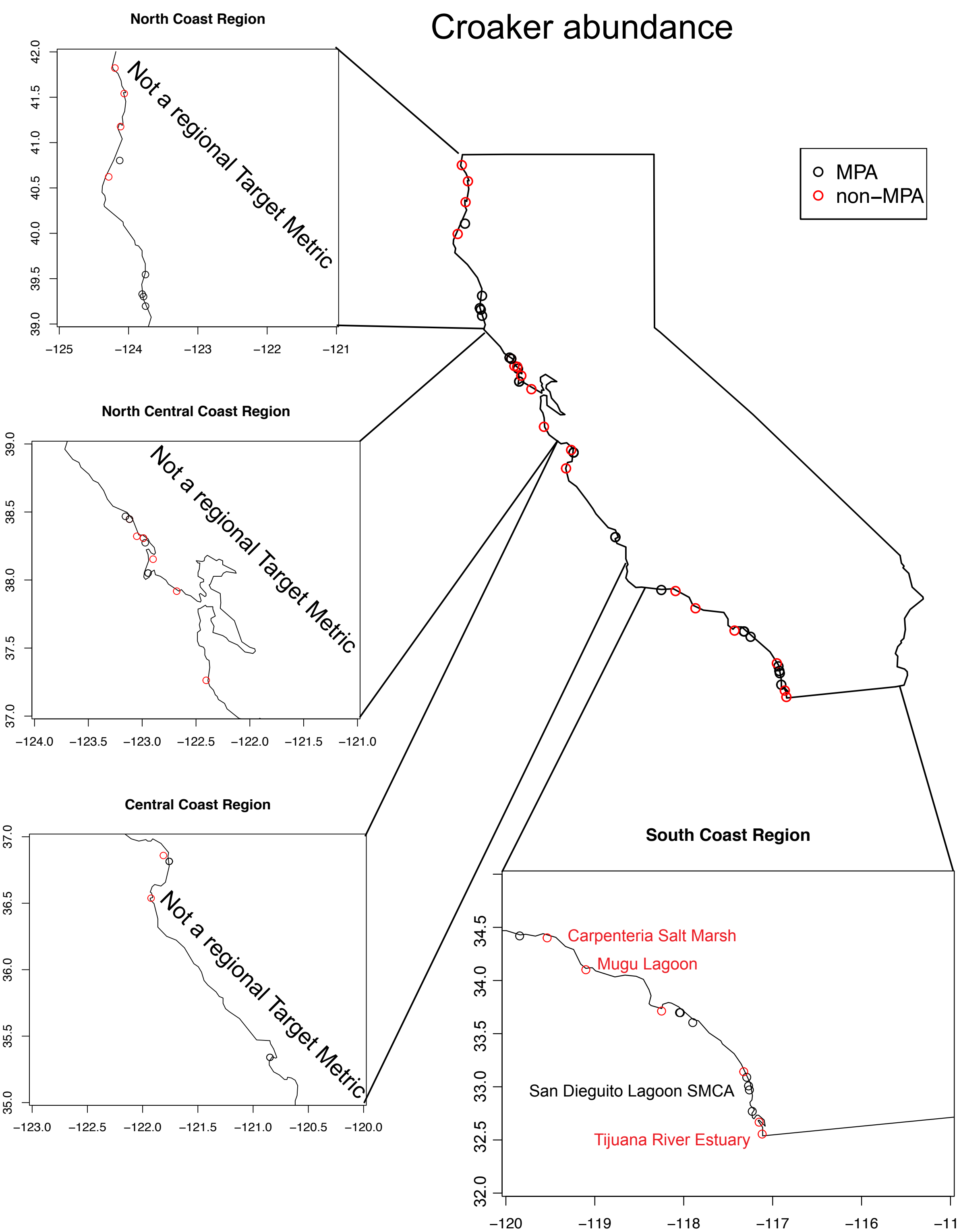

Figure 11. Distribution of croaker (*Menticirrhus* sp.) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

