Baseline Characterization of Sandy Beach Ecosystems Along the South Coast of California

Final Report

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Sandy Beach Ecosystems: Baseline Characterization and Evaluation of Monitoring Metrics for MPAs along the South Coast of California

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Cover photo: Shorebirds foraging in the swash zone and giant kelp wrack washing in to the sandy beach in the Campus Point MPA on a crisp winter morning (Photo taken by David Hubbard)

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Executive Summary

Sandy beaches are among the most intensely used coastal ecosystems for human recreation and are vitally important to coastal economies. Beaches support unique biodiversity and provide essential ecosystem functions and services including endemic invertebrate communities and food webs that are prey for birds and fish, buffering and absorption of wave energy by stored sand, filtration of large volumes of seawater, extensive detrital processing and nutrient recycling, and the provision of critical habitat and resources for declining and endangered wildlife, such as shorebirds and pinnipeds. Sandy beaches compose 36% of the 693 km of shoreline in the South Coast (SC) region, including the California Channel Islands. The goal of this ecological characterization study is to provide a quantitative, baseline description of sandy beach ecosystems in the region from which future ecological changes may be assessed, and to document any differences that may already exist between sandy beaches located within and outside of Marine Protected Areas (MPAs). We also evaluated potential ecological indicators for monitoring and developed and tested new protocols for potential use by citizen-scientists and educators.

Our baseline study program consisted of the following components:

1. Two years of monthly surveys of birds, macrophyte wrack (seaweeds and seagrasses deposited on the beach), human use and physical characteristics of 12 focal mainland sandy beaches and their adjacent surf zones (6 MPA, 6 reference sites);
2. A one-time, comprehensive survey of intertidal invertebrate biodiversity of the 12 focal sandy beaches;
3. Spring and Fall surveys of proposed invertebrate indicator species, beach hoppers (talitrid amphipods, *Megalorchestia* spp.) and sand crabs (*Emerita analoga*), at the 12 focal sandy beaches for two years;
4. Surveys of clam populations at two pairs of MPA and reference beaches
5. Surveys of birds on rocky intertidal sites (MPA and reference) studied in the rocky intertidal baseline study program;
6. Collaborative evaluation of modified sand crab survey design for the Channel Islands National Marine Sanctuary's Long-term Monitoring Program and Experiential Training for Students (LiMPETS) program, a education and citizen-science effort that focuses on sand crabs, a proposed indicator species, at one beach;
7. Collaborative development of beach indicators and protocols for a new citizen science-based monitoring program for sandy beach ecosystems.

The study beaches were physically and ecologically diverse. All 12 beaches in this study were located on the mainland coast. All of the study beaches were backed by sea bluffs, at least in part. However, the heights of the bluffs, adjacent coastal development, infrastructure, management and access, and beach widths and characteristics varied considerably among the 12 study beaches. Six of the beaches were located within MPAs and six were reference beaches chosen to complement an MPA beach. All of the study beaches were intermediate in morphodynamic type (Dean's parameter >1 and <6). Dissipative beaches did not occur in the SC region and reflective beaches in the region are generally too short in length (< 1km) to fit our site criteria. Intermediate type beaches are the most variable type in shape and in intertidal conditions therefore it was not surprising that physical characteristics differed considerably among the study beaches and over the 2 years of the baseline study. However, no consistent differences in physical characteristics were detected among MPA and reference beaches on the South Coast during the baseline study.

Major findings of our baseline characterization of South Coast beaches include:

- Human use of the study beaches and surf zones was high even on weekday surveys. As many as 627 people and 15 dogs per km of shoreline and as few as none were observed in our monthly surveys. Visitor use increased significantly from north to south in a way that was broadly consistent with populations of nearby communities. The use of the beaches by humans and dogs did not differ between MPA and reference beaches in the baseline study.

- Regional patterns detected in physical forcing and overall beach characteristics (wave height, Dean's parameter, beach width) across the study beaches and region were not associated with any patterns in the ecological components measured in the baseline study.

- The north-to south gradients in visitors, climate, and beach features, identified in this study are consistent with: 1) human population density along the coast, 2) regional climate patterns (temperature gradients), and 3) wave exposure of beaches in relation to North and South Pacific swell windows and the shadowing effects of Point Conception and the California Channel Islands.

- Birds were abundant on the study beaches with over 27,982 birds of 73 species observed in two years of monthly surveys (288 surveys). Shorebirds were most abundant group (12,555 birds) followed by gulls (11,494 birds). Although only a small proportion of birds observed were terrestrial (~ 5%), they were strikingly diverse (29 species). The richness and abundance of birds did not differ between MPA and reference beaches in the baseline study.

- The south coast region represents an important area for shorebirds with 12,555 individuals of 24 species of shorebirds observed and an average overall abundance of 44 shorebirds km^{-1} year-round. Peak average abundance exceeded 100 shorebirds km^{-1} year round at two study beaches (Figure 1). Many shorebirds spend most of each year on the California coast, departing in May for breeding outside the state and returning to California by August.

- Marine macrophyte wrack is a key ecological element that links beaches with kelp forests and reefs. Abundance of wrack varied greatly among the study beaches (Figure 1). Wrack abundance, especially giant kelp, tended to be greater on beaches in the northern bioregion compared to the southern bioregion. Average cover of marine macrophytes ranged from 0.87 to 4.76 m^2 per meter of shoreline and counts of kelp plants ranged from 5 to 150 plants km^{-1} (Figure 1). Our standardized counts of fresh kelp plants were excellent predictors of the total cover of marine macrophyte wrack on the beach. Kelp plant and wrack abundance did not differ between MPA and reference beaches overall.

- Species richness of invertebrates is very high on the south coast compared to global values. We identified over 87 kinds of macroinvertebrates (animals retained on a 1 mm sieve) in surveys of the 12 study beaches and species richness exceeded 30 species on half of the study beaches. Species composition varied among beaches and only our two proposed indicator taxa, sand crabs, *Emerita analoga,* and talitrid amphipods, *Megalorchestia* spp., were observed on all 12 study beaches in the biodiversity surveys. Total abundance, biomass and richness of intertidal macroinvertebrates did not differ between MPA and reference beaches during the baseline study.

- Our results highlight the importance of wrack-associated invertebrates, including endemic beach beetles, to intertidal biodiversity (45% of species) on sandy beaches. The South Coast region may represent a biodiversity hotspot for these poorly studied and highly vulnerable intertidal animals. This unique endemic biodiversity occurs largely above the mean high tide elevation and thus is not formally protected in the new MPAs. Beach grooming and raking that removes wrack and significantly reduces the biodiversity of these taxa is permitted in a number of the mainland MPAs in the SC region.

- Total abundance and biomass of intertidal macroinvertebrates is very high on the study beaches compared to global values (Figure 1). Abundance exceeded 100,000 individuals m^{-1} on two of the study beaches and biomass exceeded 5000 g m^{-1} on four of the study beaches

- The biomass of sand crabs (*Emerita analoga*) is a strong predictor of total macroinvertebrate biomass, making it a good ecological indicator of food availability for shorebirds and for fishes that forage in surf zones.

- The striking seasonal variation in the abundance of sand crabs observed on a number of the study beaches may be associated with important food web interactions, such as predation by fishes, and warrants further investigation.

- Surveys using standard California Department of Fish and Wildlife protocols at two pairs of MPA and reference beaches found low numbers of Pismo clams. Very few clams were of legal harvest size (4.5 inches). No consistent differences in the abundance of clams were evident between MPA and reference beaches.

- Analyses of relationships among physical and biotic features of sandy beaches revealed important ecological links and associations.
    1. The overall abundance and composition of intertidal invertebrates, was related to physical characteristics of beaches associated with the influence of sand grain size on burrowing and energetics.
    2. The species richness and abundance of intertidal invertebrates was strongly correlated with the abundance of wrack subsidies from kelp forests and reefs.
    3. The species richness and abundance of shorebirds was tightly correlated with the species richness and abundance of intertidal invertebrates illustrating the strong trophic links between sandy beaches, and wildlife in the SC region.
    4. The species richness and abundance of shorebirds was also correlated with the abundance of macrophyte wrack and as well as with the abundance and biomass of talitrid amphipods alone, reflecting the strong connectivity between kelp forests, beaches and wildlife in the SC region.

- Surveys of the birds using mainland rocky intertidal sites in the winter were very successful. Rocky shores and sandy beaches supported a similar suite of birds but specialist groups of birds were apparent in both habitats. We found no significant difference in the abundance of birds including shorebirds, gulls at rocky intertidal sites located inside and outside MPAs.

- The LiMPETS citizen-scientist program can provide a pathway for K-12 students to learn about the ecology of sandy beaches, and the collection and use of scientific data. However to serve in monitoring, modifications of the protocol for sand crabs surveys are required to increase accuracy and utility of any data collected. Our study found that in comparison to the modified protocol we developed and tested, the standard LiMPETS protocol:

- Yields significantly lower total and estimated abundances of sand crabs
- Generates large numbers of core samples containing zero to 1 crab
- Results in insufficient information on size structure of populations
- Teacher evaluations of the modified sand crab protocol indicated that it is highly feasible and carries additional educational benefits in fostering scientific observation and quantitative reasoning skills in students

- Preliminary results from our ongoing collaborative development of a citizen science program to monitor the presence of key beach ecosystem indicators are very promising. A pilot study will be conducted in the coming year.

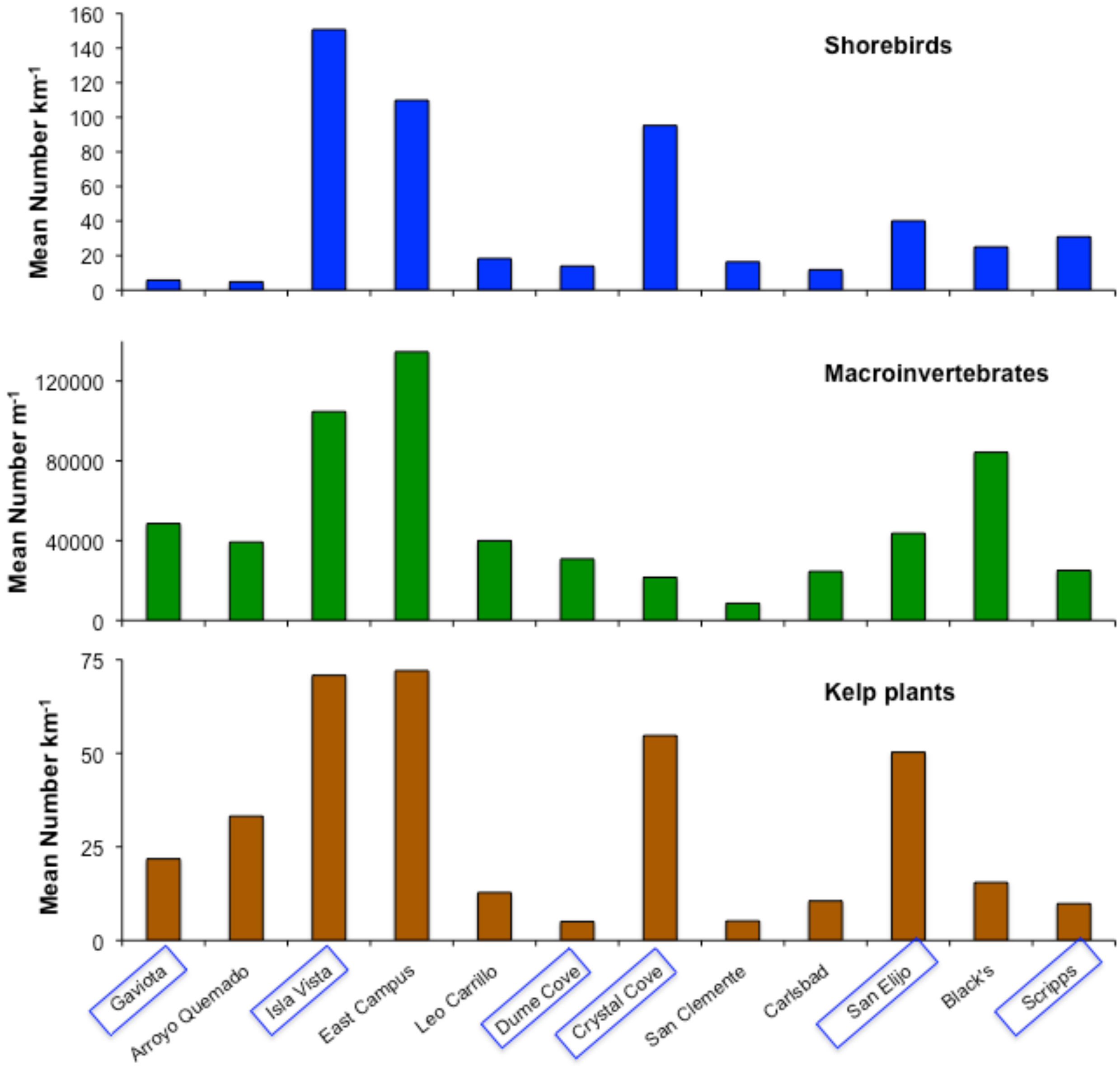

Figure 1 Overall patterns of average abundance of shorebirds, intertidal invertebrates and fresh stranded kelp plants on the study beaches in the South Coast (SC) region. Beaches are listed from north to south. Study beaches outlined in blue rectangles are MPAs, other sites are reference beaches. Abundances are expressed as per linear meter (m^{-1}) or kilometer (km^{-1}) of shoreline.

