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Integrating Spatial Data into Marine Protected Area Monitoring and Management

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ABOUT THIS REPORT

This report is a collaborative effort between California State University Monterey Bay (CSUMB), California Ocean Science Trust, and California Department of Fish and Wildlife and is intended to provide information about the importance of spatial data integration in Marine Protected Area (MPA) monitoring and management. This report is a part of the greater State of the Region report that shares the results of the North Central Coast MPA Baseline Program and adds to the comprehensive picture of California's North Central Coast region.

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California State University MONTEREY BAY

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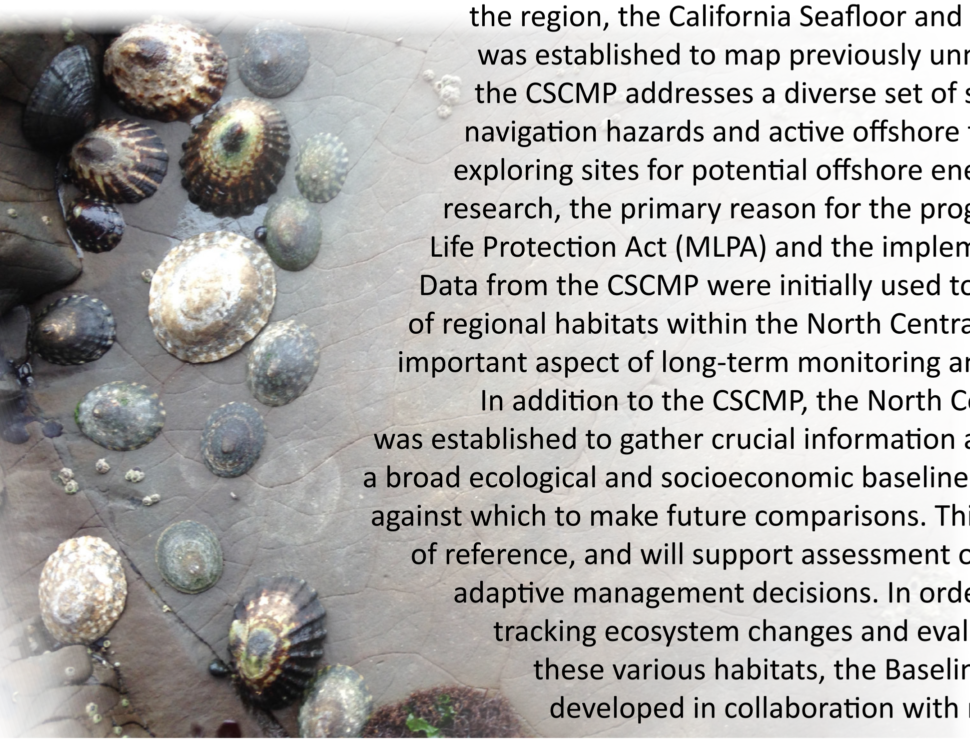
INTRODUCTION

Spatially explicit data are a key component of successful ecosystem-based management, including developing, monitoring, and managing marine protected areas (MPAs). From understanding human use patterns to determining seafloor substrates and critical habitat distribution, spatial data inform many aspects of MPA design, management, and long-term monitoring. One important application of spatial data is the incorporation of seafloor mapping data into monitoring to gain a greater insight into the dynamics of an ecosystem. Because the distribution of marine species is in part governed by available substrate types, seafloor mapping data is a critical component for tracking region-wide changes in habitats, as well as species abundances and distributions over time. For example, in a relatively small area, different species compositions occur over soft sediment versus along rocky substrate (Anderson et al. 2009). Identifying the locations and extents of these different habitat types is fundamental in understanding the ecosystem as a whole when making spatial and temporal comparisons. With California's commitment to ecosystem-based management, spatial data will be integral for successful management of marine resources, as well as anticipating and adapting for future changes. Two key programs providing spatial datasets that inform MPAs in the North Central Coast region of California are the California Seafloor and Coastal Mapping Program (CSCMP), formerly the California Seafloor Mapping Program (CSMP), and the MPA Baseline Program.

The North Central Coast region includes 22 MPAs and 3 recreational management areas that were implemented in 2010, covering approximately 20% of state waters in the region. The region spans 584 kilometers (363 miles) of California's coastline and contains a wide variety of habitats, from sandy beaches and kelp forests, to the deep waters around the Farallon Islands. Collectively, these habitats make up one of the most biologically productive areas in the world. Until relatively recently, however, the details and distribution of some of the habitats in the region were largely unknown. In order to improve understanding of the complex ecosystem in the region, the California Seafloor and Coastal Mapping Program (CSCMP) was established to map previously unmapped state waters. While the CSCMP addresses a diverse set of state needs, such as identifying navigation hazards and active offshore faults, modeling coastal change, exploring sites for potential offshore energy, and creating a basemap for research, the primary reason for the program was to support the Marine Life Protection Act (MLPA) and the implementation of the MPA network. Data from the CSCMP were initially used to establish representative coverage of regional habitats within the North Central Coast MPAs and will also be an important aspect of long-term monitoring and adaptive management.

In addition to the CSCMP, the North Central Coast MPA Baseline Program was established to gather crucial information across a variety of topics to provide a broad ecological and socioeconomic baseline characterization, or benchmark, against which to make future comparisons. This baseline will provide a frame of reference, and will support assessment of future changes and inform adaptive management decisions. In order to establish a benchmark for tracking ecosystem changes and evaluating MPA performance across these various habitats, the Baseline Program included 11 projects developed in collaboration with multiple partners, which highlighted



a suite of ecosystem features exemplifying the variety of ecosystems and human uses found within the North Central Coast MPAs.* Biological, socioeconomic, and habitat mapping data were collected in order to fill knowledge gaps and inform continued monitoring and management. Additionally, the California Department of Fish and Wildlife (CDFW) collected imagery data from remotely operated vehicles (ROV) across several underwater habitats and aerial imagery of kelp distribution along the coast. ROV data allows for extensive surveys in deeper water and as validation for remotely sensed substrate and habitat data resulting from the CSCMP and other mapping projects. Although initially designed to inform MPA monitoring, these projects also have widely valuable applications for tracking ecosystem changes and understanding the complex and dynamic habitats of the North Central Coast region over time.

Moving forward, data collected through the 11 Baseline Program projects, CDFW imagery, and seafloor data collected through the CSCMP will be utilized in long-term monitoring and informing adaptive management of the region's MPAs. The integration of biological, socioeconomic, and seafloor mapping datasets will improve understanding of complex habitats along the coast, the overall status of ocean health, and MPA efficacy over time. In addition to informing adaptive management of MPAs, integrating monitoring results with CSCMP mapping data can help to predict population responses to other changes in ocean conditions through time, and inform issues such as fishery management and climate change tracking. Here we present descriptions and maps resulting from the integration of CSCMP and Baseline Program project data, highlighting examples of where integration of various data types can provide useful knowledge for management. We discuss the current and potential applications of these integrations, and where emerging methods can offer greater insight into the dynamics of the region.

**To learn more about the Baseline Program and find the technical reports from the projects in the region, visit the North Central Coast page on Ocean Spaces.*

Mixed rocky substrate covered in Watersipora sp. *in the North Central Coast*

CALIFORNIA SEAFLOOR AND COASTAL MAPPING IN THE NORTH CENTRAL COAST REGION

What is the CSCMP?

The California Seafloor and Coastal Mapping Program was initiated in 2007 as the State's first comprehensive seafloor mapping project. At the time, only approximately 30% of the State's seafloor had been assessed. The CSCMP was therefore tasked with mapping the entire seafloor within state territory (mean high water line out to three nautical miles). As a collaborative effort between state and federal agencies, the academic community, and the private sector, the CSCMP resulted in publicly available digital map layers of the seafloor substrate along the California coast ([https://walrus.wr.usgs.gov/mapping/ csmp/)](https://walrus.wr.usgs.gov/mapping/csmp/). In support of the MLPA goals, an initial objective of the CSCMP was to create a map set to inform MPA design, and ensure inclusion of representative proportions of California's rich variety of habitats. Using the latest remote sensing and Geographic Information System (GIS) technologies, the CSCMP collected data to build a comprehensive, high-resolution set of seafloor maps. In addition to substrate data (rocky vs. soft sediment) that were collected and used to inform MPA designation in the North Central Coast, habitat type, bathymetry, offshore geology, seafloor characteristics, and sediment thickness information will also be valuable in the continued monitoring of the region, as well as tracking overall changes in ecosystems through time. These layers have already been used for a wide variety of applications in addition to MPA delineation, including modeling benthic ecosystems, updating NOAA nautical charts, providing a benchmark for measuring and modeling coastal changes, identifying active offshore faults, improving outreach for public education and awareness, and more. Current and future projects incorporating the CSCMP data will be essential to the continued monitoring and understanding of the California coast.