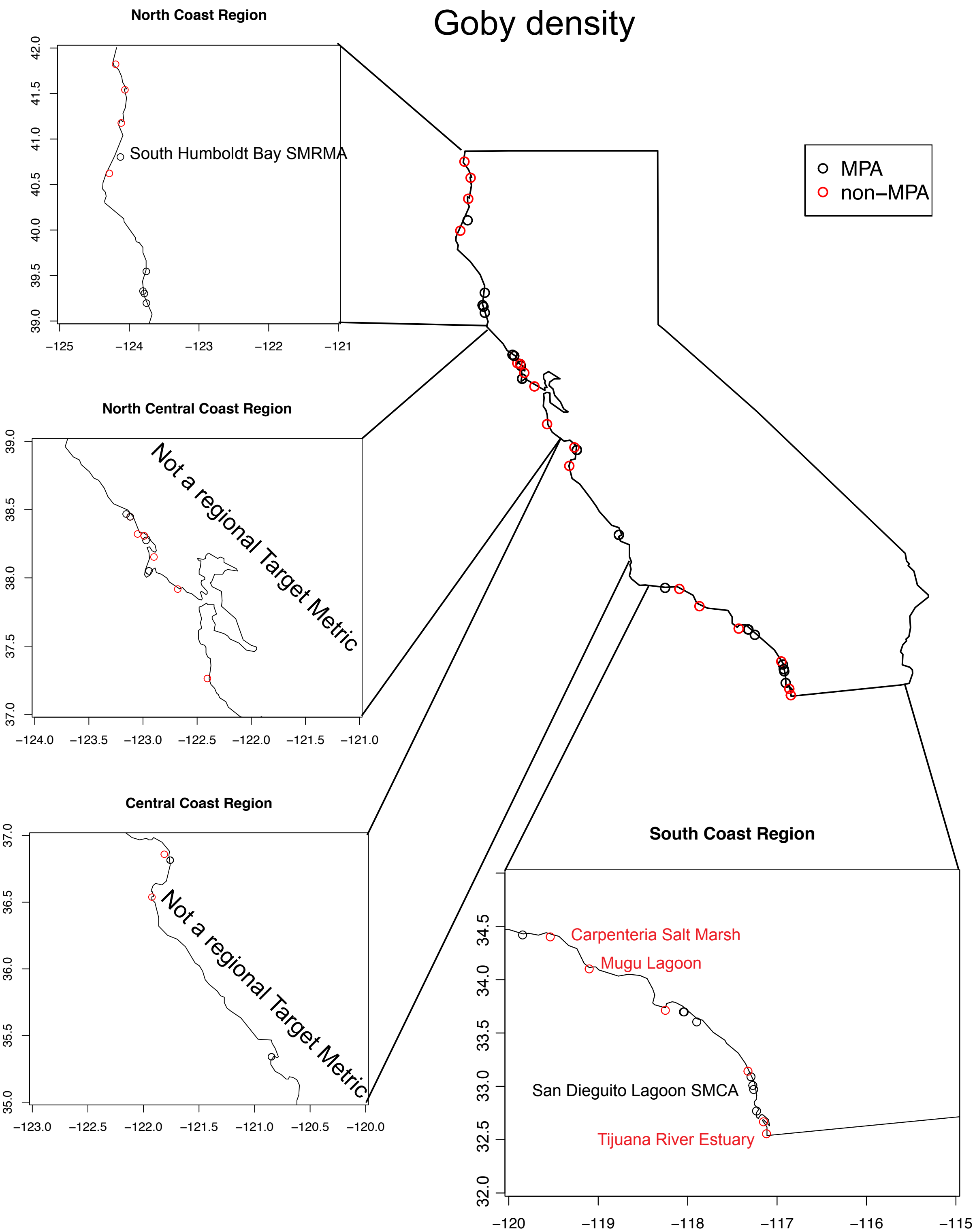

Figure 12. Distribution of Goby (family Gobiidae) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

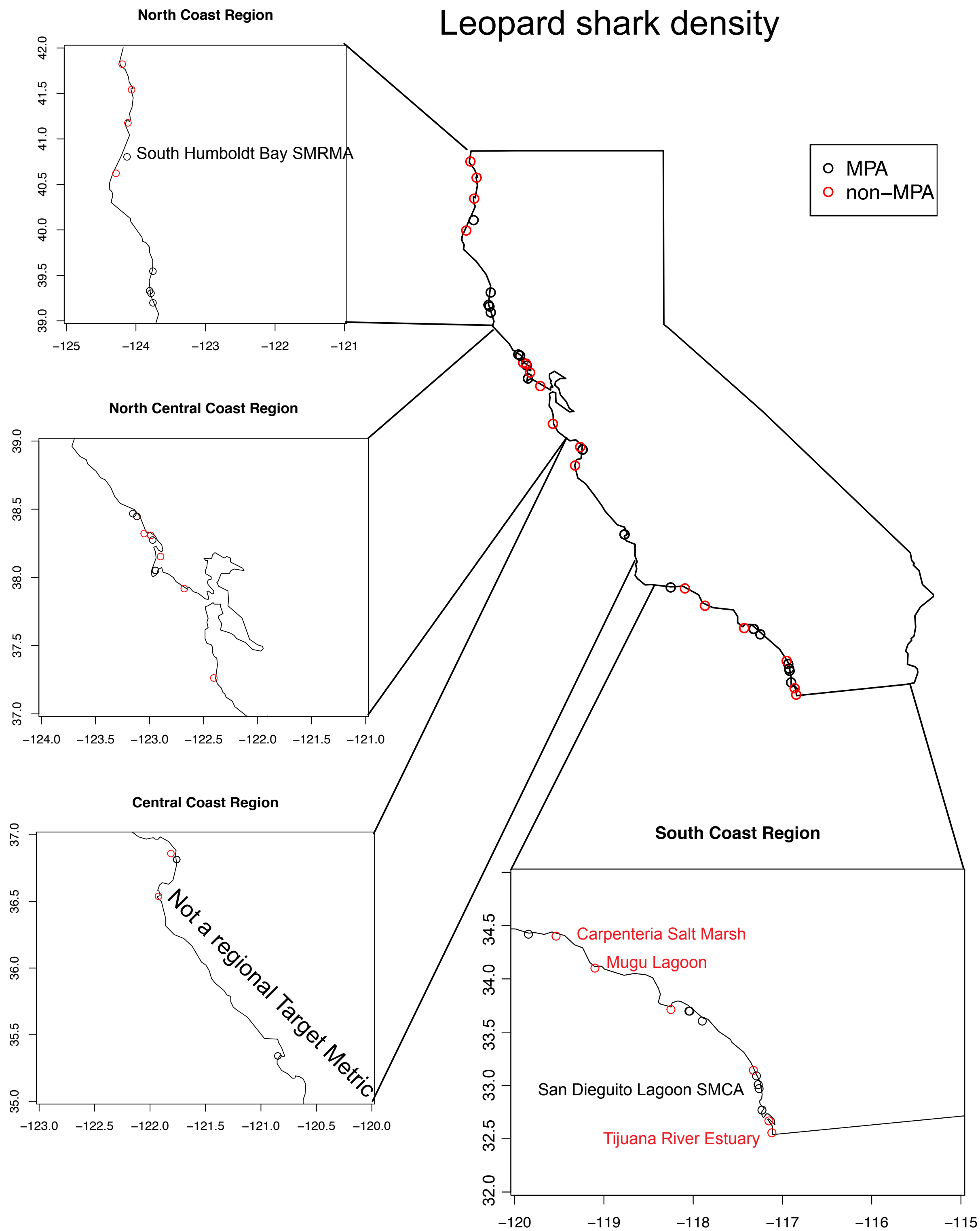

Figure 13. Distribution of leopard shark (*Triakis semifasciata*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