Study Products

Articles and Chapters

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Introduction

Sandy beaches are a widespread coastal ecosystem, making up ~70% of the shorelines in California and worldwide. Beaches are broadly recognized and highly valued as cultural and economic resources for coastal regions. However their value as ecosystems is often less appreciated. Balanced on a narrow intertidal strip at the edge of land and sea, sandy beach and adjacent surf zone ecosystems harbor unique and endemic biodiversity, are important foraging areas for wildlife and fishes, accumulate sand that can buffer the impacts of storms, filter vast volumes of seawater delivered by waves and tides, process large quantities of organic detritus and contribute to nearshore nutrient cycling. The amount of wrack and plankton cast onto sandy beaches is dynamically linked to adjacent ecosystem features, ocean climate and the population dynamics of intertidal invertebrates. However despite their ecological importance and connectivity with other marine ecosystems, sandy beach ecosystems are not as well studied as other ecosystem features and are often overlooked in coastal conservation efforts (Dugan et al. 2010).

The recent establishment of a new network of marine protected areas (MPAs) along the south coast (SC) of California has provided an opportunity to develop a comprehensive description of the biodiversity of sandy beaches in the region as part of the South Coast MPA Baseline Program. Sandy beach ecosystems contain critical ecological and socioeconomic pathways through which direct and indirect effects of MPA implementation will cascade (Figure 2), making sandy beaches an important target for long-term monitoring to assess ecosystem condition and functioning of the South Coast region. In this report we provide a baseline assessment of sandy beach ecosystems and expand our ecological understanding of their condition and functioning.

The newly established MPAs currently do not include or protect a major portion of the intertidal zone of shoreline ecosystems, including beaches, because their jurisdiction only extends up to the mean high tide line. Critical components of the structure and function of beach ecosystems rely on the zones and habitats above the mean high tide line. These critical components include upper intertidal zones that support 40-50% of the intertidal biodiversity, wrack deposition and processing zones, essential spawning habitat for California grunion, nesting habitat for endangered and threatened shorebirds and the coastal strand and dunes zones. Sandy beach ecosystems encompass the sandy habitats and intertidal zones above MHTL, as well as the surf zone. These zones are tightly linked ecologically and geomorphically and cannot be studied or managed in isolation from each other. For example the highly mobile intertidal animals may need to use much of the available beach width to adjust to changing beach conditions (Dugan et al. 2013). By extension, unless additional protection is provided to entire beach ecosystems by adjacent management entities, such as other parks or reserves, destructive management activities including beach grooming or raking, scraping and berm building with heavy equipment, vehicle driving and beach filling allowed on sandy beaches located within MPAs will remain major threats to the health of these ecosystems regardless of MPA status. For example, regular beach grooming occurs on 45% of the beaches in the south coast region (Dugan et al. 2003) including miles of beaches located in MPAs degrading both the intertidal and the coastal strand and dune zones of beaches. In addition, more than 25% of the coastline of the SC region is armored with hard structures such as seawalls and revetments (Griggs 2005). Beach filling or nourishment is widely practiced in the SC region, with >70 million m^3 of sediment added to beaches in the region in the past 75 years (Orme et al. 2011). Watershed and land use also affect sandy beaches in the region. It is estimated that dams on rivers in the SC region have reduced the sand supply to beaches by 50% (Slagel and Griggs 2008). The extensive armoring of sea bluffs has also reduced the supply of sediment to beaches by 10% (Runyan and Griggs 2003) in the region.

In 2011 we initiated a series of studies aimed at 1) providing a baseline snapshot of the ecological condition of sandy beaches, 2) developing informative ecosystem indicators that could be used for long-term monitoring and 3) interpreting the important ecological links among the components of the ecosystem, including humans, for use in a synthetic evaluation of the effectiveness and changes over time in the South Coast (SC) network of MPAs (Figure 2,Table 1). Our study sites included six beaches located within MPAs established in 2012 and six reference beaches that were outside the boundaries of the South Coast network of MPAs. Although we surveyed at least one beach inside an MPA and one reference beach in Santa Barbara, Los Angeles, Orange and San Diego Counties (Table 1), our study beaches are likely not representative of the SC region. In fact, there were no SC MPAs established on the mainland coast of Ventura County where 93% of the coastline is sandy beach that includes significant examples of the most intact beach and dune ecosystems remaining in the SC region. Our study program consisted of several distinct but inter-related components (Table 1). The majority of the work consisted of a range of standard ecological surveys that involved a scientific research team and other components developed and evaluated modified protocols for existing and new citizen-scientist survey efforts.

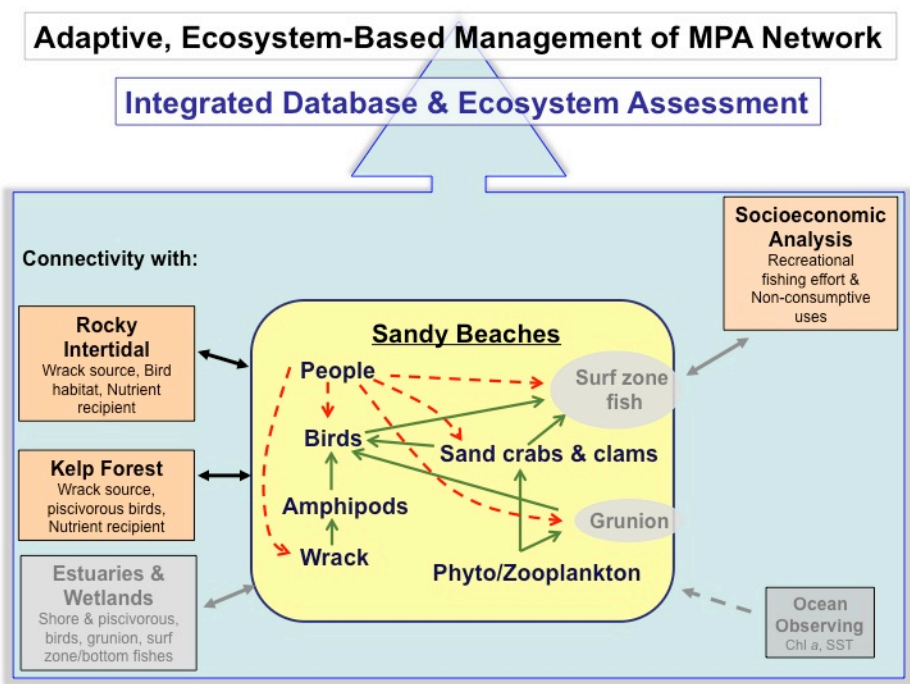

Figure 2. Links among ecosystem features, proposal components, and integrated outcomes for sandy beaches. Green arrows are links among ecosystem features; black arrows indicate positive effects; red arrows indicate negative effects; black text shows project module or ecosystem feature; blue text indicates synthetic outcomes; gray text indicates entities or outcomes outside the scope of this study.

The first standard ecological component consisted of 2 years of monthly surveys of birds, macrophyte wrack, human activities and physical characteristics of 12 focal study beaches (Figure 3). These surveys allowed us to characterize two full seasonal cycles of the dynamics of wrack deposition and the occurrence and diversity of birds and humans uses on regional beaches. The 12 study beaches included six pairs of beaches, these pairs consisted of one beach located within an MPAs and a matched beach outside the MPA to serve as a reference site. Half of the beaches were in the northern mainland bioregion and the other half of the beaches were located in the southern mainland bioregion. Importantly, because of the ecological impacts of common management practices previously shown for beaches in the SC region (e.g. Dugan et al 2003, 2008, Dugan and Hubbard 2010, Hubbard et al 2013, Viola et al 2013) our study site selection purposely excluded both MPA and reference beaches that were known to be groomed, manipulated with heavy equipment or subject to direct beach filling in the region with only one exception. However, at least six of the study beaches were subject to regular vehicle use by lifeguards and/or park rangers. No island beaches were surveyed in this study due to logistical constraints.

The second ecological component was a one-time, comprehensive survey of macroinvertebrate biodiversity of the same 12 beaches. This quantitative sampling included core sampling for infauna as well as net sweeps and sticky traps to quantify surface crawling and flying wrack-associated macroinvertebates. A third ecological component focused on semiannual surveys of two common, abundant and ecologically important taxa that comprise the bulk of the macroinvertebrate biomass at intermediate trophic levels in two primary pathways of energy in sandy beach ecosystems: talitrid amphipods (*Megalorchestia* spp.) and sand crabs (*Emerita analoga*) (Figure 2). We targeted these two taxa for evaluation as possible long-term indicators of the ecological condition of sandy beach because of their ubiquity and energetic importance to sandy beach food webs. We surveyed these target taxa at our 12 focal beaches twice per year in the SC region in 2012 and 2013 (Figure 3). A fourth component surveyed the abundance and size structure of Pismo clams on selected MPA and reference beaches using the standard survey methods developed and used by the California Department of Fish and Wildlife for decades. We used these datasets to explore the hypothesized relationships among beach ecosystem components illustrated in Figure 2.

A new integrative ecological component of our baseline study consisted of surveys of the distribution and abundance of wintering and resident birds conducted on rocky intertidal sites located inside and outside of the SC MPAs. These bird surveys were conducted at 16 rocky intertidal sites on the mainland coast where intertidal biodiversity surveys were conducted by Blanchette et al. (2014) as part of the South Coast MPA Baseline Program. Of these 16 sites, nine were located in MPAs and seven were reference sites. A minimum of three replicated surveys of birds were conducted at these sites on spring low tides between December 2013 and February 2014.

One of our two citizen scientist components focused on developing and evaluating improved protocols for a citizen science sand crab monitoring program. An important beach suspension feeding species, sand crabs are the subject of a National Marine Sanctuary (NMS) education and outreach effort, the Long-term Monitoring Program and

Experiential Training for Students or ‘LiMPETS’ program, that engages local K-12 and community college students in field surveys of these highly mobile and easily disturbed animals on the south coast and elsewhere in the state. We collaboratively developed and tested methods intended to provide much needed improvements to this program. We collaborated with NOAA NMS personnel in a replicated, side-by-side sampling effort in repeated surveys at one beach (Campus Point SMCA) to develop and evaluate modified protocols that adapted to the dynamic distribution of sand crabs. We compared the results of the standard LiMPETS sand crab sampling method, initially designed to serve an educational mission with this modified method. The aim of this component was to recommend robust and necessary adjustments to the LiMPETS protocol, to allow the program to improve its educational mission and to take steps toward developing the scientific accuracy and repeatability required to play a role as a long-term, citizen science monitoring program for regional sandy beaches.

A promising new citizen science component involved the development and testing of non-destructive data collection approaches and the training and educational materials for key ecological indicators for sandy beaches that can be used by trained citizen scientists to provide much needed information on the status of ecosystem components of sandy beaches inside and outside of MPAs in the South Coast region. This ongoing effort relies heavily on data collected in the SC MPA beach baseline study and the efforts of a diverse ad hoc working group of scientists, state park and agency representatives and marine educators.