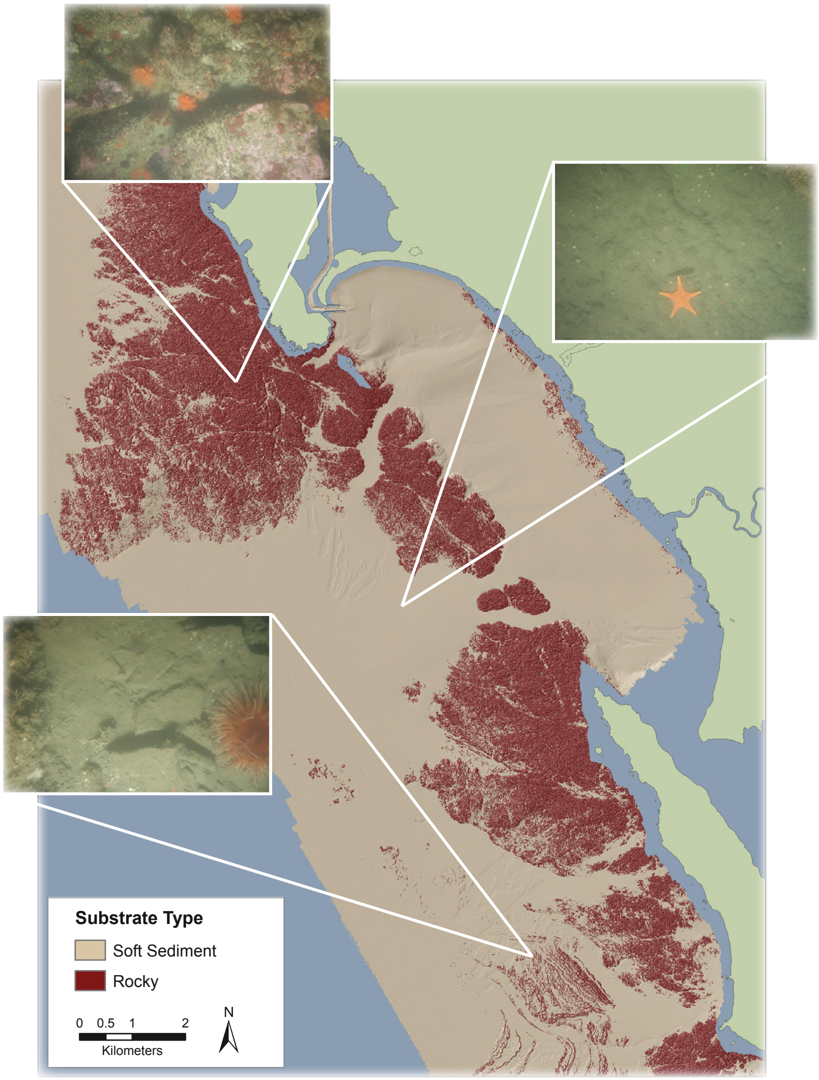


Figure 1. Example of seafloor habitat in Bodega Bay, CA. Substrate data, as represented by reddish-brown (rock) and tan (sand), collected by the CSCMP. Photos obtained from the USGS CSCMP video and photo portal.

Why is the CSCMP important for monitoring?

The health and sustainability of coastal ecosystems involves many environmental parameters, including seafloor composition and characteristics. Accurate basemaps are essential to improving the understanding of the state of marine ecosystems along the California coast. In the North Central Coast region, the CSCMP data have been foundational to monitoring efforts. Before the CSCMP was initiated, the general knowledge of the composition of the seafloor was rather limited, but this program has presented a more accurate picture of the current state of the North Central Coast region and revealed the complexity found in the mosaic of seafloor characteristics along the coast.

Seafloor characteristics (e.g., depth, slope, sediment type, and geomorphology) and associated habitat types, defined by the different combinations of seafloor characteristics (e.g., steep rocky shelves, mud flats) play a large role in driving ecosystem differences. Because many plants, fish, and invertebrates rely on particular habitat types, species compositions tend to differ between them, especially between areas of flat, soft bottom and areas of hard, rough substrate. Knowing where these different habitats are located is helpful in understanding the dynamics of the physical and biological processes in the system and identifying preferred substrate availability for different species in the region. Thus, monitoring over distinct habitat types is key to understanding some of the greater dynamics of the system. For example, in soft sediment, there are generally greater abundances of flatfishes and sea pens, whereas over rocky reefs and outcrops there tend to be higher abundances of rockfishes, sea cucumbers, and sea anemones (Anderson et al. 2009; Lindholm et al. 2014). Furthermore, it is valuable to specifically locate the boundaries between different broader habitat types because species assemblages in these transition zones are often different than in the surrounding areas. By collecting data on seafloor characteristics, like those collected through the CSCMP, seafloor mapping is a tool to estimate habitat types and species compositions where surveying all habitats extensively is impractical.

Figure 2. Distribution of rocky and soft substrate throughout state waters in the North Central Coast region. MPAs are shown in blue (SMCA) and red (SMR).

How has the CSCMP been applied?

Bathymetry data collected through the CSCMP show the shape of the seafloor, and highlight areas of rough (rocky) or smooth (soft sediment) terrain in shaded relief images, allowing via simple algorithmic measures the general classification of substrate types over a large area. Habitat classification and initial analysis of CSCMP data for MPA designation were based on roughness as a proxy for these two substrate types (rocky and soft) stratified into four separate depth zones (0-30 m, 30-100 m, 100-200 m, and > 200 m). While much of the region is comprised of soft sediment (sand or mud), there are several highly complex areas of outcrops and rocky reefs. Figure 2 shows the distribution of the two substrate types throughout the entire North Central Coast region. CSCMP bathymetry data also allow the measurement of depth to delineate the zones listed above. Figure 3 shows the two substrate types, including the delineation of the depth zones used in MPA design. Because these classifications are often associated with changes in species compositions, they were chosen as breakpoints to assess distribution of distinct habitats and ensure adequate coverage of the diversity across different habitat types in MPAs. Monitoring in these habitats region-wide will be valuable, as the habitat and species compositions change from north to south along the coast (California Marine Life Protection Act Initiative 2007).

The CSCMP not only illuminated locations of different known substrate types more specifically than before, but revealed that rippled scour depressions (RSDs), an ecologically distinct habitat feature, cover a significant area of the North Central Coast region. RSDs were noted in various places on the seafloor and have only recently been identified as ecologically important. They were found to contain species compositions different than surrounding areas, including high numbers of young rockfishes, indicating RSDs as potential nursery habitat (Hallenbeck et al. 2012). After their discovery as a relatively abundant and ecologically distinct feature along the California coast, other studies have been initiated to try to understand the dynamics of benthic habitats and general distribution of RSDs throughout state waters (see Davis et al. 2013). While RSDs were not considered in the planning and design process for the North Central Coast MPAs, it will be beneficial to monitor them to inform management going forward. This new spatial information, in conjunction with biological and socioeconomic monitoring data collected throughout the region, will provide a more holistic view of the region, as discussed in the following sections.