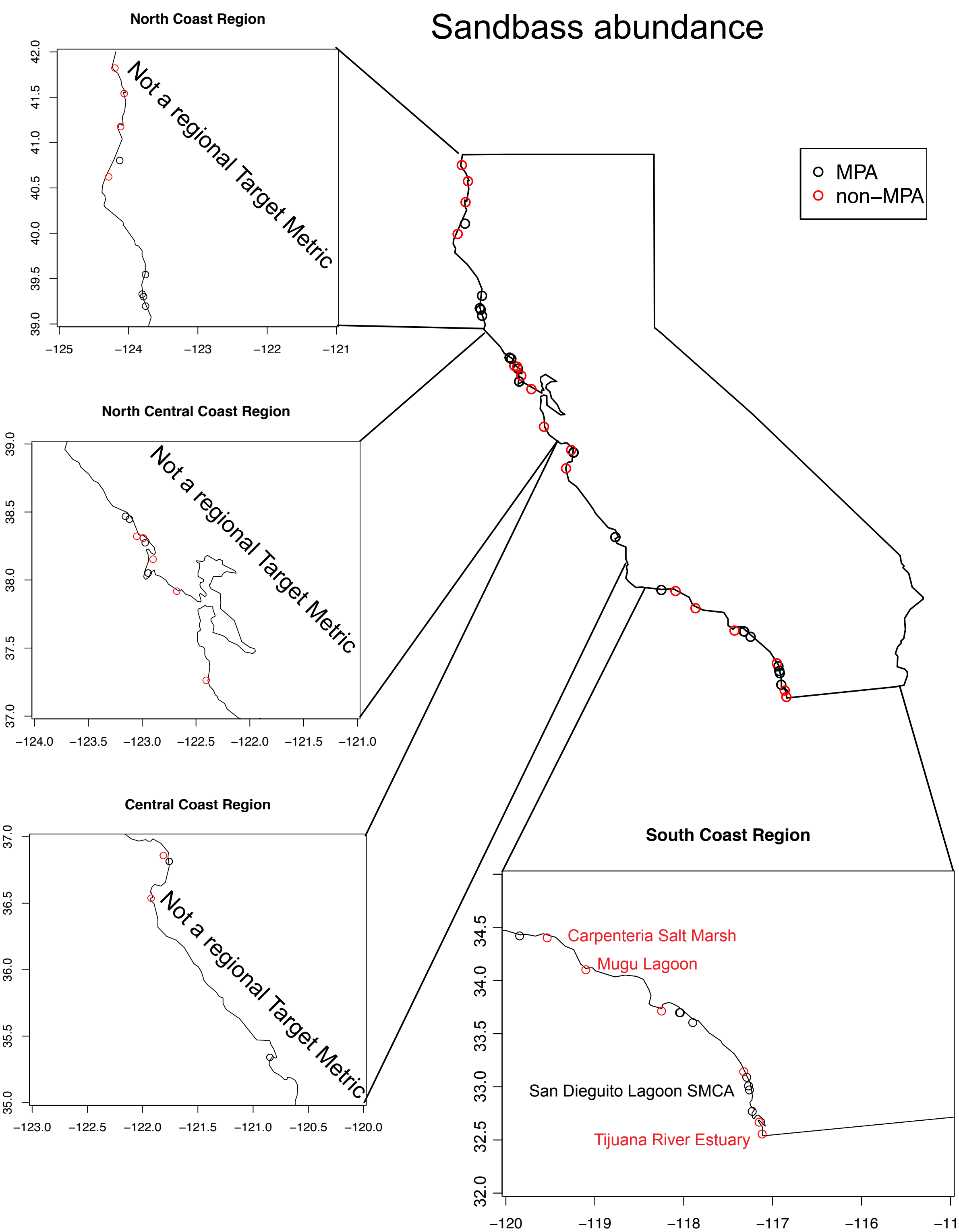

Figure 14. Distribution of spotted sandbass (*Paralabrax maculatofasciatus*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

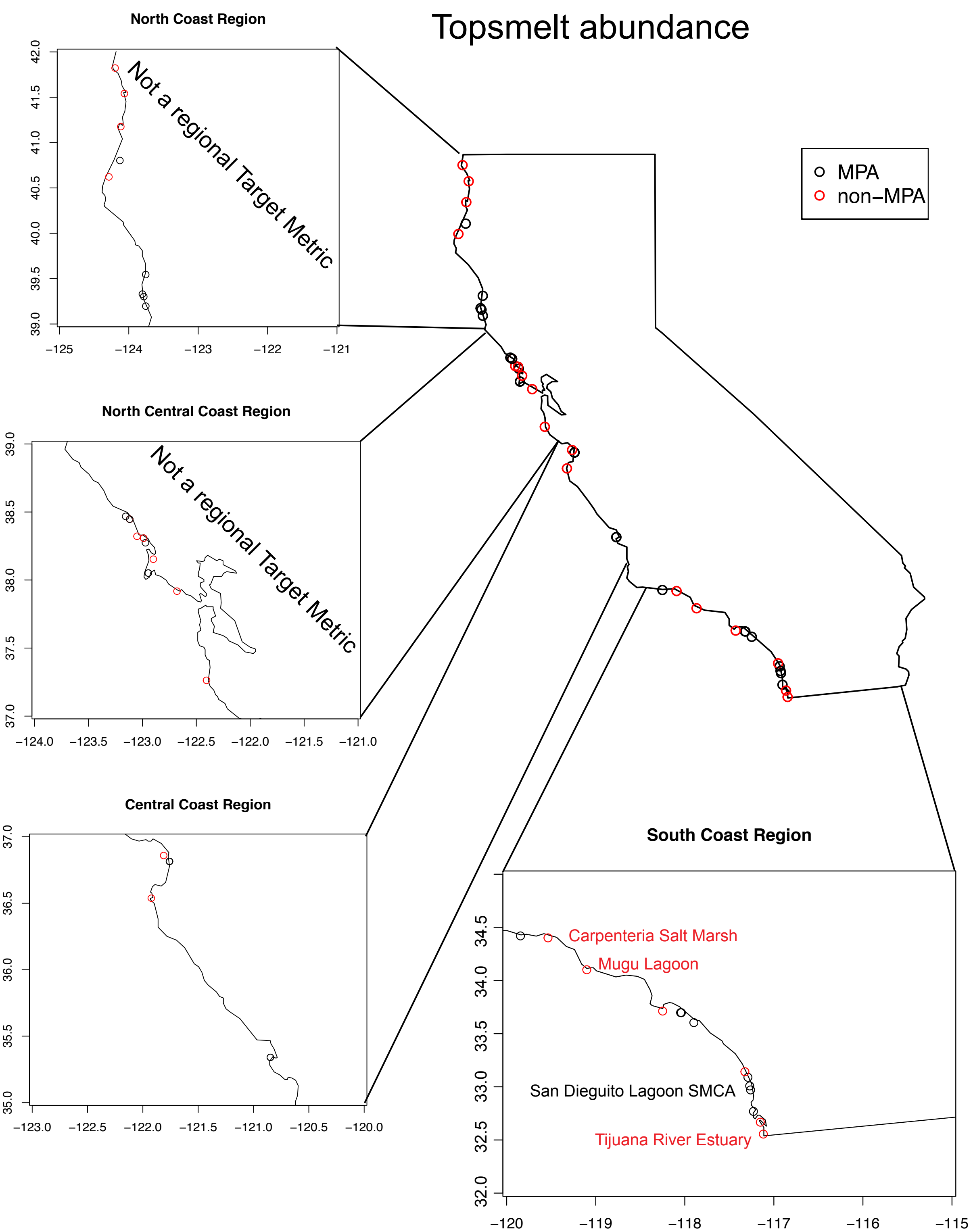

Figure 15. Distribution of topsmelt (*Atherinops affinis*) monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