We present our report in several sections:

I. The baseline ecological characterization of sandy beaches in California’s South Coast Marine Protected Areas Region
II. Results on the distribution and abundance of birds at rocky intertidal study sites as an integrative component of the South Coast Baseline study (Blanchette et al. 2014)
III. Results of our evaluation of refined and improved methods for sand crab monitoring that we developed for the LiMPETS education and outreach program
IV. Results of the ongoing development of a citizen science program based on beach ecosystem indicators

I. Baseline Characterization of Sandy Beaches in the South Coast Region

The primary goal of this section of the report is to provide a baseline assessment of the ecological state of sandy beach ecosystems against which future changes in ecosystem state might be assessed with particular emphasis on the effects of protection and management due to the designation marine protected areas (MPAs) in California's South Coast MPA region. We focused our effort on the draft metrics and key attributes listed in Table 1.

Table 1. Draft Metrics and Key Attributes for Ecosystem Assessment investigated on sandy beaches in the South Coast Region.

Draft Metrics and Key Attributes		**Draft Indicator/Focal Species or Taxa**
Trophic Structure	Predatory Birds	Marine Birds – species richness, abundance Shorebirds, Seabirds, Gulls, Other birds, Terrestrial birds, including raptors and Belding's Savannah Sparrow
	Suspension Feeders	Macroinvertebrates - abundance, biomass, size structure Sand crabs, Pismo clams, Bean clams
	Wrack Consumers	Wrack invertebrate diversity, abundance, biomass
Productivity	Beach wrack	Macrophyte wrack composition, abundance, biomass
Diversity		Intertidal macroinvertebrate species richness
Non-consumptive Use		Human use - recreational activity, zone used
Consumptive Uses		Fishing, Clamming

Background and Management Context

Sandy beach ecosystems make up 36% of the SC region's 693 km of shoreline (California Marine Life Protection Act Science Advisory Team 2009). A percentage of available sandy beach habitat in the region was protected within MPAs in each of four 'biogeographical subregions' of the SC region (California Marine Life Protection Act Science Advisory Team 2009). During the MPA planning process these biogeographical subregions were recognized as having distinctive oceanographic features, geomorphology and differing species compositions (within state waters) (California Marine Life Protection Act Science Advisory Team 2009). Broadly speaking, California MPAs restrict extractive activities or consumptive uses within the boundaries of the MPAs, but do not restrict visitation, access or numerous other activities within their boundaries, except for some 'special closures' that prohibit access or restrict boating activities in waters adjacent to sea bird rookeries or marine mammal haul-out sites. This baseline study only included selected beaches in State Marine Reserves (SMRs) and State Marine Conservation Areas (SMCAs).

Figure 3. Locations of sandy beach baseline monitoring sites and marine protected areas (MPAs) in the South Coast (SC) region. All study sites for this baseline study were located on the mainland coast. Yellow symbols and labels indicate beaches inside of MPAs and aqua symbols and labels indicate the reference beaches selected for beach and clam surveys. See Tables 2 and 3 for site and survey details.

Table 2 Names, MPA status, designations and locations of sandy beaches surveyed for the South Coast MPA Baseline Program. Beaches are listed from north to south.

Beach	MPA Name	Other Designation	County	Latitude N	Longitude W
Gaviota	Kashtayit SMCA	Gaviota State Park	Santa Barbara	34 28'14.18"	120 13'42.67"
Arroyo Quemado	Reference		Santa Barbara	34 28'14.4"	120 07'47.85"
Sands Beach	Campus Point SMCA	UC Natural Reserve	Santa Barbara		
Isla Vista	Campus Point SMCA		Santa Barbara	34 24' 26.03"	119 52' 45.92"
East Campus	Reference		Santa Barbara	34 24' 26.03"	119 52' 45.92"
Santa Claus Lane	Reference		Santa Barbara		
Leo Carrillo	Reference	Leo Carrillo State Park	Los Angeles	34 02'47.70"	118 56'55.24"
Dume Cove	Point Dume SMR	Pt Dume State Beach & Reserve	Los Angeles	34 00' 08.15"	118 48' 18.22"
Crystal Cove	Crystal Cove SMCA	Crystal Cove State Park	Orange	33 34' 39.13"	117 50' 50.30"
San Clemente	Reference	San Clemente State Beach	Orange	33 24' 05.90"	117 19' 28.74"
Carlsbad	Reference	Carlsbad State Beach	San Diego	33 06' 51.07"	117 19' 28.34"
San Elijo	San Elijo, Swami's SMCA	San Elijo State Beach	San Diego	33 01' 41.85"	117 17' 19.18"
Blacks	Reference	Torrey Pines State Beach	San Diego	32 53'15.36"	117 15' 05.36"
Scripps	Matlahuayl SMR, Scripps SMCA	UC Natural Reserve, La Jolla Shores Beach	San Diego	32 52'12.19"	117 15' 12.51"
Imperial Beach	Reference		San Diego	32°34'28.20"	117° 7'58.08"

Methods

We used three different survey and sampling approaches, denoted as 'rapid surveys' 'biodiversity sampling' and 'target sampling', to describe the abundance, diversity, occurrence or activities of birds, macroinvertebrates, wrack and people, as well as the physical characteristics of the beach and surf zone on 12 sandy beaches in the SC region. Six of these beaches were within MPAs, five in SMCAs and two in SMRs (Tables 1 & 3, note the Scripps study beach contains both an SMCA and SMR). The locations, landward boundaries and survey types and dates for the beaches are given in Figure 3, Tables 1 & 3, and Appendix A.

Table 3. Sandy beach study sites, MPAs, landward boundaries, shore features, management activities and the types and times of surveys conducted in the SC region. Beaches are listed from north to south.

Beach	MPA Name	Landward boundary	Biodiversity	Rapid	Indicators	Clams
Gaviota	Kashtayit SMCA	Bluffs, stream mouth	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Arroyo Quemado	Reference	Bluffs, stream mouth	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Sands Beach	Campus Point SMCA	Dunes, lagoon				Winter 2012, 2013
Isla Vista	Campus Point SMCA	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
East Campus	Reference	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Santa Claus Lane	Reference	Riprap, railroad tracks				Winter 2012, 2013
Leo Carrillo	Reference	Bluffs, parking lot	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013"	
Dume Cove	Point Dume SMR	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Crystal Cove	Crystal Cove SMCA	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
San Clemente	Reference	Bluffs, riprap, railroad tracks	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Carlsbad	Reference	Bluffs, riprap	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
San Elijo	San Elijo, Swami's SMCA	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Blacks	Reference	Bluffs	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	
Scripps	Matlahuayl SMR, Scripps SMCA	Seawall, Bluffs, grooming	Fall 2011	Dec 2011-Nov 2013	Spring/Fall 2012, 2013	Winter 2012
Imperial Beach	Reference	Houses, grooming, filling				Winter 2012

Rapid Surveys

To describe the distribution, abundance and seasonal occurrence of shorebirds, people and fresh kelp wrack we conducted monthly daytime surveys of during low tides on standard alongshore transects at 12 focal beaches. The 12 focal beaches were surveyed monthly for two years between December 2011 and November 2013. These focal beaches included six MPA and six reference sites (Table 3). Simultaneously with the alongshore surveys, wrack cover was measured monthly using a line intercept method on each of three shore-normal transects of variable length that extended from the lower edge of terrestrial vegetation or the bluff to the lowest intertidal level exposed by swash. Physical parameters characterizing the beach, the sand and the surf zone were also collected along these shore-normal transects monthly. A standard alongshore transect of 1 km in length was established at each of the 12 focal beaches. Once established, the endpoints of the selected segments were described and their positions determined with GPS (Appendix A).

Surveys of the 1 km transects were conducted monthly at each of the 12 focal beaches from December 2011 to November 2013 for a total of 12 km of beach per month (Table 3). Using two teams of observers who surveyed 2-4 sites per day each, surveys of all 12 beaches were generally conducted within 4 days during each month. Surveys were conducted on weekdays and scheduled so that the condition of the tide was constrained, but not the time of day. All surveys were conducted on 0.75 m (2.5 ft) or lower tides and spanned the two hours preceding and following the low tide.

During each month, all shorebirds, gulls, seabirds and other birds, including terrestrial birds, were identified and counted on the selected transects of the 12 focal beaches. Counts were conducted by a single observer (either JED or DMH) who walked the transect, recording all birds on a standard data sheet. Shorebirds and other birds were identified and counted using binoculars. Care was taken to avoid disturbing or double counting birds. As they were counted, all birds were assigned to intertidal zones (upper intertidal, mid-intertidal, below WTO, swash zone) and their behavior (feeding mode, roosting) was noted on a standard data form. Any dead or oiled birds and mammals encountered were also recorded. Birds in the surf zone and just beyond (if present) were also identified and counted. All people and dogs were counted, assigned an intertidal zone and their activity recorded for each transect during the surveys. In addition, we counted the number of ‘fresh’ beach-cast giant kelp plants (*Macrocystis pyrifera)* (not dried-up, mostly intact and located in the vicinity of the high tide strand line). To avoid over estimating their abundance due to fragmentation, we identified and enumerated only those individuals with an intact holdfast.

For each standard segment of beach, the date, observer name, start and stop times, weather conditions (average and maximum wind speeds, air temperature and wind chill) were recorded. A number of physical characteristics were measured for each beach segment surveyed including beach zone widths and slopes, macrophyte wrack cover, wave regime, and sediment grain size on cross shore transects that were established in a representative sandy area within the 1 km alongshore transect.

The extent and presence of each type of wrack was recorded on each of three shore-normal transects of variable length that extended from the lower edge of terrestrial vegetation or the bluff to the lowest intertidal level exposed by swash at each location. The transects were randomly assigned to locations within the first 100 m of shoreline from the access point using a random number table and a distance measuring wheel. We used a line-intercept method along each transect to quantify wrack cover. One edge of the track of a distance measuring wheel was used to define a reference line for enumerating wrack abundance. The extent and presence of each type of macrophyte, driftwood, carrion, tar, trash and any other beach-cast wrack was recorded along the reference line using size categories (1 mm to 8 m) yielding total wrack cover by wrack type for each transect.

To characterize the beach, surf and swash zones we measured the beach width from lower edge of terrestrial vegetation or the bluff to the lowest intertidal level exposed by swash, locations of the water table outcrop (WTO) and high tide strand line (HTS) and beach slope at these two locations. In addition, surf zone wave height and period, and swash width and period were visually estimated at the middle transect. Average air temperature, wind speed and wind chill (over three minutes) were recorded at the middle transect using a small, hand-held weather meter (Kestral®). Any vehicle tracks on the beach, including grooming marks and categorical estimates of the number of recent footprints in the sand made by people or other readily identifiable animals were also noted.

Average sediment grain size was determined from sand samples taken at the WTO and HTS of the middle transect. Sediments were rinsed in fresh water to remove salt residue, dried to constant weight and then shaken through a series of sieves (screen apertures [in microns]: 5600, 4000, 2800, 2000, 1400, 1000, 710, 500, 355, 250, 180, 125, 90, 63, 45) to determine the relative abundance of sand in each size class. We calculated the geometric mean and standard deviation (=sorting) for each sample.

A dimensionless index of beach morphodynamic state, Dean's parameter (Ω) was calculated for each survey date using mean sand grain size at the WTO and wave height and period in the following formula: $\Omega = H_b/\omega T_p$ where H_b is the significant breaker height, T_p is the significant wave period and ω is the settling velocity for the mean sand grain size.

Biodiversity sampling

To describe the biodiversity of intertidal invertebrates on the beaches, we quantitatively sampled the intertidal macroinvertebrate community at each of the 12 focal beaches (six MPA and six reference beaches) during daytime spring low tides in Fall of 2011. These community surveys were temporally constrained to a period of 2 months to reduce the potential for confounding comparisons due to seasonal variation (Table 3).

The species richness, abundance, biomass and population characteristics of the macroinvertebrate community of the 12 focal beaches was estimated using sampling protocols similar to those used in earlier studies of California beaches (Dugan et al. 2003) and MPA baseline studies (Nielsen et al. 2013). Quantitative sampling was conducted on three vertical format (shore-normal) transects as described above which extended from the lower edge of terrestrial vegetation or the bluff to the lowest level exposed by swash of the intertidal at each location. The distances between transects were randomly selected and to minimize disturbance of the mobile fauna in the lower beach in adjacent transects, a 10 m buffer zone was added between transects.