Rocky substrate in the North Central Coast

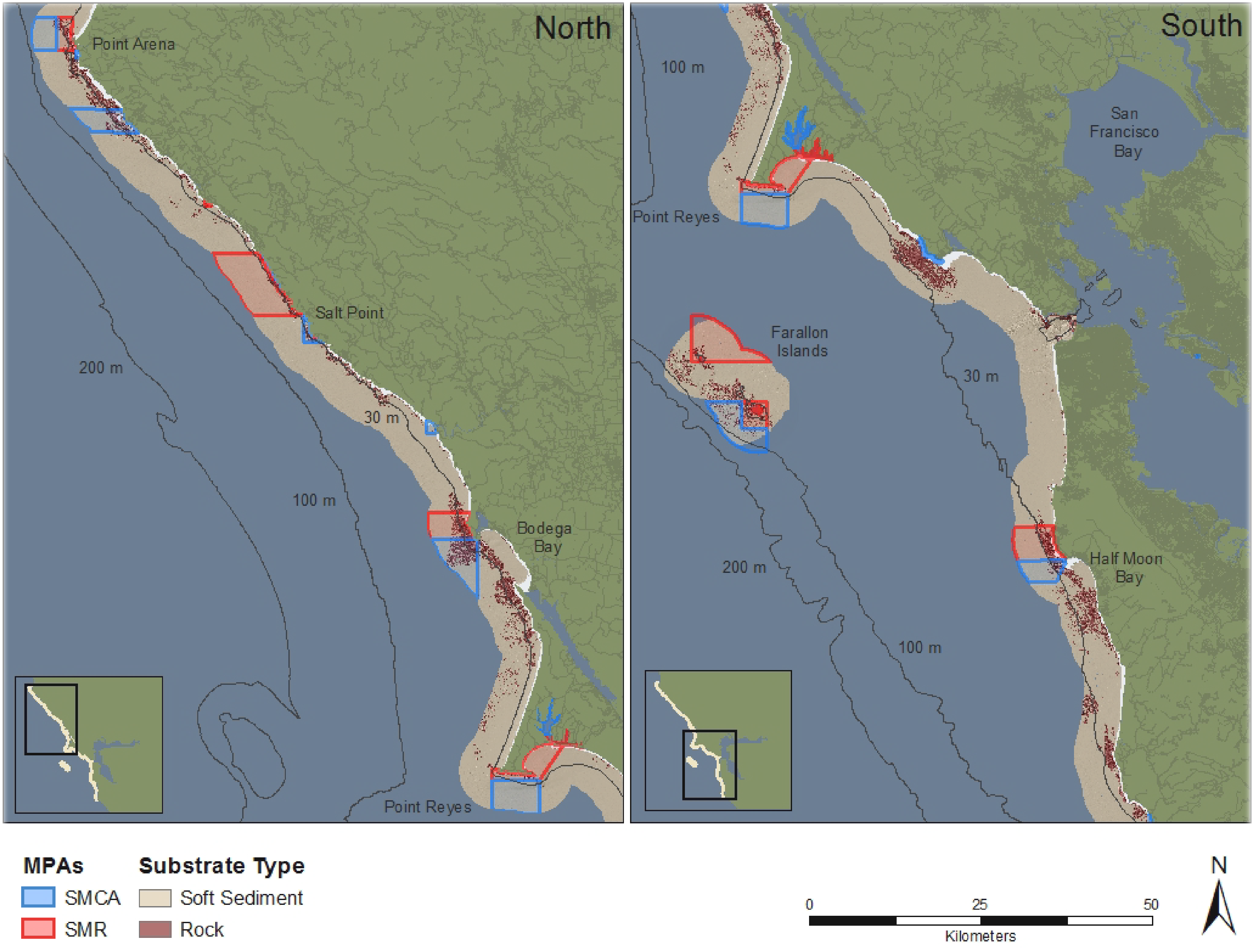
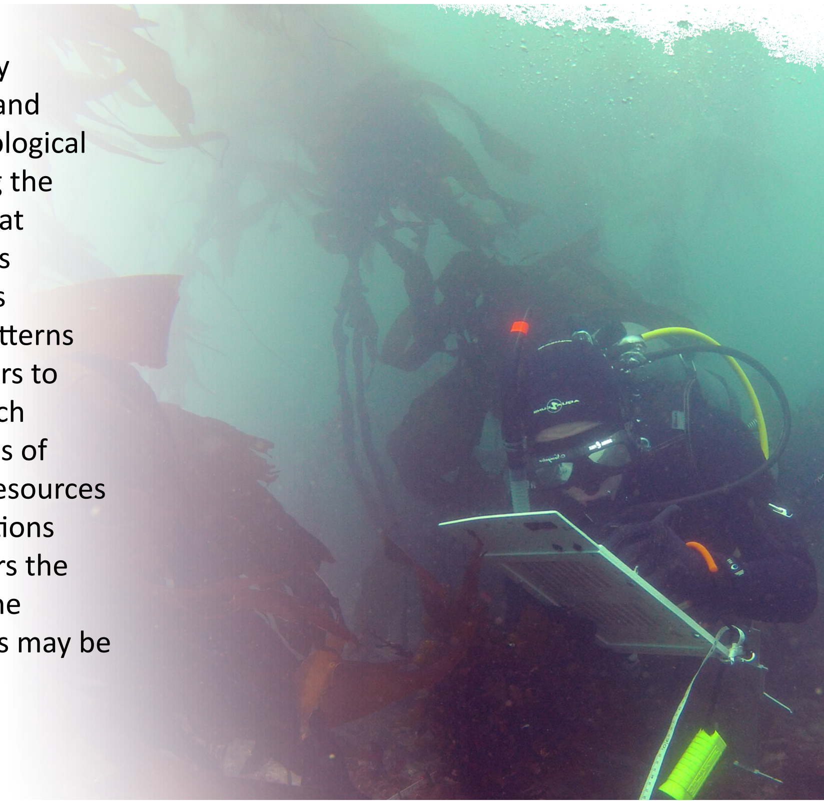


Figure 3. Habitat classifications based on the CSCMP substrate data and depth zones in the North and South parts of the NCC region.

SPATIAL MONITORING DATA FROM THE BASELINE PROGRAM

The 11 Baseline Program projects within the North Central Coast region covered a variety of ecosystems, and surveyed areas both inside and outside of MPAs. Collecting spatially explicit ecological monitoring data, in conjunction with identifying the locations and extents of different seafloor habitat characteristics, is important for tracking changes in ecosystems (including metrics such as species abundance and distribution) and human use patterns over time. It allows for researchers and managers to pinpoint locations of high human activity and rich species diversity, and to understand the patterns of species distributions and human uses, so that resources can be managed accordingly. Mapping the locations of all of the Baseline Program projects also offers the opportunity to identify ideal sampling sites in the future, and where integrating various data types may be most informative.



Diver with Reef Check CA collecting monitoring data during the Baseline period

Harvesting abalone in the North Central Coast

Of the 11 Baseline Program projects, eight (including three citizen science projects) collected primarily biological data in the intertidal and subtidal environments. While human use data were additionally collected in some these projects, they are not displayed specifically in the map set below. Another project collected socioeconomic data throughout the region, and one collected aerial imagery-based habitat information. One final project, The Baseline Characterization of Environmental Conditions, conducted statistical modeling of ocean metrics to develop an index of ocean conditions, therefore it was less suitable for spatial representation and is not included in the following map set. Raw data from these monitoring projects may be downloaded from OceanSpaces (www.oceanspaces.org).

Biological Data (Fig. 4)

Citizen Science. Identifying citizen science efforts and data collection highlights where the community has the greatest opportunity to directly connect to the monitoring activities in the region. Additionally, it brings in new knowledge and experience, leverages a cost-efficient workforce, and identifies where projects could be augmented to include more citizen science for greater capacity in monitoring.

Seabirds. Seabirds are an integral component of the marine ecosystems as upper level predators. Due to their broad habitat use and tight links to fish populations as a food source, monitoring nearshore seabird populations can be a cost-effective indicator of overall health of offshore ecosystems.

Subtidal. Integrating seafloor maps with these various projects offers insights regarding why certain ecosystem patterns are observed, why species are located where they are, why changes occur in some places and not others, and how to make predictions over the entire region based on the seafloor characteristics. It also allows for the identification of specific habitat characteristics that are important to certain stages of a species' life cycle, where these characteristics occur throughout the region, and whether they may be important to adaptively manage. These integrations will help to understand fish populations and fisheries that are common in the subtidal zone.

*Intertidal. S*imilar to the subtidal environment, integrating seafloor maps with intertidal biological data offers insights regarding various ecosystem patterns and identifying the distribution of key habitats. As the intertidal zone is important for many human uses and can often host zones of high biodiversity, integrating spatial data to understand these habitats is important for future adaptive management.