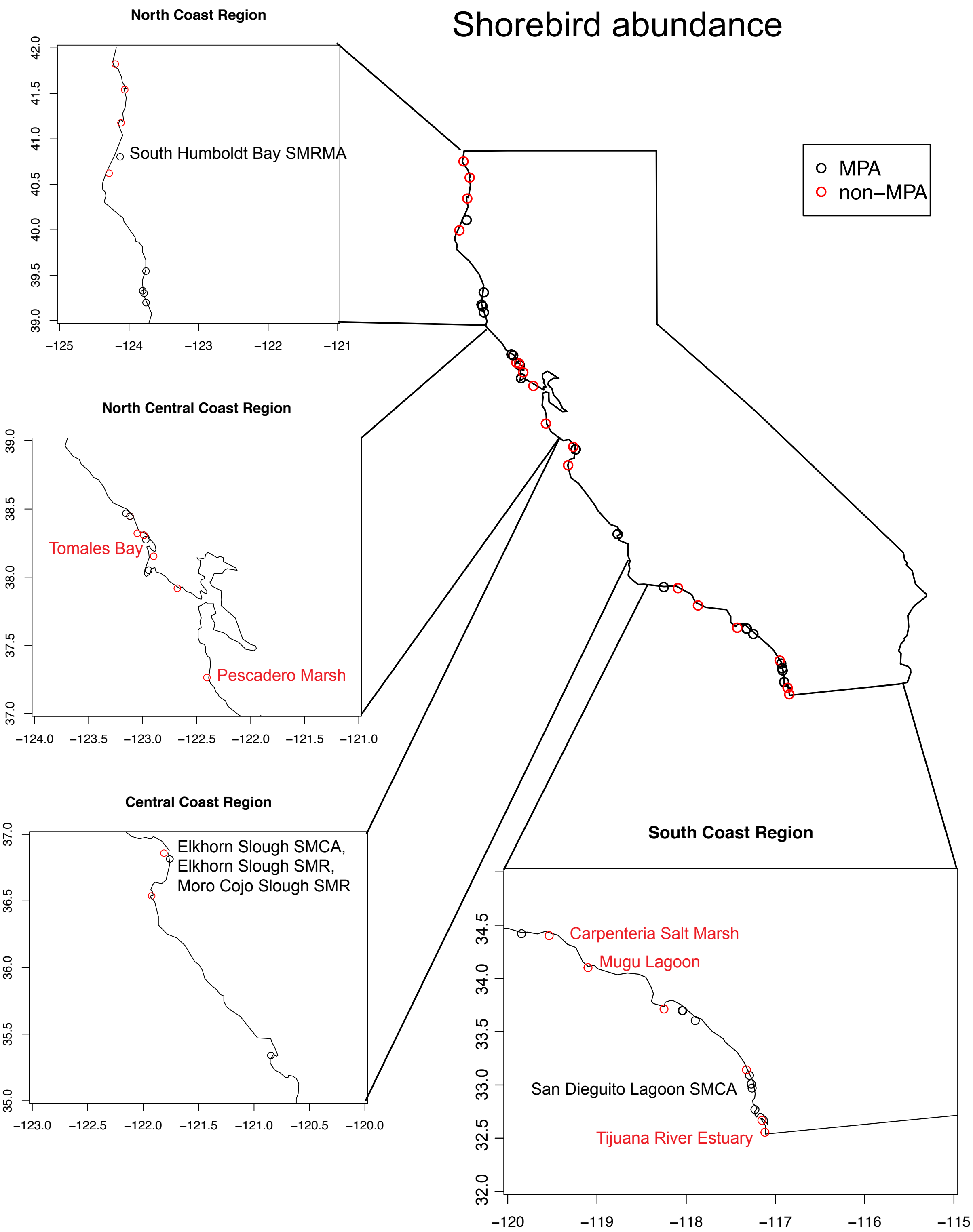

Figure 16. Distribution of shorebird monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