Each vertical transect was divided into 15 uniformly spaced levels to facilitate sample handling and processing and allow future analyses of intertidal zonation. Ten evenly spaced cores were collected in each of the 15 levels and pooled. We collected a series of 150 core samples along each transect with the top core corresponding to the lower edge of the terrestrial vegetation or the bluff edge and the lowest core corresponding to the low swash level. A cylindrical core (0.0078 m^2, 100 mm diameter) was taken to a depth of 200 mm at uniform intervals of 0.25 to 2.0 m depending on the width of the beach. The 10 cores from each of the 15 transect levels were placed in a mesh bag with an aperture of 1.5 mm for sieving. This sampling design yields a total sampling area of 3.5 m^2 and 45 biological samples at each beach. Most species of macroinvertebrates likely to be prey of shorebirds were retained on a 1.5 mm sieve. Sediments were removed from the accumulated core samples from each of the sampling levels by sieving in the swash zone (at a distance from the sampling transects).

Samples in which large amounts of coarse sediments were retained in the mesh bag were elutriated *in situ* to separate the macroinvertebrates from the sand. Upper cores with retained coarse sediments were transported back to the laboratory and frozen prior, to elutriation to retain any of the highly active taxa characteristic of the upper intertidal. In the elutriation process, a moderate amount of coarse sediments containing macroinvertebrates (~two large handfuls) was placed in a bucket with a pour spout, seawater was added to fill the bucket and mixed vigorously with the sediments. The seawater was then poured rapidly into a sieve that retained macroinvertebrates and the process was repeated. After three elutriations in which no additional macroinvertebrates were removed, coarse sediments were inspected by eye and discarded.

All macroinvertebrates retained on the sieves were placed in labeled plastic bags, chilled and transported to the laboratory for preservation and processing. All macroinvertebrates were preserved in buffered formalin in seawater for later identification with the exception of the upper shore samples without polychaetes, which were frozen. All animals retained on the sieves were identified, enumerated, blotted dry and weighed to the nearest 0.001 g.

As in the rapid surveys described above we also quantified abundance of wrack along the three transects as well as physical characteristics of the beach and surf zone. However, during these surveys we quantified wrack by direct measurement of the length and location of contact of each wrack type encountered along the transect tape (allowing for future mapping of abundance by zone). We also measured physical parameters and collected sand samples on all three transects instead of just the middle transect as in the rapid surveys.

Indicator taxa surveys

The suspension-feeding common sand crab, *Emerita analoga* and the macroalgal wrack-associated talitrid amphipods in the genus *Megalorchestia* were chosen as potential macroinvertebrate indicator taxa on the beaches. To describe the abundance, distribution and mean individual size of these potential indicators, we conducted targeted quantitative sampling of populations of these species on each of the beaches in Spring (May/June) and Fall (September/October) in 2012 and 2013 for each of the 12 focal beaches. Sampling sites and dates appear in Table 3.

The abundance, biomass and population characteristics of *Emerita analoga* and *Megalorchestia* spp. were estimated using sampling protocols that were generally similar to those used in the intertidal biodiversity sampling but with some variation in the layout, depth and number of cores collected. For *E. analoga*, which inhabits the lower beach and swash zone of the beaches, an informal spade transect was used to determine the upper boundary and lower boundary of occurrence of the crabs). Quantitative sampling was conducted along the three vertical format (shore-normal) transects used for physical measurements and macrophyte wrack sampling (see ***rapid sampling*** methods above) which extended from the lower edge of terrestrial vegetation or the bluff to the lowest level exposed by swash of the intertidal at each location. The distances between transects were randomly selected and to minimize disturbance of the mobile fauna in the lower beach in adjacent transects, a 10 m buffer zone was added between transects. Sampling was done during predicted low tides of 0.75 m (2.5 ft) above MLLW or lower and constrained to occur within two hours of low tide.

For *Emerita analoga*, we collected a series of 30-50 cores on the lower part of each transect with the top core corresponding to the upper edge of the crab's distribution and the lowest core corresponding to the lowest swash level or the lowest zone of occurrence of the crabs. A cylindrical core (0.0078 m^2, 100 mm diameter) was taken to a depth of 100 mm at uniform intervals of 0.25 to 1 m depending on the width of the zone of occurrence of *E. analoga*. The cores from each transect were pooled and placed in a mesh bag with an aperture of 1.5 mm for sieving. Sieving and elutriation were conducted as described for macroinvertebrate community sampling above (see ***biodiversity sampling*** methods). All macroinvertebrate retained were placed in labeled mesh bags, chilled and transported to the laboratory for processing. All animals retained on the sieves were identified, enumerated, blotted dry and weighed to the nearest 0.01g. Carapace lengths of crabs were measured with a series of graded sieve to the nearest 1 mm and vernier calipers to the nearest mm. Sex and reproductive condition was determined for crabs that could be unambiguously sexed by eye (generally >8 mm) for future determination of mean adult body size, reproductive effort and sex ratios.

For upper beach fauna, including *Megalorchestia* spp., we collected a series of 10 uniformly spaced cores from the upper edge of talitrid burrows to the lowest level where talitrids were burrowed. Cores were pooled and placed in a bag with an aperture of 1.5 mm for sieving and sieved as described immediately above (see ***biodiversity sampling*** methods). Animals retained on the sieve were placed in labeled plastic bags, chilled and transported to the laboratory for freezing and later processing. All macroinvertebrate species retained on the sieves were identified, enumerated, blotted dry and weighed to the nearest 0.001g.

In addition to talitrids, kelp flies were sampled using 50-100 standard sweeps of insect nets along the 3 transects during the Spring and Fall indicator taxa surveys. Flies collected on each transect were chilled, transported and then stored frozen for later processing. Flies from aerial sweeps were counted and identified by size and species. Flies were also sampled using sticky traps of commercial fly paper (Revenge Fly-catcher®). Two strips of fly paper were deployed in the wrack zone within one meter of each transect line. After 15 minutes, the strips were collected, folded in thirds and placed in one-gallon plastic bags. All fly paper samples were frozen before processing. Flies and other fauna adhering to the strips were counted and identified by size (for flies) and taxa for other fauna.

All bird, human, dog, fresh kelp, beach wrack and physical characteristics from the rapid surveys, biodiversity and target sampling were entered into Microsoft Excel spreadsheets following the completion of field work, and laboratory processing and taxonomic identification, in the case of macroinvertebrate samples. The data were processed and basic descriptive statistics calculated using Excel and JMP Pro 11. The abundance of birds, humans, dogs and fresh kelp plants from the alongshore transects were expressed as the number per km of shoreline. Macroinvertebrate abundance derived from core samples were expressed as number per meter of shoreline and biomass are expressed as grams wet weight per meter of shoreline. Beach wrack data are expressed as cover in square meters per meter of shoreline. We used the basic descriptive statistics on the abundance and distribution of bird, human, dog, fresh kelp, beach wrack and physical characteristics to describe their temporal and spatial variation on the beaches.

Clam surveys

Surveys for Pismo clams, *Tivela stultorum*, were conducted using the standard California DF&W protocols that have been used since the 1950’s by the Department. All surveys are conducted on spring low tides of -1.0 ft or more. Surveys were initiated 2 hours before the time of low tide. A 100 m baseline was established parallel to the shoreline, about 30 m above the water line. Three to six random, pre-selected, transect points were marked along the 100 meter base line and a 30-50 m shore-normal transect is extended toward the water from each of those points. The trench sampling for clams was started where wet saturated sand began on each 30 meter transect. Starting on either side of the transect line at a 3 meter mark, a 25 cm wide trench was dug to depth of standard square shovel (~ 8 inches) for 3 meters along the transect. When sampling above the reach of the swash, sand from the trench was searched after spreading using a flinging motion of the shovel. If there was a layer of water, the sand from the trench was placed in a mesh bag to sieve sand and retain animals. A trench was dug on every other 3 meters of each shore normal transect until a clam was found. Once a clam is found, then a trench is dug for every 3 meters of each shore normal transect. Transects were trenched as low in the intertidal and swash zone as possible until water or wave wash made it too difficult to determine if clams were present. All clams were counted and measured.

Statistical Analyses

We present our results for SC beaches primarily using descriptive summary statistics, contrasting results from MPA and reference beaches. We explore relationships among a variety of key response variables representing important or hypothesized ecological links and connections through correlation analyses. Multivariate analyses that investigate community composition and consider the effects of covariates on the basic descriptive patterns are part of ongoing integrative efforts.

Results and Discussion

Physical Characteristics of the Beaches

Intertidal widths and zone widths

Mean overall beach widths (landward boundary to low swash level) varied over two fold, ranging from 48 m to 111 m (San Clemente and Black Beach, respectively) among the 12 beaches surveyed (Figure 4). The widest beaches were Black's Beach and Scripps Beach with mean values of > 100 m in overall width. Mean overall widths of five of the 12 beaches were greater than 60 m. For the 12 focal beaches, the mean widths of the upper zones (above the HTS) varied over 3 fold ranging from 7.8 to 29.5 m (Arroyo Quemado and Black's, respectively).

Mean active intertidal widths (HSL to LSL) also varied over twofold among the study beaches, ranging from 34 to 83 m (Figure 5). Mean active intertidal zones exceeding 70 m occurred at only 3 of the study beaches, San Elijo, Blacks and Scripps, all located in the southern part of the study region.

Surf zone width is related to wave height and period, subtidal slope, bar topography, and ultimately beach morphodynamic state (Dean's parameter). Mean surf zone widths varied over an order of magnitude among the beaches, ranging from 15 to 62 m. Blacks and Scripps had the widest average surf zones (59 and 62 m, respectively). The mean surf zones at Gaviota and Arroyo Quemado were narrow (15 and 16 m, respectively.

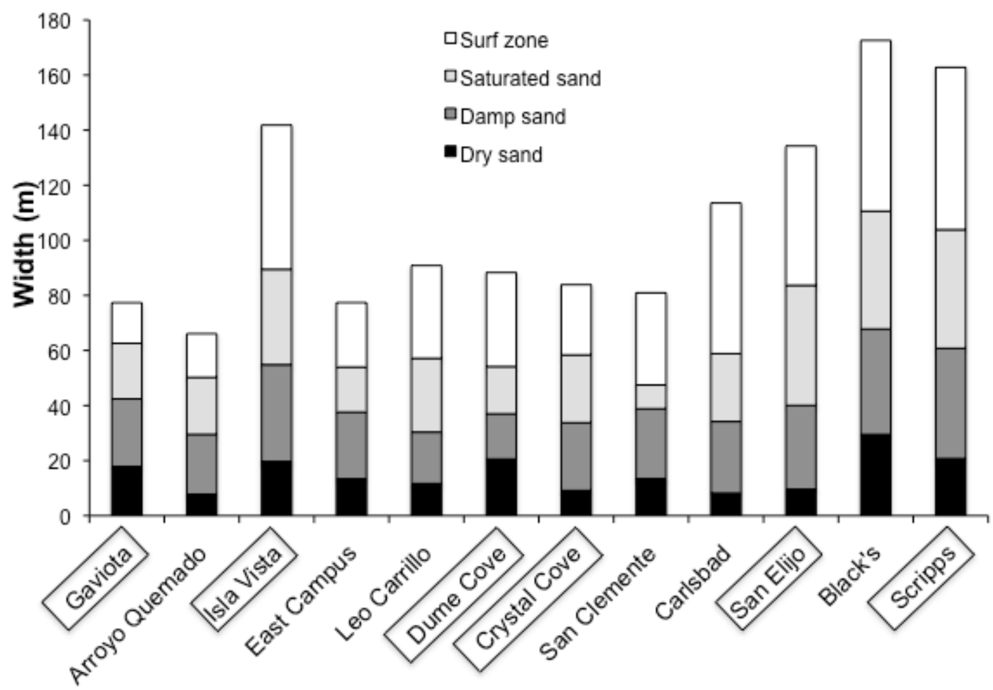

Figure 4 Overall mean widths of the dry, damp, and saturated sand zones, and surf zones of the study beaches in monthly surveys from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