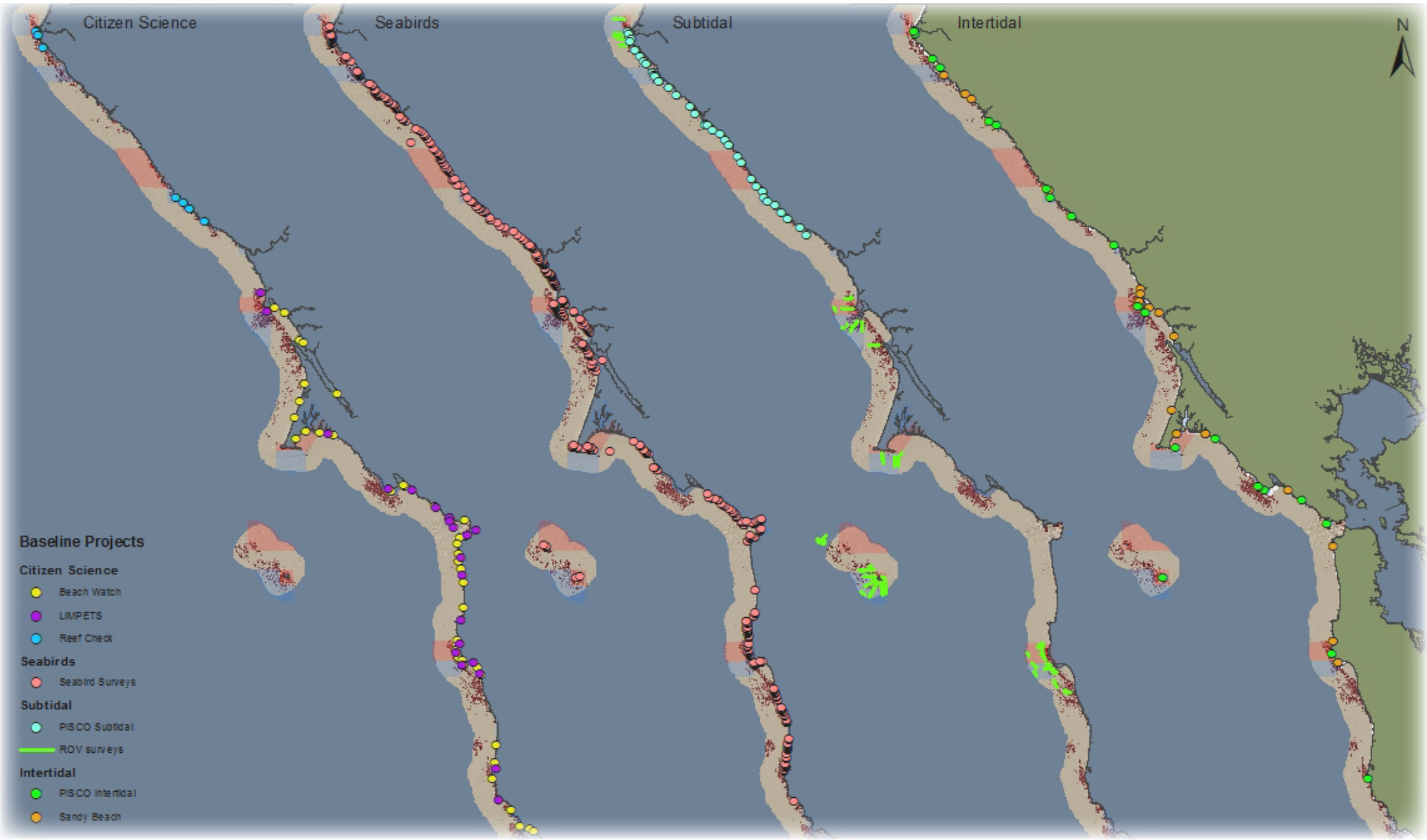


Figure 4. Distribution on biological Baseline Monitoring efforts

Socioeconomics (Fig. 5)

Spatial components of socioeconomic data highlight commercial and recreational fishing, and non-consumptive recreational use occurrences and density across different habitats within the ecosystem. This allows for understanding of how MPAs are affecting fisheries and recreational activities in the region. Presented below are just three of many socioeconomic layers available for public access on CDFW's web mapping and GIS data distribution platform MarineBIOS (https://map.dfg.ca.gov/marine/). CPFV Rockfish refers to a popular Commercial Passenger Fishing Vessel (CPFV), a vessel in which anglers pay a fee to fish. Recreational activities represented in the map below include beach going, hiking or biking, watching wildlife, and surfing, among others.

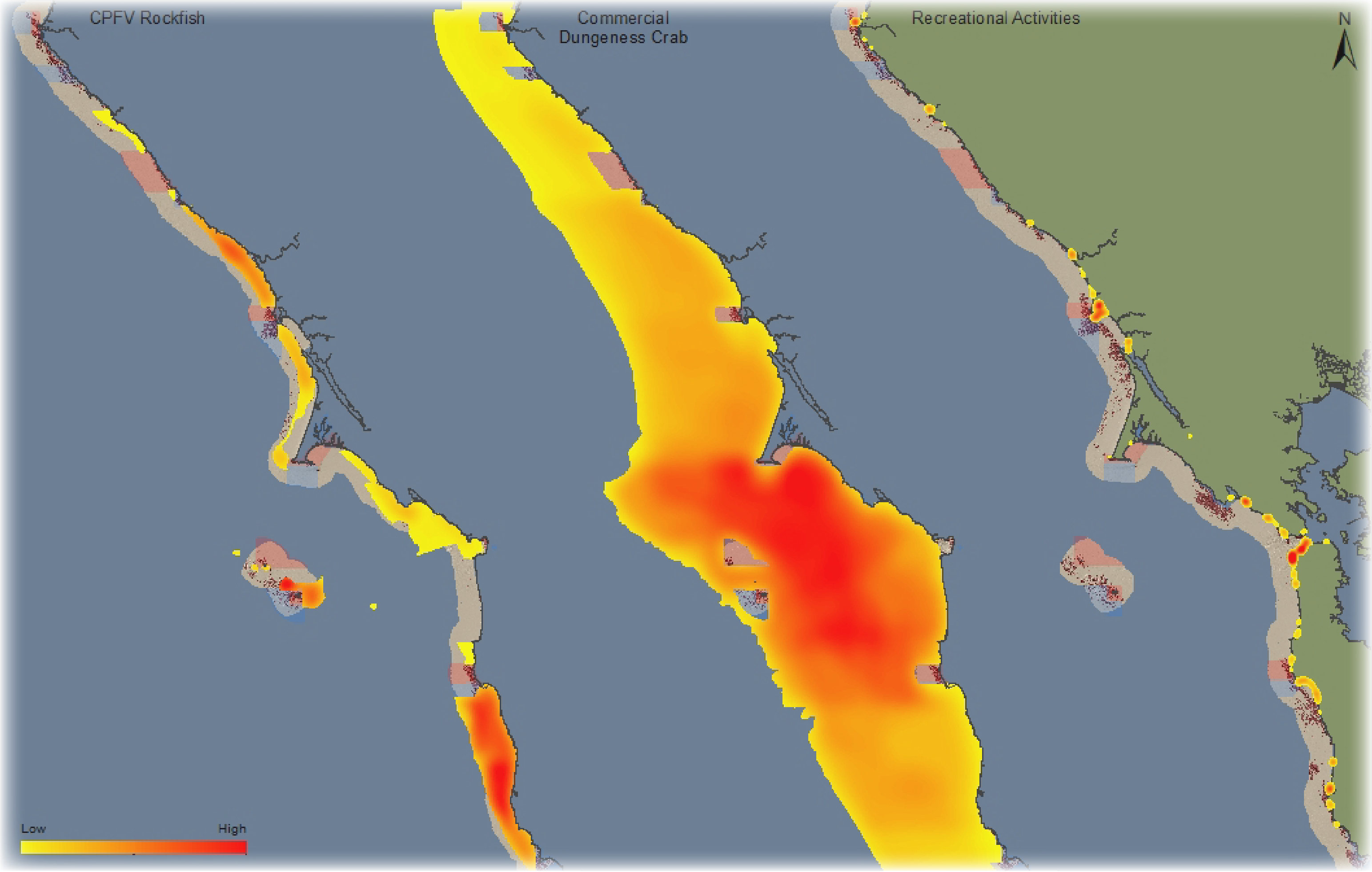


Figure 5. Distribution of socioeconomic Baseline Monitoring efforts.