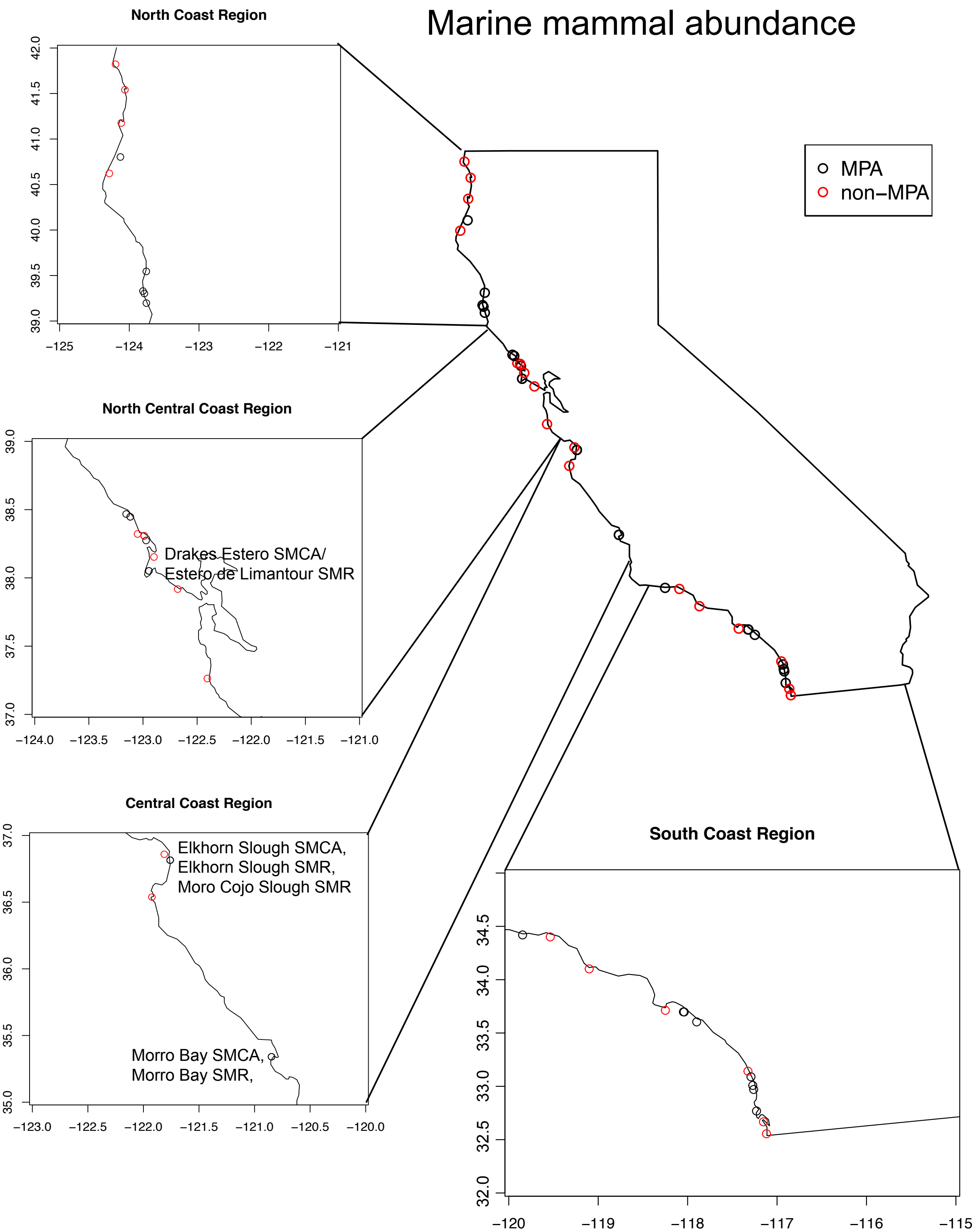

Figure 17. Distribution of marine mammal monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

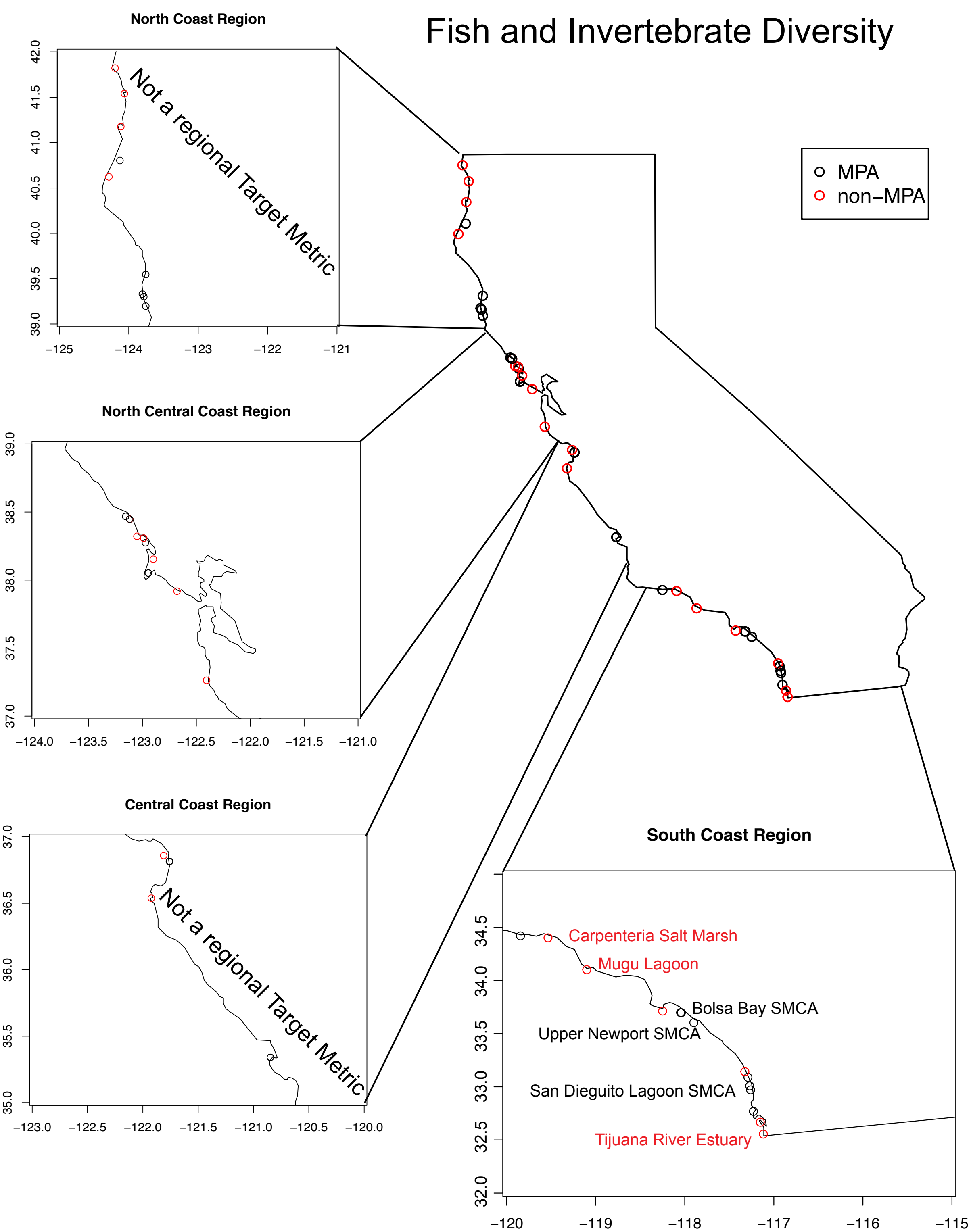

Figure 18. Distribution of species diversity monitoring programs in estuarine MPAs (black) and non-MPA reference sites (red) in four regions across California.

Discussion, Recommendations and Next Steps

Paucity of existing monitoring programs and funding for CA estuaries

This project demonstrates that there is a general lack of monitoring in California estuaries, including within the MPA network. The programs that do exist are not integrated into a larger network. This translates to a lack of standardized methodologies making it difficult to assess MPA performance and goals.

Throughout the four regions targeted in this report there are few target metrics that are consistent across the entire range (Table 2). The metrics that are targets across all four regions include: 1) eelgrass areal coverage, 2) clam abundance, 3) marine/shorebird abundance, 4) marine mammal abundance, 5) DO, and 6) pH. The latter two were not originally target metrics from the Regional Monitoring Plans (MPA Monitoring Enterprise 2010, 2011, 2014), but were added based on OST and OPC recommendations. These six target metrics could be used as indicators of condition across estuarine MPAs and reference sites given the higher overall distribution of these six metrics.

Funding for long-term monitoring is generally lacking across the world. Trends in funding indicate the investment into long-term monitoring is going down (Hughes et al. 2017). Within the California MPA network, investment in monitoring estuarine and wetland ecosystems has fallen behind other MPA ecosystems (e.g., kelp forests and rocky intertidal). Without more funding California estuarine MPAs might not meet essential monitoring goals, or, if left to only a few target metrics, monitoring might not capture MPA performance.