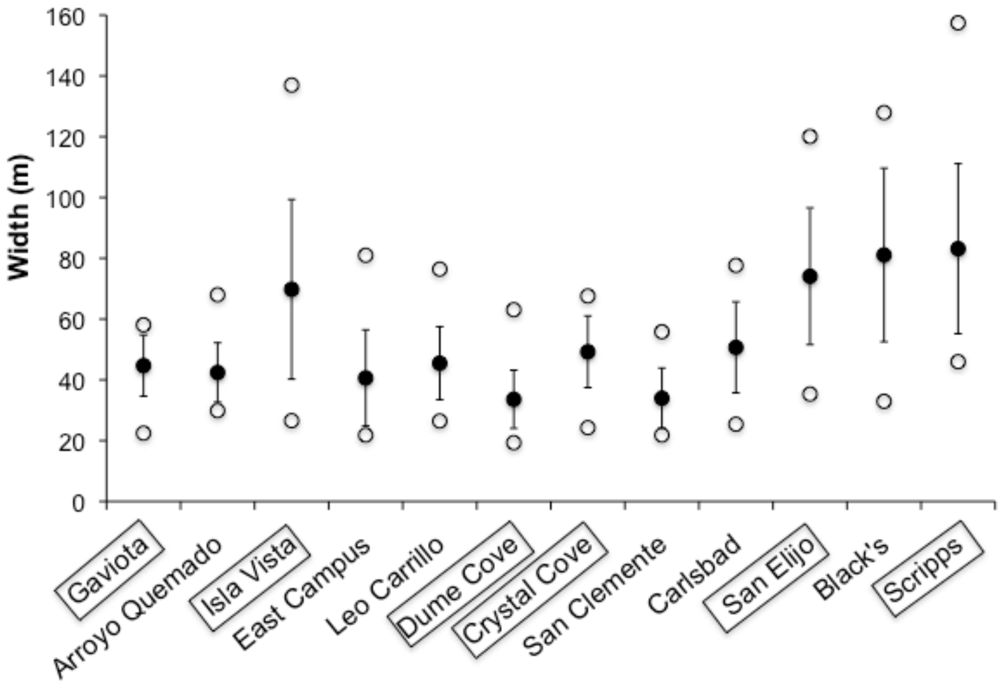

Figure 5 Mean (•)(± one standard deviation) and maximum (o) and minimum (o) values of widths of the active intertidal zone (damp and saturated sand, swash zones) observed for the study beaches in monthly surveys from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

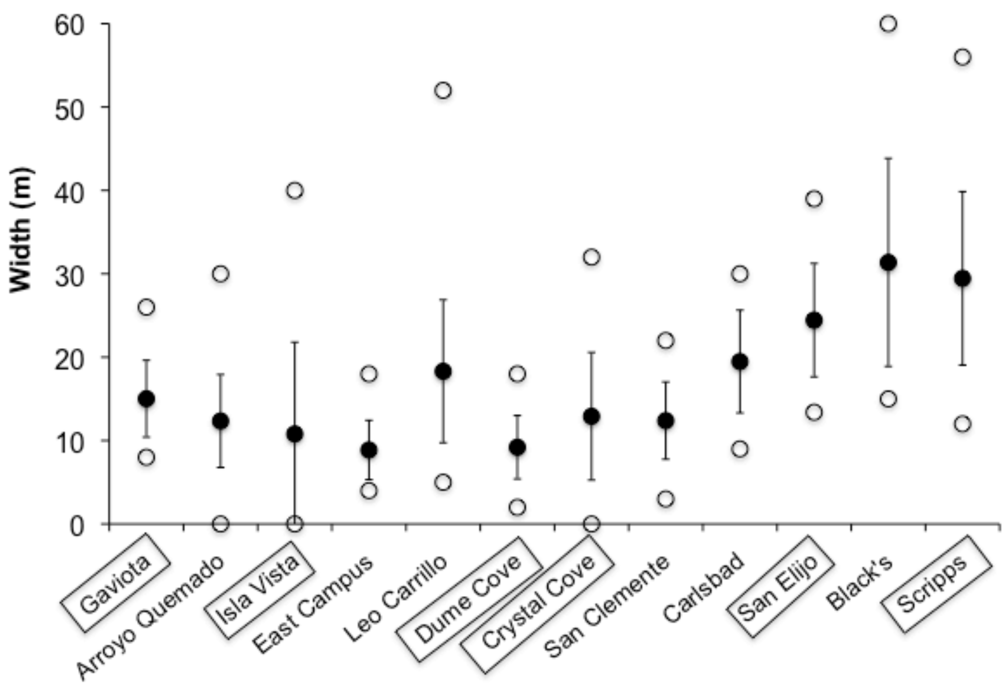

Figure 6 Overall mean (•) (± one standard deviation) and maximum (o) and minimum (o) values of swash zone width for monthly surveys of the study beaches from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Mean swash zone widths varied over threefold among study beaches, ranging from 8 to 31 m, in the monthly surveys (Figure 6). Generally, the greatest swash widths occurred on wider flat beaches. Mean swash zone widths exceeded 25 m on two of the study beaches, Blacks and Scripps, both intermediate type study beaches, which formed low tide terraces. Narrow swash zones, with mean $\leq$ 15 m, were observed on seven of the study beaches (Gaviota, Arroyo Quemado, Isla Vista, East Campus, Dume Cove, Crystal Cove, San Clemente).

Beach Slope

Mean values of beach slope did not vary consistently with intertidal level, (e.g. high tide strand line vs. water table outcrop), at the beaches, although the steepest slopes were generally observed at the high tide strand line. Beach slope at the WTO and the HTS varied more than three fold among beaches (Figure 7). Mean slopes at the water table outcrop varied from 2.0° to 7.4° among the 12 focal beaches (Figure 7). Slopes were highly variable and generally were steeper at the HTS where mean values varied from 3.0° to 9.7° among the 12 focal beaches (Figure 7). The lowest mean WTO slopes (< 3°) occurred on the wide flat beaches of Scripps, Blacks and San Elijo during the baseline study. The steepest mean WTO slopes (>6°) were observed at Dume Cove, San Clemente, and Leo Carrillo. Moderately steep mean slopes (4.2° at the WTO) also occurred at East Campus. Beach slopes at the HTS and WTO were not significantly correlated ($r = 0.557$, $p > 0.05$) for the 12 primary study sites.

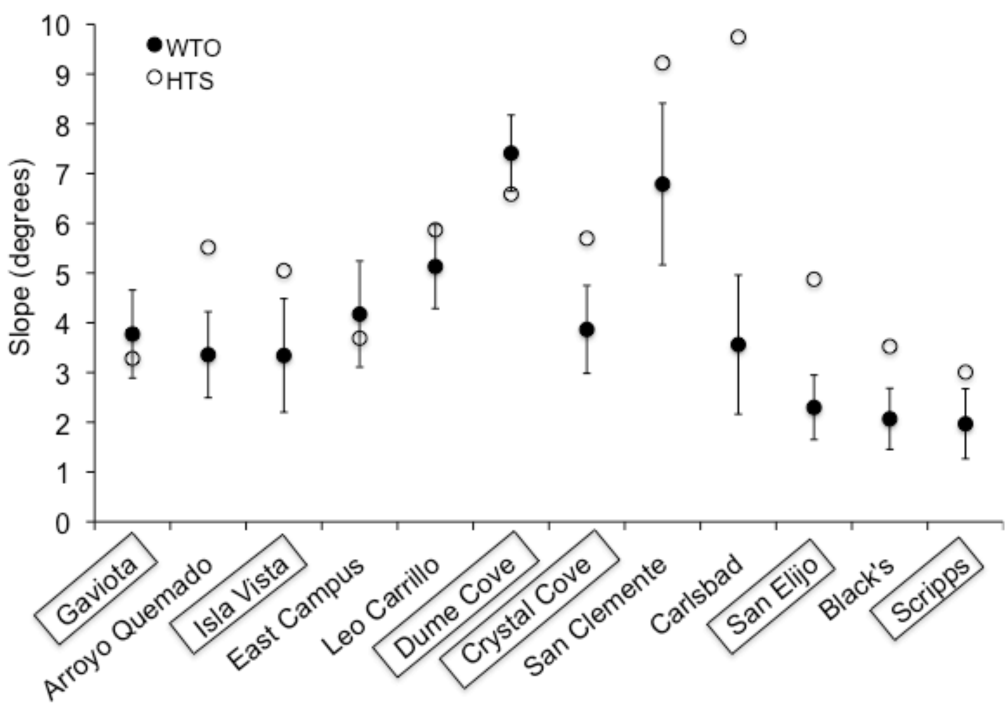

Figure 7. Mean values of beach slope measured at the water table outcrop WTO ($\pm$ one standard deviation) and at the high tide strand (HTS) of the study beaches in monthly surveys from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Sand Grain Size

The mean grain size of sediments from the water table outcrop varied more than two fold among the 12 study beaches, ranging from fine sand, 0.212 mm, at Scripps to very coarse sand, 0.563 mm, at San Clemente (Figures 8, 9). Mean grain size at the HTS was highly correlated with mean grain size at the WTO ($r = 0.760$, $p < 0.001$).

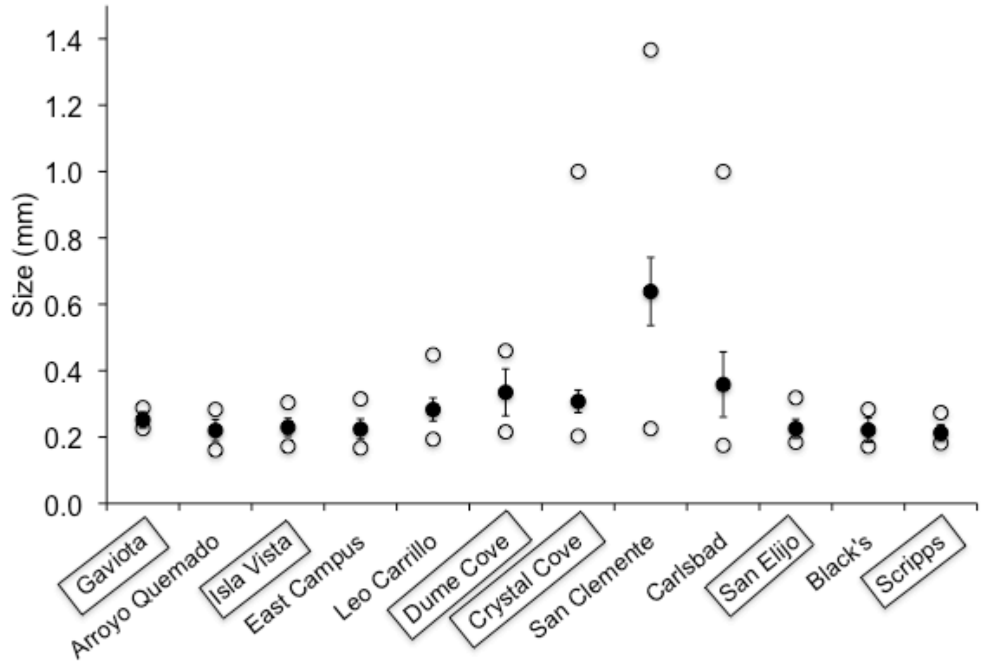

Figure 8 Overall mean (•), maximum (o) and minimum (o) values for sediment grain size at the WTO level for monthly surveys of the study beaches from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

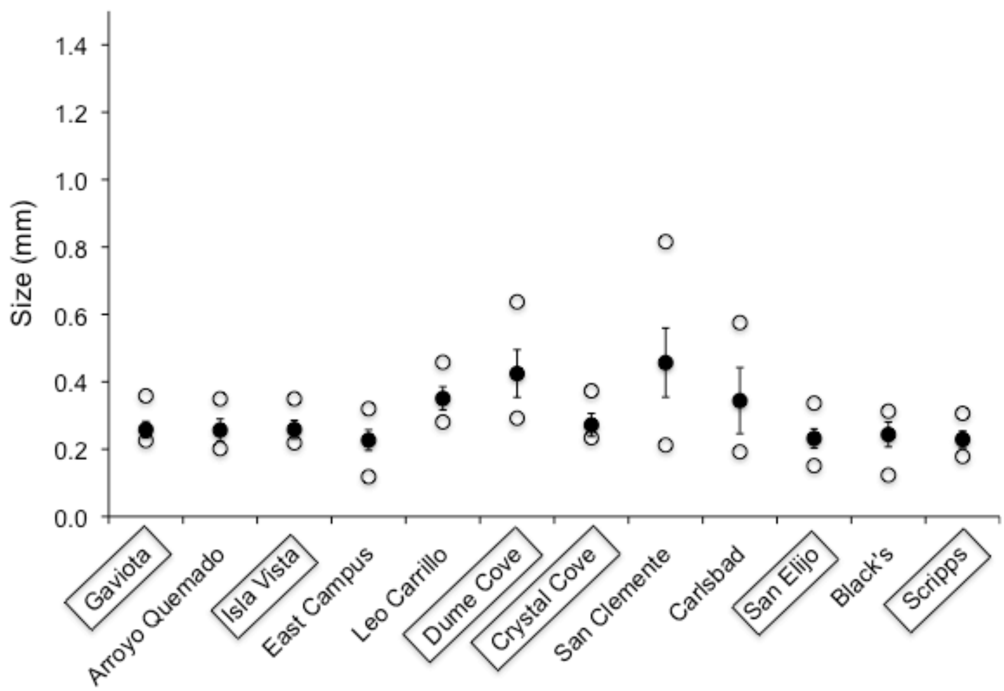

Figure 9 Overall mean (•), maximum (o) and minimum (o) values for sediment grain size at the HTS level for monthly surveys of the study beaches from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Significant breaker height and period

The mean values of significant breaker heights varied more than two fold among the beaches, with means ranging from 0.5 m to 1.8 m at the 12 focal beaches (Figure 10).