Habitat Mapping

Mapping efforts in addition to the CSCMP, including aerial imagery mapping kelp distribution and cover collected by Ocean Imaging, augment seafloor habitat maps for a more comprehensive picture of the region by providing another layer of habitat characteristics that informs biological survey efforts. A subset of results from these efforts will be shown in more detail in Figure 6 in the next section.

INTEGRATION OF DATASETS

Each of the aforementioned Baseline Program projects contributed important information about the region, but when viewed collectively and in combination with the detailed CSCMP data, they provide a broader and more nuanced view of the dynamics along the North Central Coast. The integration of diverse datasets such as biological, oceanographic, socioeconomic, and physical seafloor data, can fill knowledge and data gaps in order to inform adaptive management and more precisely guide site selection for monitoring and ecosystem health assessments. Figure 6, for example, shows the integration of CSCMP data with the aerial mapping data collected by the Baseline Program project conducted by Ocean Imaging. Information about some of the areas that were not able to be mapped through the CSCMP were partially filled by the additional Ocean Imaging data. As monitoring continues, results from monitoring projects will also be able to highlight where additional mapping products would be informative.

Currently, there are several projects working to integrate these various datasets together to build on existing knowledge and create the resources to draw upon multiple projects. Imagery data collected using remotely operated vehicles (ROVs) by both the Institute for Applied Marine Ecology (IfAME) at California State University Monterey Bay (CSUMB) and CDFW are being analyzed in conjunction with data collected through the CSCMP to learn how these datasets interact and complement each other and what new knowledge can be gleaned from combining multiple data types. A similar integration is overlaying kelp coverage data collected separately by Ocean Imaging and CDFW, with the CSCMP seafloor data layers. When all of these datasets are joined and compared, it allows for the analysis of multi-scale, ecosystem-based questions, efficiently filling gaps in data and knowledge, and the illumination of additional data gaps that may still be present. Overlaying these integrations on the MPA boundaries will also be informative in long-term monitoring as spatial and temporal changes are assessed. Many synthesized map layers can be accessed and downloaded from CDFW's MarineBIOS with more being added continually.

ADDITIONAL DATA RESOURCES

Here we have focused on CSCMP and MPA Baseline Program project data. However, there are many other datasets that have the potential to be integrated to inform the understanding and management of the State's marine ecosystem. Coastal datasets (coastal change), additional biological datasets (ROV, other kelp and seagrass mapping), human use datasets (coastal access, water sports, ports/harbors, fisheries datasets), and cadastral datasets will all be useful in the continued monitoring and assessment of change throughout time and space.

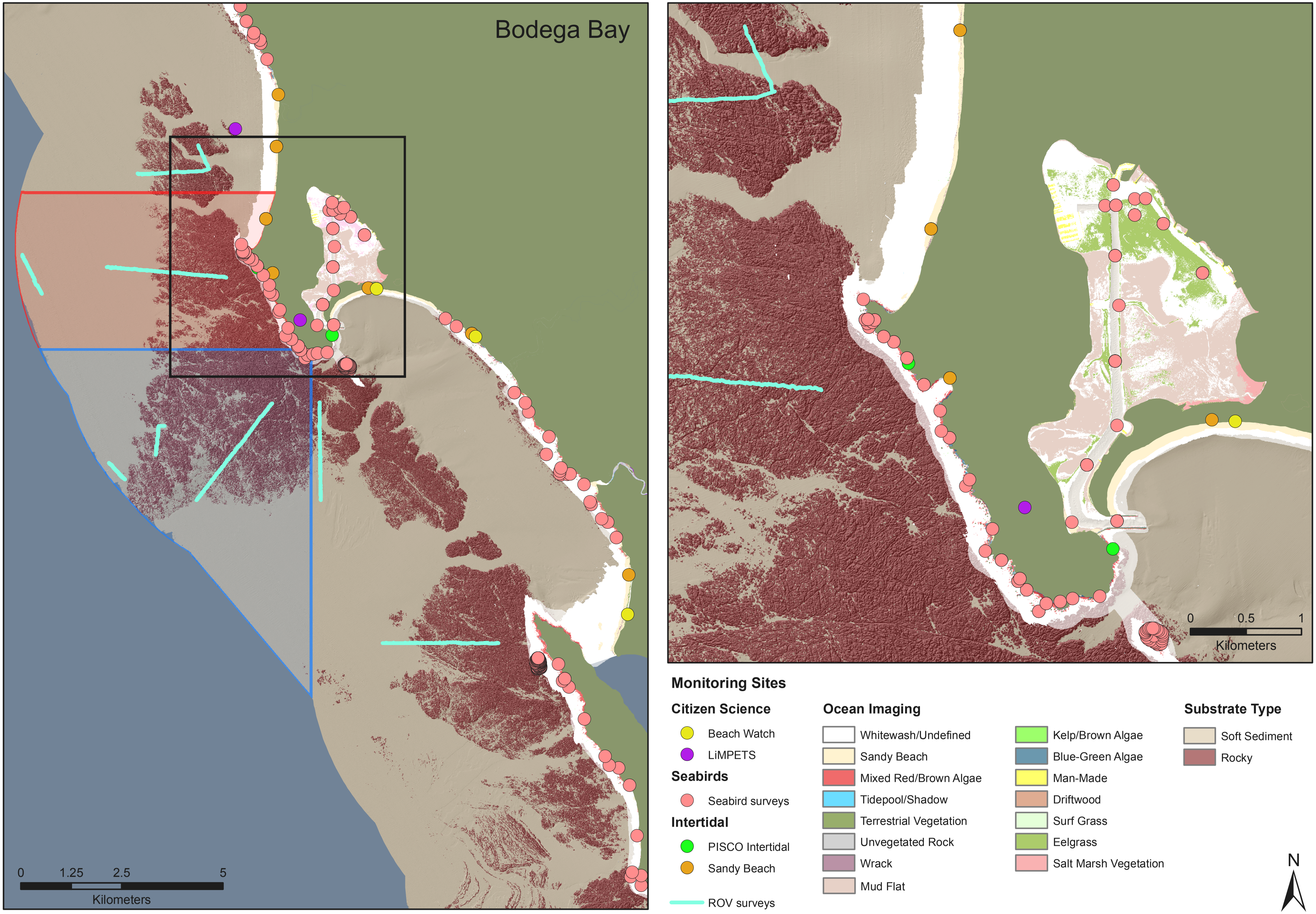


Figure 6. Example of the integration of seafloor mapping data, habitat mapping data collected by Ocean Imaging, and biological monitoring locations in Bodega Bay, CA.

APPLICATIONS TO MODELING, MONITORING, AND MANAGEMENT

As seafloor mapping and other spatial data become more readily available, the applications to monitoring and management continue to grow. Already, the integration of various data types has allowed better predictions of the abundance and distributions of local populations and a greater understanding of habitat connectivity, as we describe below. These predictions will be able to guide future monitoring site selection, assess MPA design and performance, and help inform adaptive management decisions by enhancing understanding of regional ecosystem dynamics and making predictions of populations' responses to changing ocean conditions. In addition, there are an increasing number of derivative seafloor map products becoming available which could provide inputs for more accurate models and predictions of species distributions, and ocean and coastal processes. Areas that are lacking in spatial information are also progressively being filled by data from new mapping technology and prediction methods. As the ways in which all of these products and datasets can complement and augment each other evolve, the applications to a diverse set of ocean issues will likely increase and encourage continued collaborations and contributions from partners in various disciplines. Accordingly, the projects mentioned throughout this section are just a small subset of the projects integrating spatial data with other data types and should be regarded as a brief example and not an extensive list.

BUILDING COMMUNITIES

Beyond the direct application of spatial data to MPA monitoring, the integration of various data types can lead to new collaborations among a wide variety of interdisciplinary partners. Diverse partnerships can add incredible value to the effort by establishing new networks, and creating access to a wider array of knowledge and skills to effectively solve issues. These collaborations include state and federal agencies, private industry, and academia in varying disciplines such as ecology, oceanography, geology, and technology, with contributions from policymakers, researchers, students, and the greater community. Overall, connecting communities through the integration of data and complementary efforts has incredible value in assessing, tracking, and managing ocean health.