Recommendations moving forward

Other than the six consistently monitored target metrics, other metrics could be added to a statewide monitoring program. Marine vegetation (e.g., seagrass, macroalgae, salt marsh) is consistently found in estuaries across the entire state. Various types of vegetation are also indicators of change resulting from either increased human stress or management (Cloern 2001, Dyke and Wasson 2005, Hughes et al. 2011). For example, healthy and stable seagrass beds and salt marshes (e.g., *Zostera marina*) are indicators of a healthy ecosystem (Waycott et al. 2009). Whereas certain species of macroalgae (e.g., *Ulva* sp. and *Gracilaria* sp.) can be indicators of nutrient overenrichment (Burkholder et al. 1992, 2007, Huntington and Boyer 2008). Additionally, marine vegetation is relatively easy to monitor from LIDAR and aerial photography, so effort in monitoring is minimal compared to other metrics. Salt marshes, a key feature of almost every estuary in California, are conspicuously absent in monitoring programs across the state, or where there is monitoring of salt marshes they are not in a region in which they are recognized as a target metric (Table 2).

Other recommendations from results of this effort and other researcher input include:

- Salinity: should be a commonly targeted metric as it can inform on changes in land-use, and can be a good predictor of estuarine communities.
- Nutrients (nitrate, ammonia, phosphate): Are key drivers of estuarine food-webs and can shift community states (Cloern 2001)
- Invasive species: the presence of invasive species is a key feature of California estuaries and is a good indicator of overall estuary health.

- Olympia oysters: These populations have suffered heavy losses over the last century due to poor water quality and species invasions (Cheng et al. 2015, Jeppesen et al. 2016, Wasson et al. 2016). They are also relatively easy to monitor.
- Fish sampling: protocols should be developed to standardize monitoring of fish communities because they could achieve monitoring objectives for many target metrics (Tables 1 and 2). Developing standardized beach seining could help achieve these goals.
- Estuarine MPA Symposium: There is now a need for to bring together key estuarine researchers (e.g., conference, symposium, workshop) to:
    - Search for traditional and non-traditional funding sources.
    - Integrate metrics and sampling protocols
    - Develop control sites that will be used to measure MPA effectiveness.
    - Addressing key monitoring gaps.
    - Develop a network of researchers across the state, much like Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), ReefCheck, or NERR.
    - This could be achieved using regional conferences, such as CAERS[1].

[1] http://caers.squarespace.com

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APPENDIX 1: TABLES

Table 1. Cross-walk of estuaries from the PMEP/TNC inventory of 303 California estuaries and the MPA network, along with non-MPA reference sites. Ha = Hectares, Lat = Latitude, Long = Longitude. Coastal and Marine Ecological Classification Standard (CMECS) categories determines estuary types based on local geology.

Estuary_PMEP	Estuary_MPA	MPA_type	Ha_PMEP	Lat_PMEP	Long_PMEP	CMECS	Region_MPA
Lake Earl	Reference	NA	1565	41.821	-124.196	Lagoonal Estuary	North Coast
Klamath River	Reference	NA	375	41.540	-124.062	Riverine Estuary	North Coast
Big Lagoon	Reference	NA	720	41.176	-124.114	Lagoonal Estuary	North Coast
Humboldt Bay	South Humboldt Bay SMRMA	SMRMA	7211	40.802	-124.127	Embayment/Bay	North Coast
Eel River	Reference	NA	1277	40.622	-124.286	Riverine Estuary	North Coast
Ten Mile River	Ten Mile Estuary	SMCA	61	39.545	-123.756	Lagoonal Estuary	North Coast
Russian Gulch (Mendocino)	Russian Gulch SMCA	SMCA	1	39.329	-123.803	Lagoonal Estuary	North Coast
Big River Mendocino	Big River Estuary SMCA	SMCA	91	39.302	-123.783	Riverine Estuary	North Coast
Navarro River	Navarro River Estuary SMCA	SMCA	36	39.197	-123.754	Lagoonal Estuary	North Coast
Russian Gulch (Sonoma)	Russian River SMCA	SMCA	2	38.467	-123.155	Lagoonal Estuary	North Central Coast
Russian River	Russian River SMRMA	SMRMA	172	38.447	-123.117	Lagoonal Estuary	North Central Coast
Bodega Bay Estuary	Reference	NA	372	38.321	-123.049	Embayment/Bay	North Central Coast
Estero Americano	Estero Americano SMRMA	SMRMA	65	38.307	-122.988	Lagoonal Estuary	North Central Coast
Estero de San Antonio	Estero de San Antonio SMRMA	SMRMA	17	38.273	-122.971	Lagoonal Estuary	North Central Coast
Tomales Bay	Reference	NA	3126	38.153	-122.898	Embayment/Bay	North Central Coast
Drakes Estero/Estero de Limantour	Drakes Estero SMCA	SMCA	1115	38.051	-122.945	Embayment/Bay	North Central Coast
Drakes Estero/Estero de Limantour	Estero de Limantour SMR	SMR	1115	38.051	-122.945	Embayment/Bay	North Central Coast
Bolinas Lagoon	Reference	NA	471	37.918	-122.679	Embayment/Bay	North Central Coast
Pescadero Marsh	Reference	NA	124	37.262	-122.405	Lagoonal Estuary	Central Coast
Pajaro River	Reference	NA	82	36.859	-121.812	Lagoonal Estuary	Central Coast
Elkhorn Slough/Moro Cojo/Salinas River	Elkhorn Slough SMCA	SMCA, SMR	1390	36.814	-121.759	Embayment/Bay	Central Coast
Elkhorn Slough/Moro Cojo/Salinas River	Elkhorn Slough SMR	SMCA, SMR	1390	36.814	-121.759	Embayment/Bay	Central Coast
Elkhorn Slough/Moro Cojo/Salinas River	Moro Cojo Slough SMR	SMCA, SMR	1390	36.814	-121.759	Embayment/Bay	Central Coast
Carmel River Estuary	Reference	NA	37	36.537	-121.923	Lagoonal Estuary	Central Coast