Mean breaker heights > 1.5 m were observed on five of the beaches, San Clemente, Carlsbad, San Elijo, Blacks, and Scripps. Regional variation in wave heights was evident with greatest values on study beaches in the south (Orange and San Diego County) (Figure 10). Mean breaker period was less variable among sites, ranging from 11.3 to 14.2 seconds (East Campus and San Clemente, respectively).

Swash climate

Swash period represents the conversion of surf energy to intertidal swash, and depends upon significant breaker period, surf zone and swash zone slope and processes. Mean swash periods varied nearly twofold among the study beaches (10.2 to 20.0 seconds) in the monthly surveys (Figure 11). The comparison of mean wave and swash period shown in Figure 11, gives a visual summary of the conversion of surf energy to swash on the study beaches. On beaches, such as Gaviota, Arroyo Quemado and Leo Carrillo, where the mean swash period was very similar to the mean wave period, little conversion of surf energy occurred in the surf zone and waves broke almost directly on the beach face, creating harsh intertidal conditions. Where the mean swash period greatly exceeded the wave period as seen for San Elijo, Blacks and Scripps, surf energy was greatly transformed before reaching the intertidal swash zone, resulting in lower swash frequency and gentler intertidal conditions.

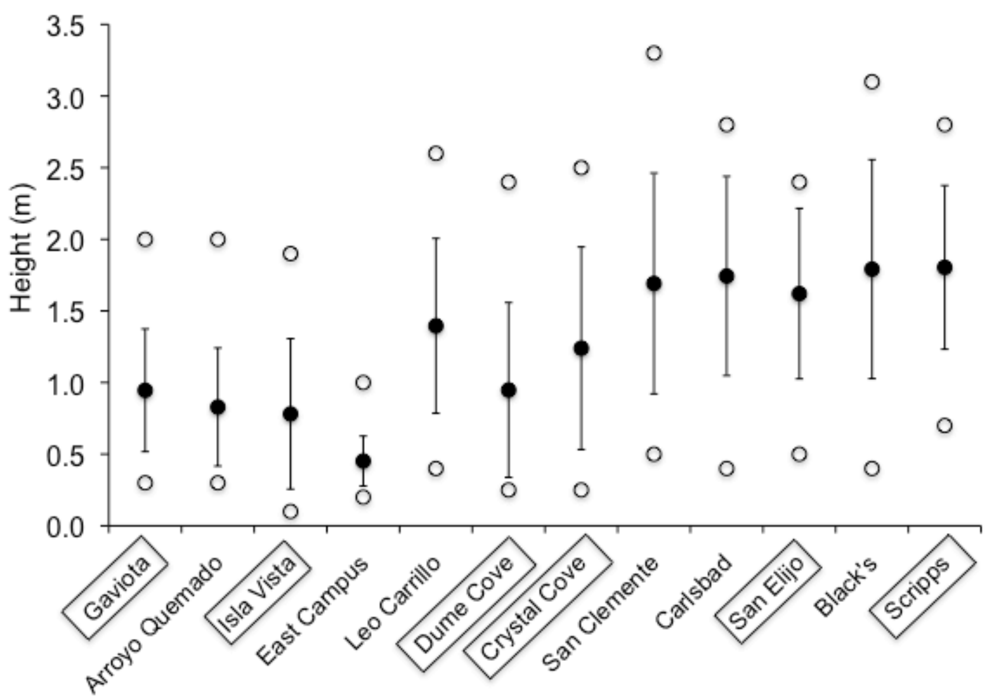

Figure 10 Mean (•) (± one standard deviation), maximum (o) and minimum (o) values of significant breaker height observed in monthly surveys of the study beaches from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

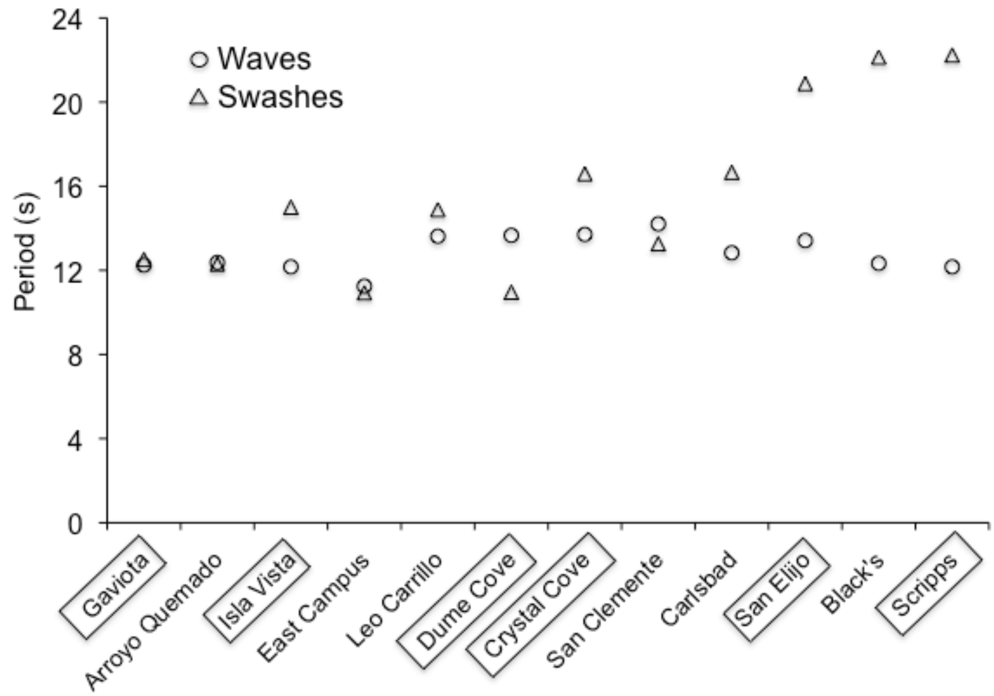

Figure 11 Mean values for wave and swash periods observed in monthly surveys of the study beaches from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Beach morphodynamics - Dean's parameter

The morphodynamic state of beaches as estimated by Dean's parameter (Ω), which combines significant wave height and period with sand grain size in a dimensionless index, can range from reflective (Dean's <1) to dissipative (Dean's >6) conditions (Figure 12). This index provides an estimate of the ability of the wave regime to suspend and move the sand at a particular beach. Reflective beaches are steep with coarse sand, narrow surf and swash zone and plunging breakers that break on the intertidal beach face. At the opposite end of the spectrum, dissipative beaches are wide and flat with fine sand and wide surf and swash zones where wave energy is dissipated before reaching the intertidal zone. Intermediate type beaches (Dean's >1 to < 6) are highly variable, responding strongly to wave conditions. They are also the most common type of beach on most continental coastlines. All twelve of the focal beaches were intermediate in morphodynamic type with mean values of Dean's parameter ranging from 1.3 to 4.4 (East Campus and Scripps, respectively (Figure 12). An intermediate morphodynamic state is typical of beaches in the SC region where no modally dissipative beaches are found and only a few modally reflective beaches exist, primarily on the California Channel Islands. The mean values of Dean's parameter increased from north to south with highest values in the south where mean values for the 4 beaches in San Diego County were ≥3. The lowest mean values of Dean's parameter were found in Santa Barbara County beaches with means of < 2. The mainland coast of the Santa Barbara Channel is considered protected outer coast. However, Dean's parameter alone is not considered the best estimator of the morphodynamic state for embayed or topographically constrained beaches, such as

East Campus or Dume Cove, due to the topographic constraints of headlands on wave climate and beach morphology.

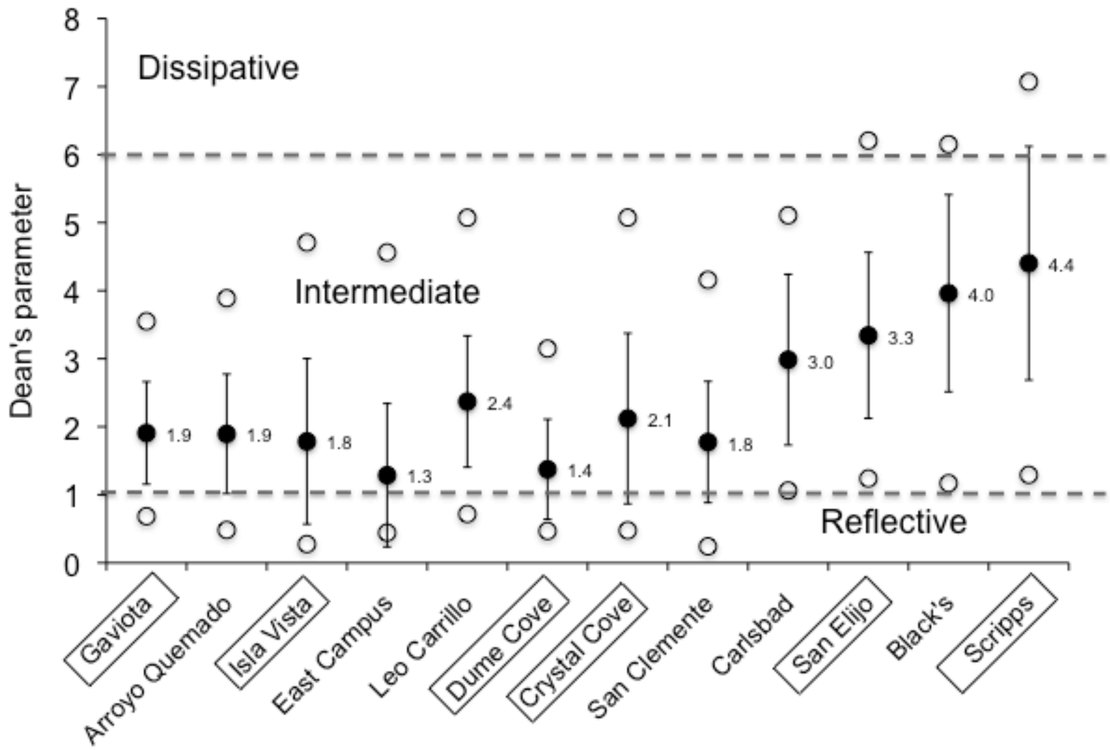

Figure 12 Overall mean (•)(+ one standard deviation), maximum (o) and minimum (o) values of Dean's parameter for monthly surveys of the study beaches from December 2011 to November 2013. Dotted lines separate the major morphodynamic beach types: dissipative (≥5), intermediate (<5 >1) and reflective (≤ 1). Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Wind speed and air temperature

Mean values for average wind speeds during surveys varied more than two fold among the beaches, ranging from 1.5 m s^{-1} to 3.5 m s^{-1} (Figure 13). Peak wind speeds observed ranged from 2.1 m s^{-1} to 4.4 m s^{-1}. Seasonally averaged wind speed varied less than two fold among months with strongest overall average (2.7 m s^{-1}) and peak winds (3.6 m s^{-1}) observed in August (followed by March and April), when upwelling favorable winds are strong, and the lightest winds (1.4 to 1.5 m s^{-1}) were observed in January and February (Figure 13) as is typical in fall.

Spatial variation in mean values for air temperature among the beaches was low (17.1 to 19.6 °C) (Figure 13). Seasonal variation in overall mean air temperatures ranged from 14.9 °C in March to 21.7 °C in September during the baseline study (Figure 13). Wind chills varied from 14.4 °C to 18.9 °C during the study.