Rosy rockfish
hovering over
the seafloor

Landscape Ecology Models

From sea stars to rockfish, and many species in between, integrations of multiple data types offer better stock assessments and more precise distribution estimates. Along the North Central Coast, as well as other regions, landscape ecology models - linking habitat and biological data to make predictions about species distributions and abundances - have been implemented to assess and predict where certain key populations are found within the region, and fill data gaps in stock assessments. Many marine species predictably associate with certain seafloor characteristics, including depth, slope, roughness, and sediment type. The fine-scale seafloor data collected through the CSCMP provide a foundation of where different combinations of these characteristics occur. By combining these data with biological survey data collected with ROVs, researchers are able to develop landscape ecology models to predict species abundance, population distributions, species richness, and more. Models can be incredibly useful to visualize where species occur through predictive maps, which are developed by taking species observation data from a set of narrow transects, identifying the combination of seafloor characteristics and environmental variables present at each observation point, and extrapolating to unsurveyed locations (Fig. 7). By analyzing and anticipating various species' habitat associations and responses to environmental variables, this research provides managers with more accurate information about key species populations and distributions, characterization of essential habitat, and a foundation for adaptively managing for a changing environment without having to extensively survey large areas of habitat.

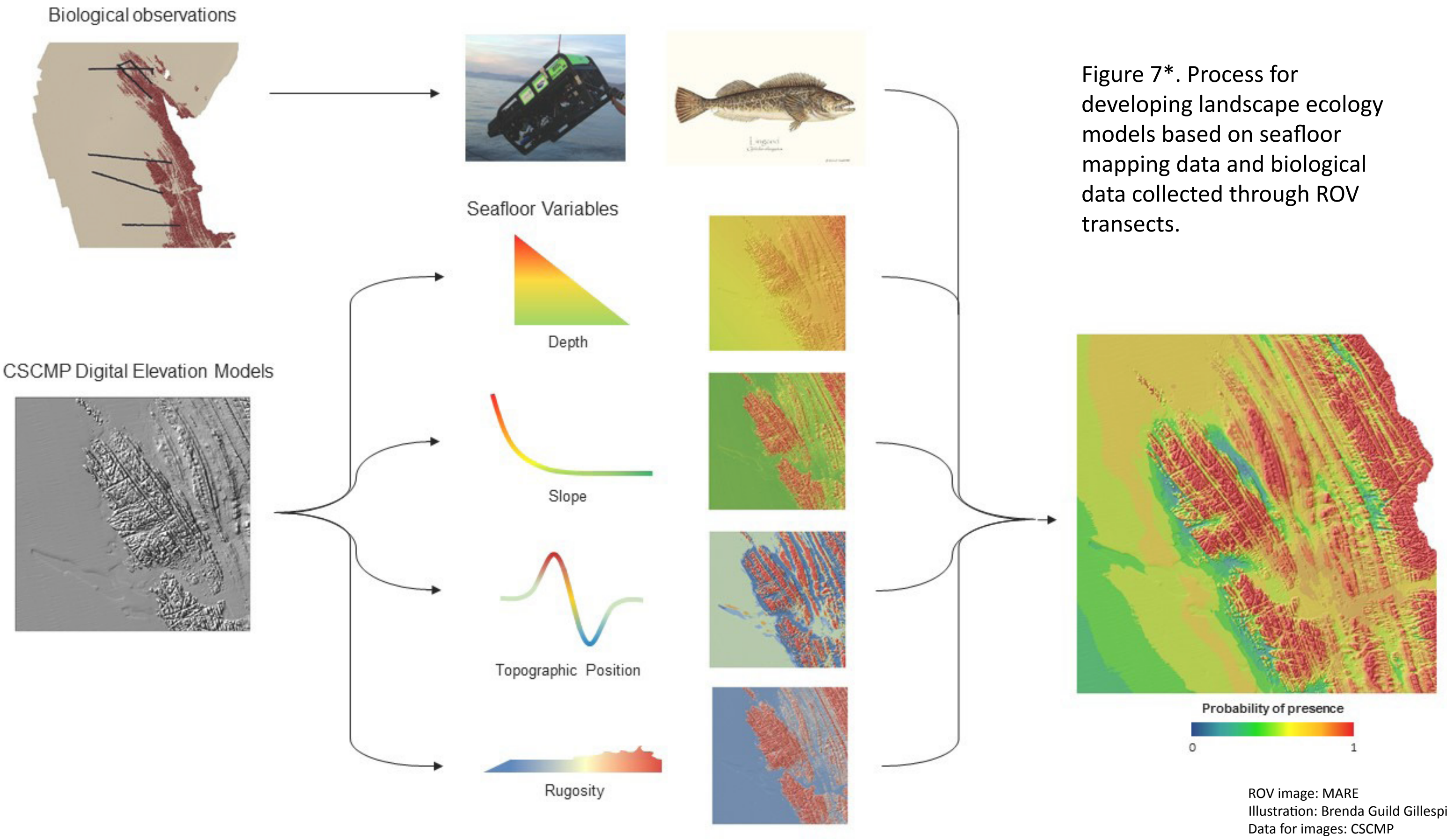


Figure 7*. Process for developing landscape ecology models based on seafloor mapping data and biological data collected through ROV transects.

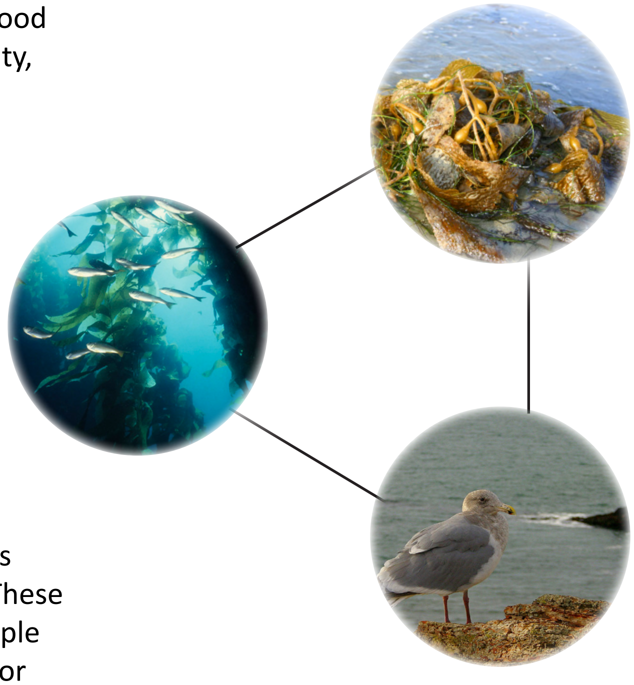
ROV image: MARE
Illustration: Brenda Guild Gillespie
Data for images: CSCMP

*Adapted from *California Seafloor Mapping Program: Central Coast Marine Protected Areas.* CSUMB Seafloor Mapping Lab, California, USA. 2013.

Several projects along California's coast are using these types of methods to better understand marine ecosystems. Young et al. (2010) used ROV and CSCMP data collected in Cordell Bank, offshore of the North Central Coast region, to predict the distribution of several rockfish species across the seafloor and assess the predictive modeling techniques. Collaborations between CDFW and National Marine Fisheries Service (NMFS) are establishing projects with similar methods to develop models that may be able to inform data poor stock assessments. While bottom dwelling fish species, like rockfish, have been the subject of many of these studies because of their strong association to the seafloor, similar methods have also been employed to predict, and analyze the modeling techniques for, the distributions of several invertebrate species (Krigsman et al. 2012). In the Central Coast region, Young et al. (2011) used and tested seafloor mapping tools to analyze squid egg mop distribution, providing information and techniques that are highly useful for managers. These types of predictions and tools are still being tested for accuracy and scalability for many different species, but so far studies using these methods of integration have shown promising and valuable uses for these tools.