Morro Bay Estuary	Morro Bay SMR	SMR, SMRMA	1026	35.340	-120.847	Embayment/Bay	Central Coast
Morro Bay Estuary	Morro Bay SMRMA	SMR, SMRMA	1026	35.340	-120.847	Embayment/Bay	Central Coast
Goleta Slough	Goleta Slough SMCA (No-Take)	SMCA (No-Take)	97	34.419	-119.845	Lagoonal Estuary	South Coast
Carpenteria Salt Marsh	Reference	NA	85	34.401	-119.536	Embayment/Bay	South Coast
Mugu Lagoon	Reference	NA	937	34.101	-119.100	Riverine Estuary	South Coast
Los Angeles Harbor	Reference	NA	1332	33.712	-118.248	Embayment/Bay	South Coast
Muted Bolsa Bay	Bolsa Bay SMCA	SMCA	80	33.697	-118.047	Embayment/Bay	South Coast
Bolsa Chica-Fully Tidal	Bolsa Chica Basin SMCA (No-Take)	SMCA (No-Take)	171	33.697	-118.038	Embayment/Bay	South Coast
Newport Bay	Upper Newport Bay SMCA	SMCA	671	33.604	-117.898	Embayment/Bay	South Coast
Agua Hedionda	Reference	NA	152	33.141	-117.325	Embayment/Bay	South Coast
Batiquitos Lagoon	Batiquitos Lagoon SMCA (No-Take)	SMCA (No-Take)	224	33.089	-117.291	Embayment/Bay	South Coast
San Elijo Lagoon	San Elijo Lagoon SMCA (No-Take)	SMCA (No-Take)	215	33.008	-117.271	Embayment/Bay	South Coast
San Dieguito Lagoon	San Dieguito Lagoon SMCA	SMCA	75	32.970	-117.261	Embayment/Bay	South Coast
Mission Bay/Famosa Slough	Famosa Slough SMCA (No-Take)	SMCA (No-Take)	880	32.768	-117.229	Embayment/Bay	South Coast
San Diego Bay	Reference	NA	5026	32.667	-117.151	Embayment/Bay	South Coast
Tijuana River estuary	Reference	NA	354	32.555	-117.118	Riverine Estuary	South Coast

Table 2. Representation of target monitoring metrics distributed across the four regions.

Target_Metrics	Type	Key Attribute	South Coast	Central Coast	North Central Coast	North Coast	Total
Black seaperch density & size structure	Feature Assesment	Trophic Structure: Resident fishes	0	1	0	0	1
Diamond turbot density $ size structure	Feature Assesment	Trophic Structure: Resident fishes	0	1	0	0	1
Pile surfperch density & size structure	Feature Assesment	Trophic Structure: Resident fishes	0	1	0	0	1
Pickleweed areal extent	Assesment Add-on	Biogenic Habitat	0	0	1	0	1
Fat innkeeper worm	Feature Assesment	Trophic Structure: Infaunal Assemblage	0	1	1	0	2
Anas spp.	North Coast metric	Dabbling Ducks	0	0	0	1	1
Anthya spp.	North Coast metric	Diving Ducks	0	0	0	1	1
Black Brandt	North Coast metric	Black Brandt	0	0	0	1	1
Western Gull	North Coast metric	Western Gull	0	0	0	1	1
Scolopacidae	North Coast metric	Shorebirds	0	0	0	1	1
Acipenser spp.	North Coast metric	Sturgeon	0	0	0	1	1
Oncorrhyncus spp.	North Coast metric	Salmonids	0	0	0	1	1
Pleuronectidae	North Coast metric	Pleuronectidae	0	0	0	1	1
Urechis caupo	North Coast metric	Fat Innkeeper Worm	0	0	0	1	1
Cancer magister	North Coast metric	Dungeness Crab	0	0	0	1	1
Harbor porpoise	North Coast metric	Harbor porpoise	0	0	0	1	1
Pinnipedia	North Coast metric	Pinnipedia	0	0	0	1	1
Surfperch abundance & size frequency	Feature Checkup/Vital Sign	NA	0	1	0	1	2
Eelgrass density & % cover	Feature Assesment	Biogenic Habitat: Plants	0	1	0	1	2
Starry flounder abundance & size frequency	Feature Checkup/Vital Sign	NA	0	0	1	1	2
Bat ray abundance	Feature Assesment	Trophic Structure: Predatory fishes	0	0	1	1	2
Eelgrass shoot density	Assesment Add-on	Biogenic Habitat	0	0	1	1	2
Starry flounder abundance & size frequency	Assesment Add-on	Diversity	0	0	1	1	2
CA halibut abundance & size frequency	Assesment Add-on	Diversity	0	0	1	1	2
Shiner perch density & size	Feature Assesment	Trophic Structure: Resident	0	1	1	1	3

structure		fishes						
Striped seaperch density & size structure	Feature Assesment	Trophic Structure: Resident fishes	0	1	1	1	3
Marine mammal density	Feature Assesment	Habitat Provisioning: marine mammals	0	1	1	1	3
Native oyster bed areal extent/abundance	Assesment Add-on	Biogenic Habitat	0	1	1	1	3
Ulva areal extent	Assesment Add-on	Biogenic Habitat	0	1	1	1	3
Croaker abundance & size frequency	Feature Checkup/Vital Sign	NA	1	0	0	0	1
Pickleweed areal extent	Feature Assesment	Biogenic Habitat: Plants	1	0	0	0	1
Washington clam abundance	Feature Assesment	Trophic Structure: Infaunal Assemblage	1	0	0	0	1
Spotted sand bass density & size structure	Feature Assesment	Trophic Structure: Resident fishes	1	0	0	0	1
Croaker density & size structure	Feature Assesment	Trophic Structure: Resident fishes	1	0	0	0	1
Parasite diversity	Assesment Add-on	Trophic Structure	1	0	0	0	1
Topsmelt denisty & size structure	Feature Assesment	Trophic Structure: Resident fishes	1	1	0	0	2
Spp richness (inverts and fishes)	Assesment Add-on	Diversity	1	0	1	0	2
Spp diversity (invert and fish functional groups)	Assesment Add-on	Diversity	1	0	1	0	2
CA halibut abundance & size frequency	Feature Checkup/Vital Sign	NA	1	0	0	1	2
Arthropod biomass	Feature Checkup/Vital Sign	NA	1	0	0	1	2
CA halibut density & size structure	Feature Assesment	Trophic Structure: Predatory fishes	1	0	0	1	2
Gobies density & size structure	Feature Assesment	Trophic Structure: Resident fishes	1	0	0	1	2
Arthropod biomass	Feature Assesment	Producitivty	1	0	0	1	2
Abundance & foraging rates of shorebirds	Assesment Add-on	Trophic Structure: Infaunal Assemblage	1	0	0	1	2
Piscivorous bird richness & abundance	Feature Assesment	Trophic Structure: Predatory birds	1	1	0	1	3
Shorebird richness & abundance	Feature Assesment	Trophic Structure: Predatory birds	1	1	0	1	3
Common littleneck clam abundnce	Feature Assesment	Trophic Structure: Infaunal Assemblage	1	0	1	1	3
Leopard shark density & size	Feature Assesment	Trophic Structure: Predatory	1	0	1	1	3