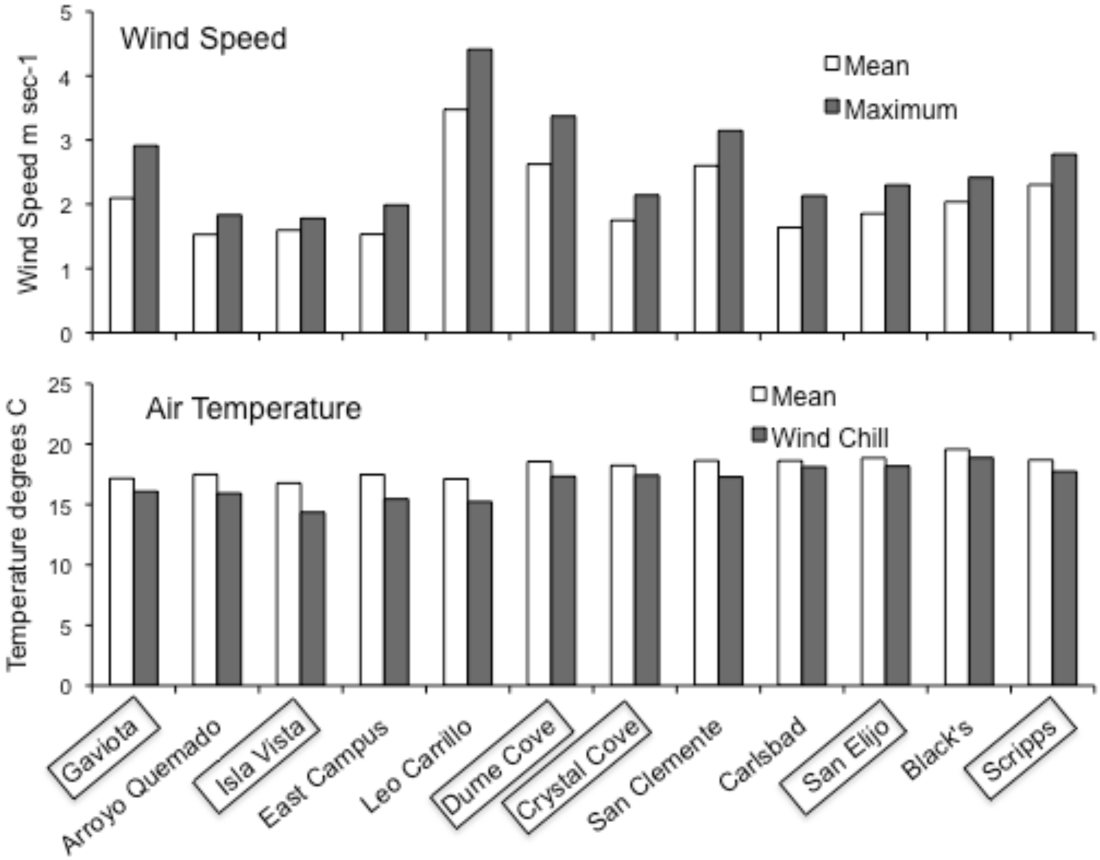

Figure 13. Values of mean and maximum wind speeds and of mean air temperatures and wind chills observed for the study beaches in monthly surveys from December 2011 to November 2013. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Relationships between Physical Parameters

Many of the physical characteristics measured during the surveys were significantly correlated reflecting the strong influence of coastal processes on beach ecosystems. Significant correlations occurred between mean values of beach zone widths, swash regime, beach slopes and Dean's parameter. Dean's parameter values were positively correlated with intertidal, swash and surf zone widths, and swash periods indicating that swash climate and morphodynamics are highly related as suggested by McArdle and McLachlan (1991). Dean's parameter was negatively correlated with slopes at the water table outcrop. Dean's parameter was not correlated with the width of the supralittoral or dry sand zone, as expected due to the dominance of aeolian and other non-wave climate related physical processes on upper beach zones. Breaker height was correlated with surf zone and swash zone widths. Sediment grain size was significantly correlated with slope at the WTO.

Regional Patterns

We found spatial gradients (north-to-south) in some of the physical characteristics of the study beaches when we examined correlations between mean values of measurement at the sites over the study period and coastline distance from Gaviota in the north to Scripps in the south. The total width of the beach and surf zone system increased towards the south ($r^2 = 0.359$, $p < 0.05$) and several measures of surf dynamics showed a similar trend: wider surf zones ($r^2 = 0.509$, $p < 0.01$), taller ($r^2 = 0.831$, $p < 0.001$) and steeper breakers ($r^2 = 0.824$, $p < 0.001$), and longer swash periods ($r^2 = 0.691$, $p < 0.001$). These patterns were also reflected in a geographic trend in the mean values of the beach morphodynamic index, Dean's parameter ($r^2 = 0.583$, $p < 0.005$). There were no simple geographic trends in measures of sand grain size, beach slope, or the widths of upper beach zones. Mean air temperatures ($r^2 = 0.771$) and wind chills ($r^2 = 0.751$) increased from north to south in the study area but mean and maximum values for wind speeds did not vary spatially.

Ecological Characteristics of Sandy Beaches

Birds:

Abundance

During the baseline study, 288 monthly surveys were conducted on the 12 focal beaches between December 2011 and November 2013. We counted birds on 12 km of beach and surf zone each month. A total of 27,982 birds of 73 species were observed in the 288 surveys (Table 3). We observed 12,555 individuals of 24 species of shorebirds, 11,494 individuals of six species of gulls and 2695 individuals of 11 species of seabirds in the monthly surveys (Table 3). We also recorded 241 aquatic birds of 7 species and 997 terrestrial birds of 29 species in our monthly surveys (Table 3). On average we observed 97.2 birds km^{-1} in the monthly surveys with averages of 43.6 birds km^{-1} for shorebirds, 39.9 birds km^{-1} for gulls and 9.4 birds km^{-1} for seabirds (Table 3).

Shorebirds and gulls were the most important groups making up 86% of birds observed in the study. Overall composition of the birds observed in our surveys was 45% shorebirds, 41% gulls, 9.6 % seabirds, <1% aquatic/wading birds and 3.6% terrestrial birds. The mean number of species observed was 7.4 species per km with 3.2 shorebird species 2.0 species of gulls and 2.2 other species. Shorebirds and gulls accounted for 70% of the average richness but only 45% of the total species richness of birds observed in the study (33 out of 73 species). Terrestrial birds were very diverse (29 out of 73 species) but in low abundance.

Birds: Temporal patterns

Shorebirds

Shorebird abundance exhibited a strong seasonal pattern (Figure 14). With the exception of three breeding species, Western Snowy Plover, Killdeer, and Black Oystercatcher, the majority of shorebirds observed in the study were migratory species that nest in other regions during the summer. The monthly average abundance of shorebirds observed on the 12 beaches (12 km of shoreline) varied more than an order of magnitude among survey months, ranging from 3.5 birds km^{-1} in June to 74.9 birds km^{-1} in April. The greatest numbers of shorebirds (mean abundance > 40 birds km^{-1}) were observed on the study beaches in the fall and winter surveys (September through February) and in spring surveys (April - May), coinciding with wintering and migration periods (Figure 14). The low number of shorebirds observed at the beaches in June in both years, corresponded to the breeding season for many shorebird species.

Gulls
Gulls were the 2nd most abundant type of bird observed in our surveys of the beaches. The abundance of gulls also varied seasonally over an order of magnitude with lowest abundance in June (Figure 14). The average monthly abundance of gulls observed on the 12 study beaches ranged from 10.7 gulls km^{-1} in June to 125.1 gulls km^{-1} in November. The highest abundance of gulls (mean > 50 birds km^{-1}) occurred from November through January on the study beaches.

Seabirds
Seabirds were the third most abundant type of bird observed in the study. The abundance of seabirds observed on the beaches and in the nearshore waters of the study beaches varied seasonally with greatest numbers observed in the fall and winter surveys (October to February) and lower numbers in the spring and summer (Figure 14). Monthly average abundance for seabirds ranged from 2.9 birds km^{-1} in August to 23.1 birds km^{-1} in February.

Other Birds
Aquatic/wading birds and terrestrial birds were present year round but their abundance was much lower than shorebirds, gulls and seabirds in the baseline study (Figure 15). The abundance of aquatic/wading birds observed on the study beaches varied seasonally with greatest numbers observed in the November surveys (and lower numbers in the spring and summer (Figure 15). Monthly average abundance for these birds ranged from < 0.3 birds km^{-1} in most months to 3.1 birds km^{-1} in November. The abundance of terrestrial birds, primarily insectivorous species, such as flycatchers and swallows, peaked in the summer surveys (June and July) ranging from 2 birds km^{-1} to 7.1 birds km^{-1}. The increased use of intertidal beach habitats by these birds at this time likely coincides with the typical Mediterranean summer dry season and a corresponding lack of insect prey in adjacent terrestrial habitats. These birds were primarily observed flycatching on and around wrack deposit and feeding on other wrack-associated invertebrates. This observed use of beaches for foraging by resident breeding birds is an example of a marine subsidy to terrestrial ecosystems that could be affected by MPA protection of nearshore and beach ecosystems.

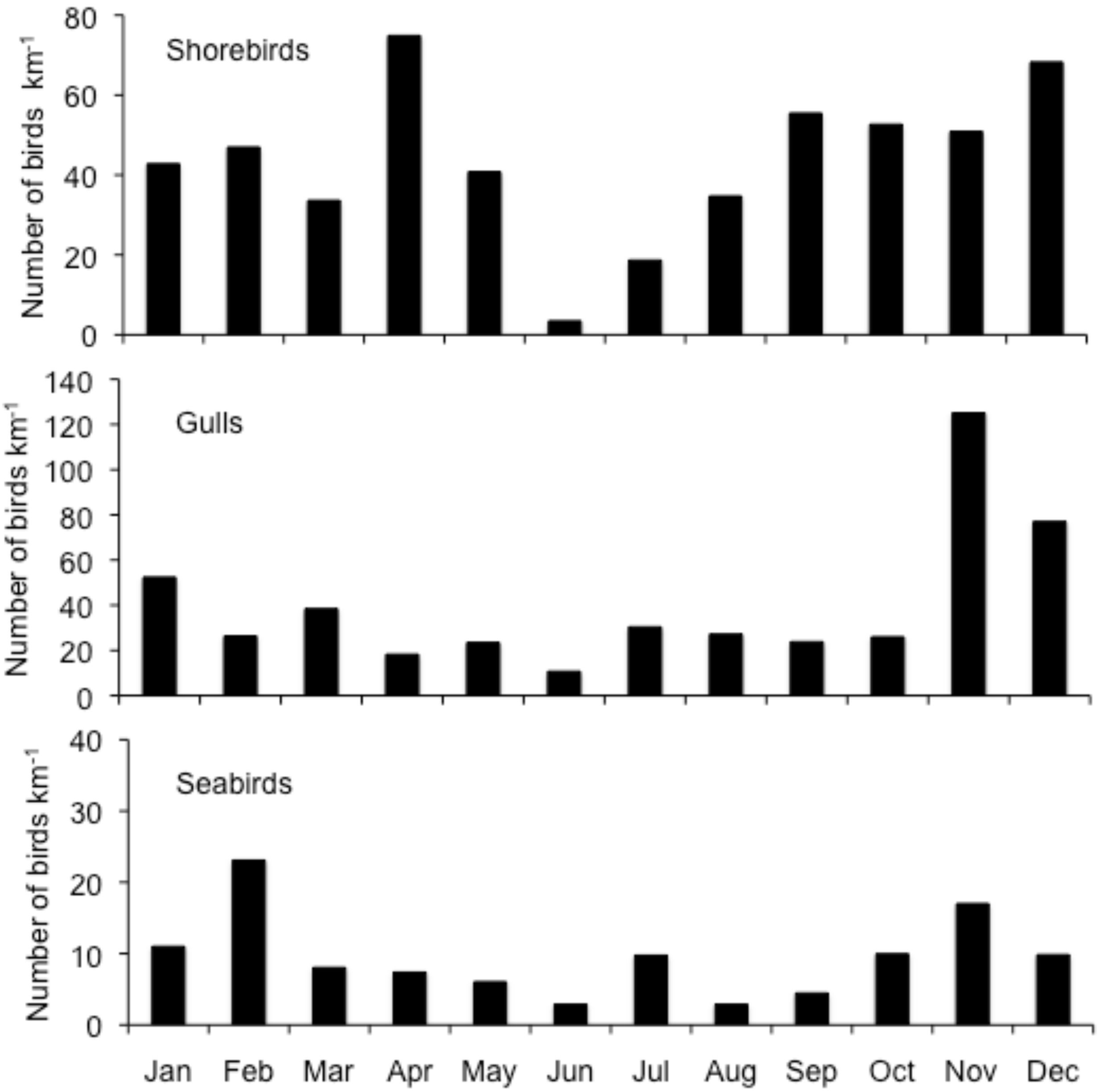

Figure 14. Monthly values of mean abundance of shorebirds, gulls and seabirds observed on SC sandy beaches expressed as mean number km^{-1} (n = 24). Surveys were conducted once a month for 2 years from December 2011 to November 2013. All observations were made along a standard 1 km transect.