Ecosystem Connectivity Analyses

Another way in which multiple datasets can be integrated to gain a deeper understanding of the ecology, and apply those insights to management of the region, is through examining the connectivity among ecosystems. Connectivity of nutrients and resources can strongly influence the distributions of diversity and productivity, especially for ecosystems such as sandy beaches, which have very little primary production. Beach wrack (detached pieces of aquatic plants and algae, driftwood, or animal remains that wash up on the beach) supports beach food webs, including up to ~ 50% of invertebrate biodiversity, abundant shorebirds, terrestrial fauna, and several endangered species. Baseline Program researchers worked together to draw upon the Ocean Imaging ecosystem maps and the sandy beach monitoring project to look at the sources and patterns of wrack along the North Central Coast of California, and to investigate the potential drivers of these patterns. They found that the beach wrack came from multiple sources, including kelp forests, rocky intertidal, and estuarine ecosystems. The local abundance of their source ecosystems was the most important predictor of the supply of wrack, while physical factors (wind, waves, etc.) were only sometimes significant. These results suggest that simultaneous monitoring of multiple marine ecosystems is emerging as an important tool for understanding ecosystem connectivity, and essential for informing adaptive, ecosystem-based management. This work is being written up and submitted for publication (Liebowitz et. al., in prep), and results will be available soon on OceanSpaces.



Derivative Seafloor Maps

Many new spatial products are continually being released, including new map layers derived from CSCMP data. Some of the derivative products available from the CSCMP are various GIS layers displaying the distribution and detail of specific habitat types (Fig. 8A), seafloor characteristics (Fig. 8B), and geology (Fig. 9). These layers (shown below in Bodega Bay as an example), produced by extracting specific information from the original CSCMP data, add valuable detail and while not used in the initial design process, will be useful moving into long-term monitoring and adaptive management of MPAs, and assessment of ocean health. For example, while the region overall consists of about 88% soft sediment and 11% rock (the classification used in initial MPA design), the makeup of the rocky and soft substrate are different throughout different parts of the region, making each location unique (Fig. 9). Around Bodega Bay much of the rocky habitat is extensive Cretaceous granitic rock (dark teal), whereas in Half Moon Bay the rock is comprised mostly of sedimentary rock in the Miocene and Pliocene Purisima Formation (light green). Where granitic rock tends to have a fractured surface with deep faults, the Purisima Formation tends to be "ribbed," caused by differential erosion (Greene et al. 2014; Johnson et al. 2014). While both are rocky habitats, the incorporations of enhanced detail from new geologic layers makes it easier to assess where these different formations occur and aids in the understanding of the variation seen among different locations in the region.

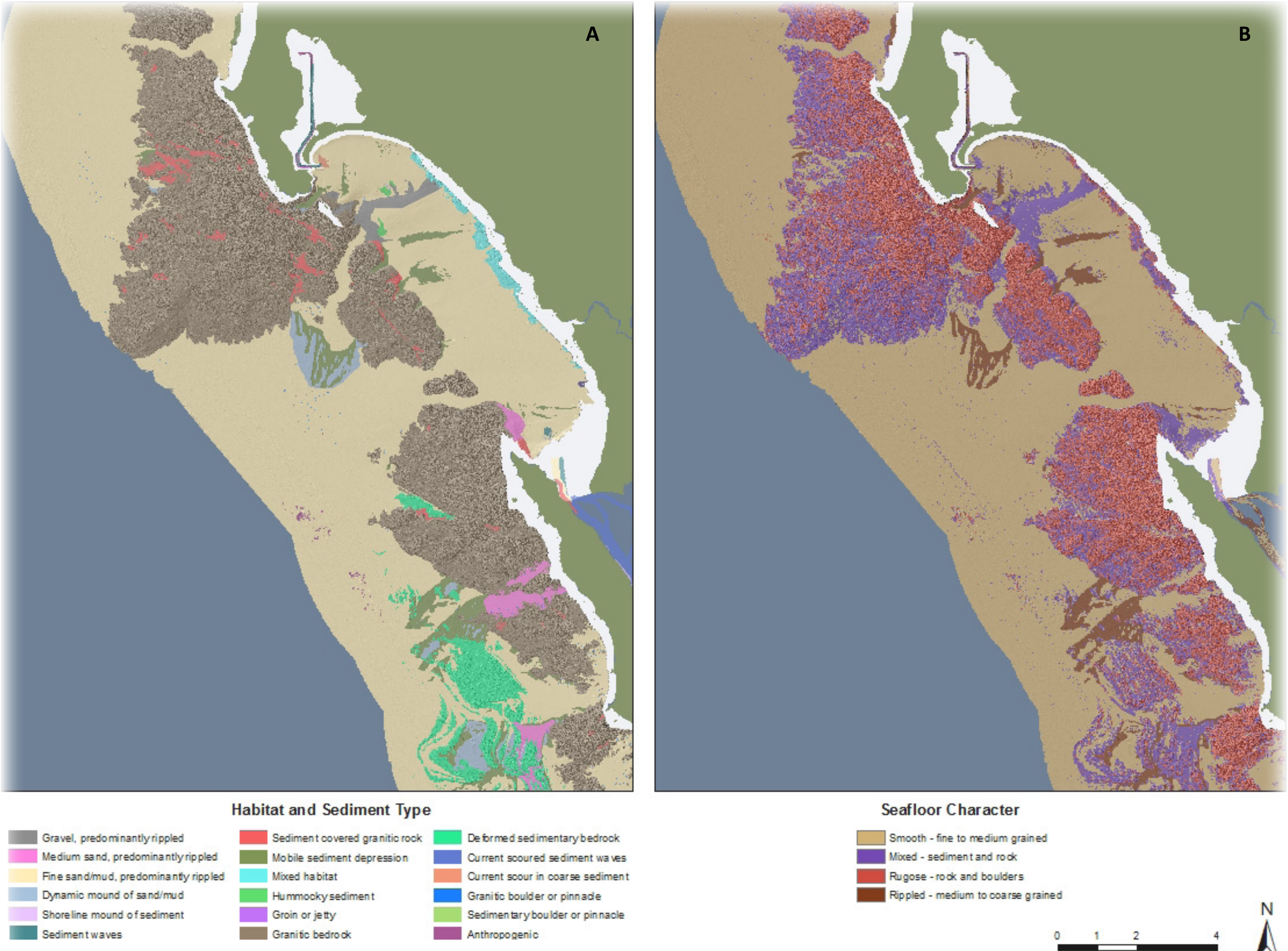


Figure 8. Habitat and seafloor characteristic layers in Bodega Bay.

Additionally, fine-scaled habitat classifications and seafloor characteristics such as sediment grain type and size can contribute to better predictions of species distributions and abundances, as well as help understand past and future coastal dynamics through the analysis of the distribution of sediment types. Derivative maps could also aid in the understanding the potential impacts of environmental change. Detailed data on geologic structure and sediment composition and thickness are important components of seafloor assessment to gain a better understanding of coastline resilience and the need for protection under changing conditions, such as sea level rise. Used together, these new derivative layers offer a more holistic view of the seafloor and a better understanding of the dynamics occurring over it.

Due to the high degree of detail available in the new map layers and processed data from the CSCMP, the categories included in Figures 8 and 9 can be broadened or broken down into more detailed classifications, depending on the application of the data, for multi-scale information. While shown here in Bodega Bay and Half Moon Bay, the various CSCMP products for all of the North Central Coast region are, or soon will be, available for access and download (https://walrus.wr.usgs.gov/mapping/csmp/).