structure/abundance		fishes					
pH/Carbonate chemistry	COST/OPC	NA	1	1	1	1	4
DO	COST/OPC	NA	1	1	1	1	4
Eelgrass aereal extent	Feature Checkup/Vital Sign	NA	1	1	1	1	4
Ghost and mud shrimp abundance	Feature Checkup/Vital Sign	NA	1	1	1	1	4
Clam adundance and size frequency	Feature Checkup/Vital Sign	NA	1	1	1	1	4
Marine bird richness & abundance	Feature Checkup/Vital Sign	NA	1	1	1	1	4
Marine Mammal/Pinniped abundance	Feature Checkup/Vital Sign	NA	1	1	1	1	4
Eelgrass aereal extent	Feature Assesment	Biogenic Habitat: Plants	1	1	1	1	4
Mud shrimp abundance	Feature Assesment	Trophic Structure: Infaunal Assemblage	1	1	1	1	4
Ghost shrimp abundance	Feature Assesment	Trophic Structure: Infaunal Assemblage	1	1	1	1	4
Pacific gaper clam abundance	Feature Assesment	Trophic Structure: Infaunal Assemblage	1	1	1	1	4

APPENDIX 2: FORM LETTERS

Initial Request for information on long-term monitoring:

Dear Colleague,

I am working on a project with California Ocean Science Trust, the Ocean Protection Council, and the California Department of Fish and Wildlife to develop on inventory of monitoring programs in estuaries throughout California to inform monitoring goals as established by the MPA program. The goal of the project is to see who is doing what across the CA estuaries (especially MPAs), and to determine what key MPA metrics are being monitored and what is missing.

You are being contacted because we have determined that you have been monitoring estuaries in California. Although we aware of your monitoring efforts, we are asking for your help in giving us more specific details on your projects. We are only concerned with projects that will monitor estuaries for the next 5 years or longer. So if your plan is to only sample a given estuary for 4 years or less then you can just respond as “My project is not long-term”.

However, if your project is expected to be long-term we are looking for the following target metrics as outlined in each MPA region:

Acipenser spp.	Marine mammal density
Anas spp.	Native oyster bed areal extent/abundance
Anthya spp.	*Oncorhyncus* spp.
Arthropod biomass	Pacific gaper clam abundance
Arthropod biomass	Parasite diversity
Bat ray abundance	pH/Carbonate chemistry
Black Brandt	Pickleweed areal extent
Black seaperch density & size structure	Pile surfperch density & size structure
CA halibut abundance & size frequency	Piscivorous bird richness & abundance
Cancer magister density	Pleuronectidae
Clam adundance and size frequency	Scolopacidae
Common littleneck clam abundnce	Shorebird richness & abundance
Croaker abundance & size frequency	Spotted sand bass density & size structure
Diamond turbot density $ size structure	Spp diversity (invert and fish functional groups)
DO (dissolved oxygen)	Spp richness (inverts and fishes)
Eelgrass areal extent	Starry flounder abundance & size frequency
Eelgrass density & % cover	Surfperch abundance & size frequency (any spp.)
Fat innkeeper worm	Topsmelt denisty & size structure
Ghost and/or mud shrimp abundance	*Ulva* areal extent
Gobies density & size structure	*Urechis caupo*
Harbor porpoise	Washington clam abundance
Leopard shark density & size structure/abundance	Western Gull
Marine bird richness & abundance	

Please let me know if you are planning on monitoring any of these metrics over the next five years in California estuaries. If you can please let me know the following for each metric you are monitoring:

1. The target metric.
2. The estuary where you are sampling each target metric.

This project aims to identify who, what, and where is being monitored in CA estuaries, and allow us to assess where monitoring gaps occur. All of which is a first step in establishing rigorous monitoring programs in CA estuaries (both MPA and non-MPA).

I look forward to any input you might be able to provide. Please forward on to anyone who might be interested. We are hoping to collect all responses by March 17, 2017.

Kind regards,

Brent Hughes
bbhughes@ucsc.edu

Follow-up Request for long-term monitoring information:

Dear Colleague,

A few weeks ago I contacted you requesting details of your monitoring programs in California estuaries. I am hoping that you could spare a few moments to respond to the request, and give us some brief details about your monitoring program.

Purpose:

The California Ocean Science Trust, the Ocean Protection Council, and the California Department of Fish and Wildlife are developing an inventory of monitoring programs in estuaries throughout California to inform monitoring goals as established by the MPA program. The goal of the project is to see who is doing what across the CA estuaries (especially MPAs), and to determine what key MPA metrics are being monitored and what is missing.

Details:

We are only concerned with projects that will monitor estuaries for the next 5 years or longer. So if your plan is to only sample a given estuary for 4 years or less then you can just respond as "My project is not long-term".

However, if your project is expected to be long-term we are looking for the following target metrics as outlined in each MPA region:

Acipenser spp.	Marine mammal density
Anas spp.	Native oyster bed areal extent/abundance
Anthya spp.	*Oncorhyncus* spp.
Arthropod biomass	Pacific gaper clam abundance
Arthropod biomass	Parasite diversity

Bat ray abundance	pH/Carbonate chemistry
Black Brandt	Pickleweed areal extent
Black seaperch density & size structure	Pile surfperch density & size structure
CA halibut abundance & size frequency	Piscivorous bird richness & abundance
Cancer magister density	Pleuronectidae
Clam adundance and size frequency	Scolopacidae
Common littleneck clam abundnce	Shorebird richness & abundance
Croaker abundance & size frequency	Spotted sand bass density & size structure
Diamond turbot density $ size structure	Spp diversity (invert and fish functional groups)
DO (dissolved oxygen)	Spp richness (inverts and fishes)
Eelgrass areal extent	Starry flounder abundance & size frequency
Eelgrass density & % cover	Surfperch abundance & size frequency (any spp.)
Fat innkeeper worm	Topsmelt denisty & size structure
Ghost and/or mud shrimp abundance	*Ulva* areal extent
Gobies density & size structure	*Urechis caupo*
Harbor porpoise	Washington clam abundance
Leopard shark density & size structure/abundance	Western Gull
Marine bird richness & abundance	

Please let me know if you are planning on monitoring any of these metrics over the next five years in California estuaries. If you can please let me know the following for each metric you are monitoring:

1. The target metric.
2. The estuary where you are sampling each target metric.

This project aims to identify who, what, and where is being monitored in CA estuaries, and allow us to assess where monitoring gaps occur. All of which is a first step in establishing rigorous monitoring programs in CA estuaries (both MPA and non-MPA).

I look forward to any input you might be able to provide. We are hoping to collect all responses by March 31, 2017.

Kind regards,

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