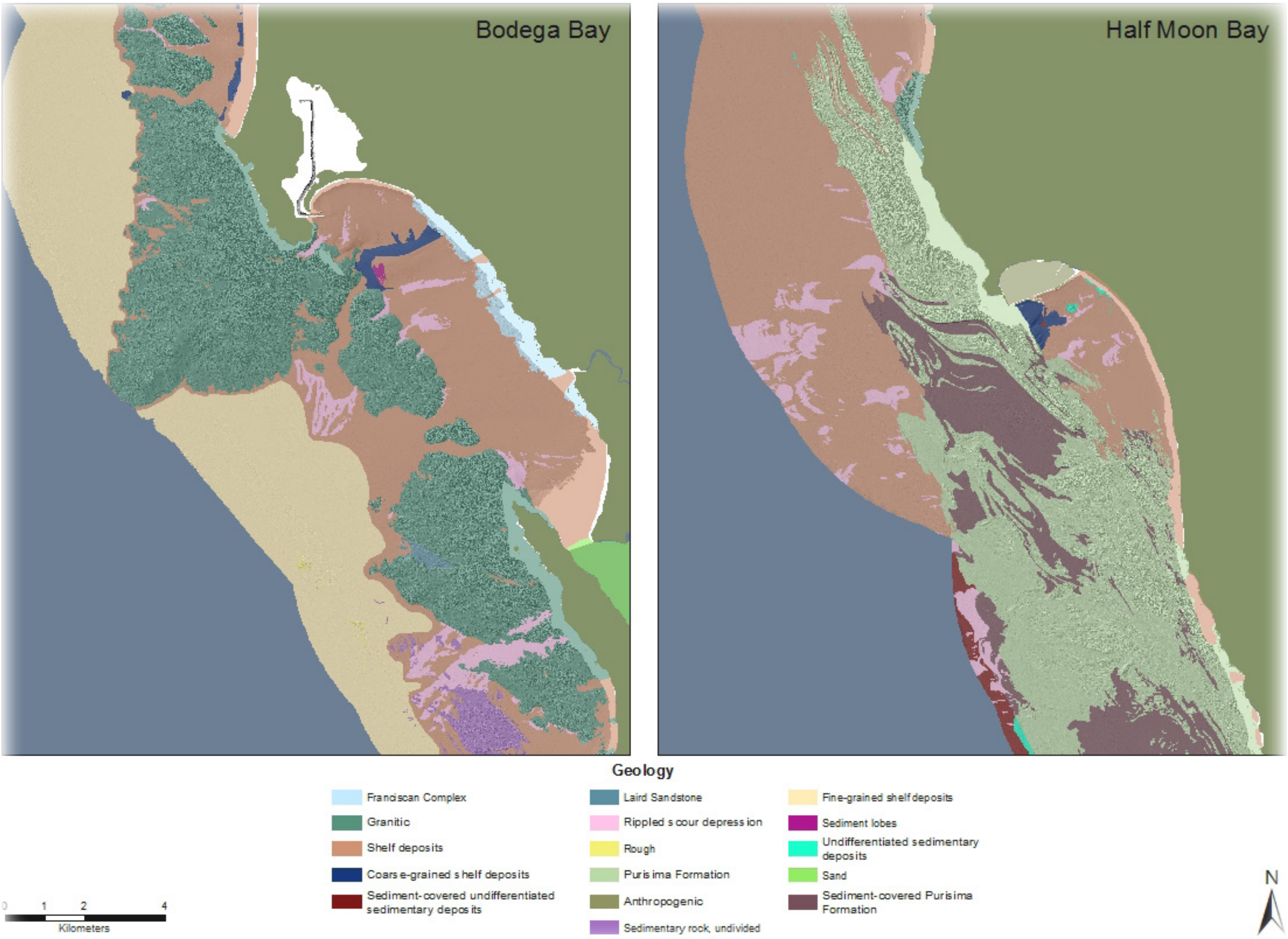


Figure 9. Geology layers in Bodega Bay (left) and Half Moon Bay (right).

While there is a great amount of detailed information about the region, there remains a critical gap—the shallow, very nearshore zone, where navigation hazards and technical limitations prevented ship-board mapping, and turbid water or obstructions prevent successful remote sensing or aerial techniques. This 50-500m wide band of unmapped seafloor, a data gap known as the "white zone," extends from shore to 10-15m depth along the length of the California coast, encompassing much of the state's kelp forests and essential habitat for commercially and recreationally important species (Fig. 10A). Improved mapping of the white zone has been repeatedly identified as an area of critical data need, yet the costs and labor associated with empirically mapping this zone statewide are prohibitive. Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO), CDFW, and California Ocean Science Trust leveraged the wealth of seafloor and shoreline mapping data from the CSCMP and the National Oceanic and Atmospheric Administration (NOAA) Environmental Sensitivity Index (ESI) shoreline habitat categorizations, to develop predictive maps of substrate characteristics in the white zone through interpolation (a mathematical technique to predict missing values in data, Fig. 10B). In order to determine an optimal method of interpolation and to test which combination generated the most accurate and precise prediction of rock versus sand substrate across the variety of white zone widths that occur along the North Central Coast, they tested ten ArcGIS interpolation techniques at various scales and habitat conditions. From these tests, a set of optimal maps were developed (see Saarman et al. 2015) and are now available to stakeholders through CDFW's MarineBIOS (https://www.wildlife.ca.gov/Conservation/Marine/GIS/MarineBIOS). These maps can be used for a range of management applications, such as population modeling for key nearshore species, setting expected rates of population change within MPAs to better evaluate MPA conservation performance, and setting guidelines for scientific collection permits.

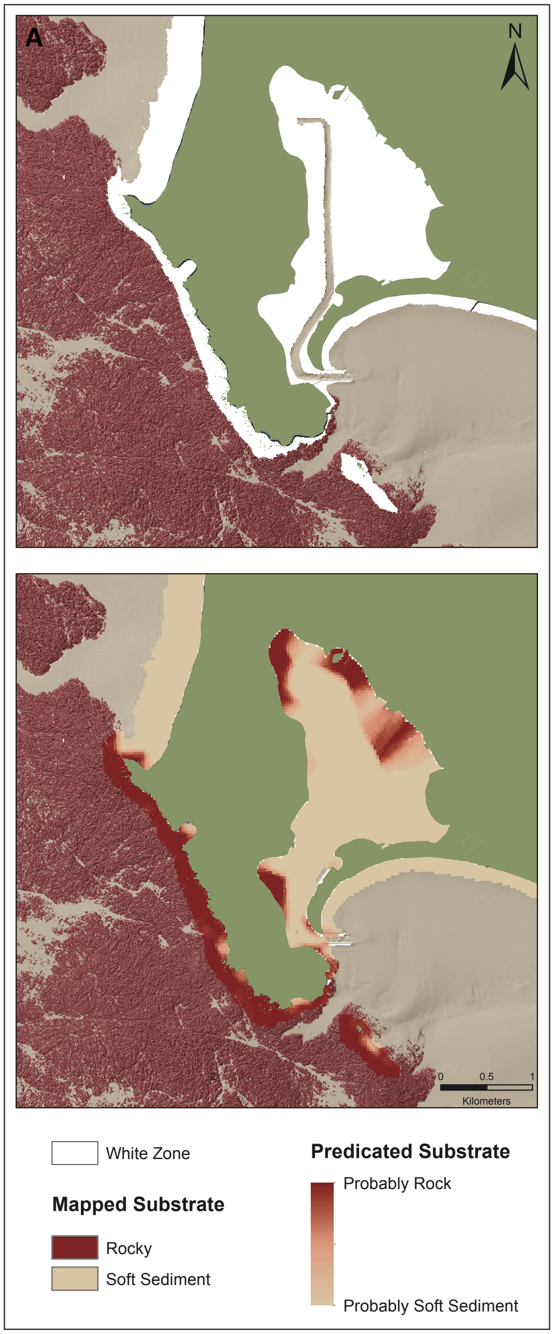


Figure 10. Very nearshore region, the "white zone" (A), and predictive maps of the substrate in this region (B).

Developing and Future Applications

In addition to the newly available map layers and the projects that are already underway utilizing integrations of various types of spatial data, there are many other potential applications that will likely receive more attention in California moving forward. Spatial data collected through improved seafloor mapping technology, like those used in the CSCMP, will be a critical component of tracking changes in California waters because it will allow the tracking of changes in the seafloor and surrounding environment due to landslides, fault activity, strong currents, or human activity and their various impacts on the ecosystem. Some of this type of work has been started by Barnard et al. (2012) at the mouth of the San Francisco Bay, estimating coastal erosion, and by Johnson et al. (2014) assessing offshore faults, both valuable in making predictions about future change and as a tool for adaptive planning. Improved mapping technology has also been used by Barnard et al. (2011) and Draut et al. (2009) to analyze and understand dynamics of sediment transport and temporal changes in seabed morphology along the coast, with clear future applications to tracking and predicting changes in seafloor formations. Furthermore, high-resolution spatial data will be useful in tracking change in California by documenting the distribution of habitat types that are vulnerable or more resistant to various human impacts, as discussed in Grabowski and Hart (2012), analyzing habitat availability and recovery potential (Hughes et al. 2013), sample site selection for research in subtidal environments, and identifying locations that require gear removal attention. Lastly, as California explores the use of alternative energy, spatial data will also be valuable in assessing potential sites for offshore energy by identifying areas of essential habitat or those that are more sensitive to disturbance versus those that may be better suited for supporting offshore energy infrastructure. All of these projects, and many more, will add an additional layer of context and insight to inform adaptive management and understand long-term change along the California coast and beyond to better prepare for the future.

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