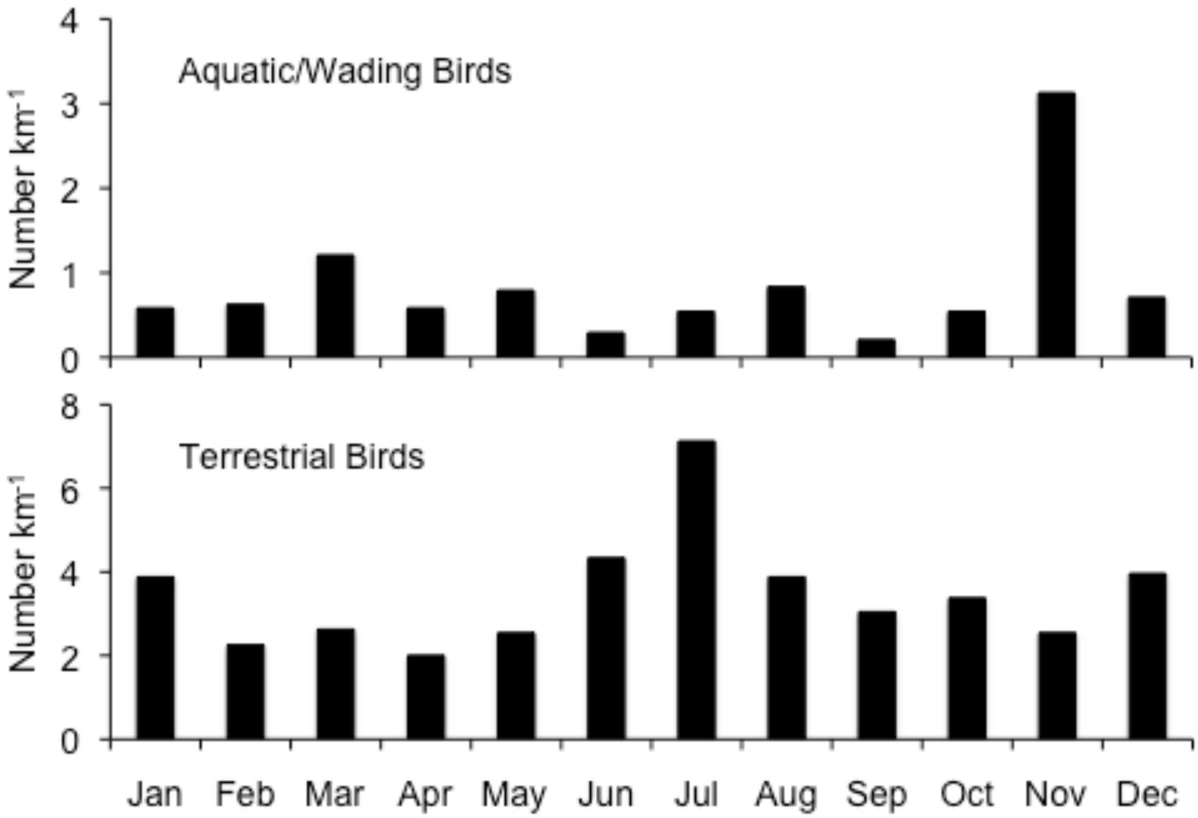

Figure 15. Monthly values of mean abundance of aquatic/wading birds and terrestrial birds observed on SC sandy beaches expressed as mean number km^{-1} (n = 24). Surveys were conducted once a month for 2 years from December 2011 to November 2013. All observations were made along a standard 1 km transect.

Birds: Spatial patterns

Shorebirds

Spatial variation in shorebird abundance and distribution was evident in the study region. Mean abundance of shorebirds varied over 30 fold among the beaches, ranging from 4.8 to 150.8 shorebirds km^{-1} (Figure 16). The highest mean number of shorebirds 150.8 birds km^{-1} was observed at Isla Vista Beach (MPA) during the 2 year study (Figure 16). The highest numbers of shorebirds on a single transect were recorded the majority of the 24 monthly surveys at this beach. Mean numbers of shorebirds observed per month exceeded 90 birds km^{-1} at Crystal Cove (MPA) and East Campus (reference) beaches. Low mean numbers of shorebirds (<10 birds km^{-1}) were observed at Gaviota (MPA) and Arroyo Quemado (reference) beaches. The greatest peak abundances of shorebirds observed in single surveys were 539 birds km^{-1} at East Campus Beach (reference) and 333 birds km^{-1} at Isla Vista Beach (MPA) both in April 2013. The beach with the lowest peak abundance of shorebirds, 28 birds km^{-1} in any survey was Arroyo Quemado (reference).

No consistent differences in the abundance of shorebirds were evident between MPA and reference beaches, during the baseline study (Figure 17). Overall, the average number of shorebirds was higher at the MPA beaches than at the reference beaches but this difference was not statistically significant ($p > 0.05$) and appeared to be largely driven by the occurrence of large numbers of Sanderlings at Isla Vista and Crystal Cove (both MPAs).

Gulls
Spatial variation was also evident in gulls among the beaches and did not match patterns of abundance we observed in shorebirds. Mean abundance of gulls varied 9 fold among the study beaches ranging from 12.4 to 112 birds km^{-1} (Figure 16). The highest mean number of gulls per month, 112 birds km^{-1} was observed at Arroyo Quemado Beach (reference). Mean abundance of gulls per month exceeded 50 birds km^{-1} at three of the beaches, Crystal Cove (MPA), San Elijo (MPA) and Leo Carrillo (reference) (Figure 16). The highest peak abundance of gulls observed in a single survey was 1010 birds km^{-1} at Leo Carrillo (reference) in November 2013. Peak abundance of gulls in single surveys exceeded 700 birds km^{-1} at Crystal Cove (MPA) and Arroyo Quemado (reference).

Seabirds
The mean abundance of seabirds also varied considerably among the beaches (Figure 16). Mean seabird abundance varied over an order of magnitude ranging from 0 birds km^{-1} to 19 birds km^{-1} at Carlsbad and Crystal Cove, respectively (Figure 16). Mean abundance of seabirds per month exceeded 15 birds km^{-1} at two other beaches, Arroyo Quemado and East Campus (both reference). The peak abundance of seabirds observed in a single survey was 230 birds km^{-1} at San Clemente (reference) in November 2013 and consisted of Western Grebes that were resting outside the surf zone.

Other birds
Spatial variation in the abundance of aquatic and wading birds appeared to be strongly regional with greatest abundance observed on the study beaches located north of San Diego County and zero to very few of these birds observed on 5 of the study beaches (Figure 16). This may be related to regional variation in habitat heterogeneity such as the presence of rocky habitat suitable for roosting along the transects. The mean abundance of aquatic and wading birds varied from 0 to 3.3 birds km^{-1}. Terrestrial birds were observed on all 12 study beaches but were more abundant on beaches north of Los Angeles County with abundance ranging from 1.0 to 11.8 birds km^{-1} and with peak values observed on beaches with high shorebird abundance.

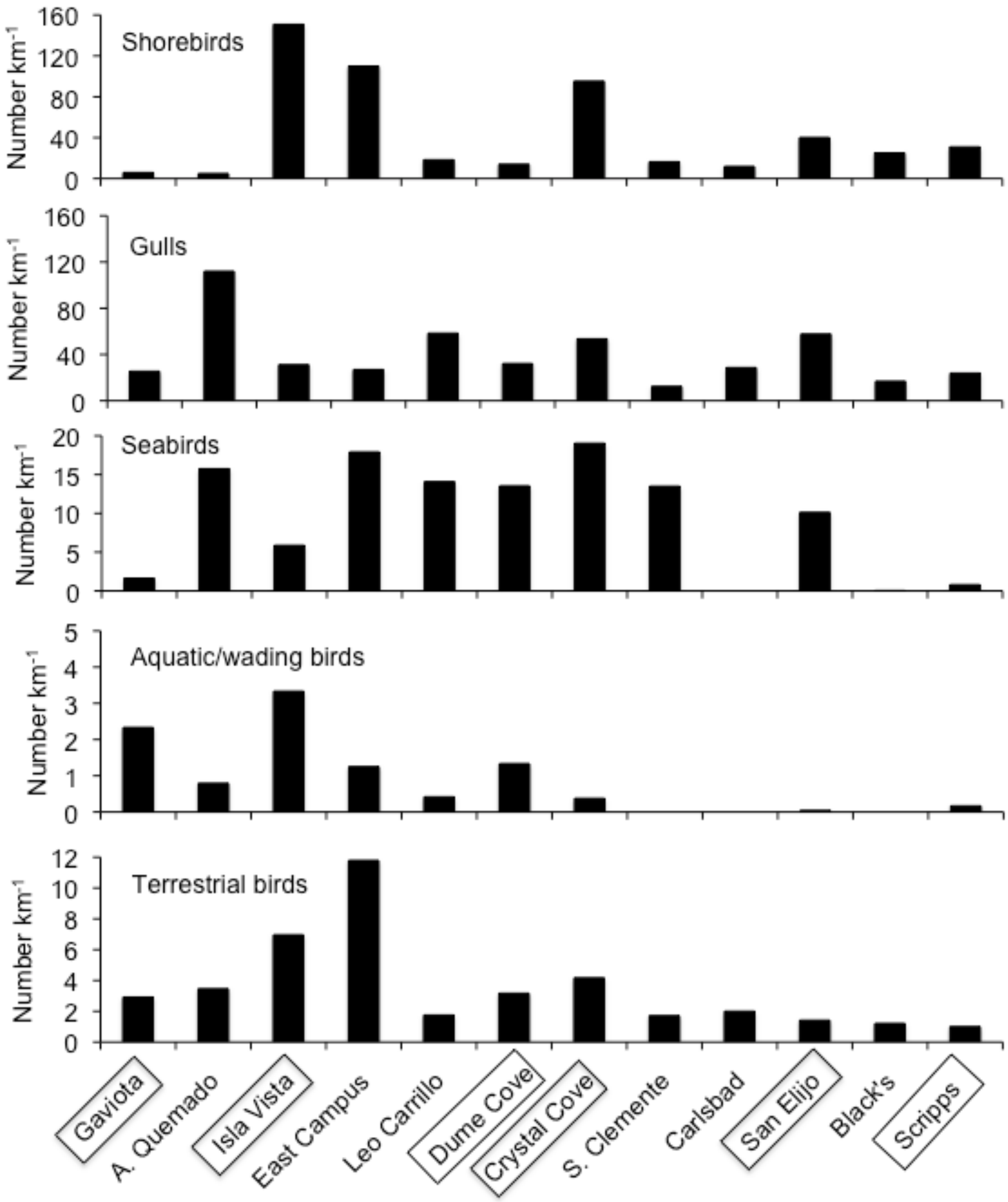

Figure 16. Average abundance of shorebirds, gulls, seabirds aquatic and terrestrial birds observed at the 12 study beaches in 24 monthly surveys conducted between December 2011 and November 2013. All observations were made along a standard 1 km transect. Abundances expressed as mean numbers of birds per km^{-1}. Beaches are listed from north to south. Names of sites located in MPAs are in boxes. Note Y-axis scales vary.

We found no consistent or statistically significant differences ($p > 0.05$ ANOVA) in the abundance of shorebirds, gulls, seabirds, aquatic birds or terrestrial birds between MPA and reference beaches in the 2 year baseline study (Figure 17).

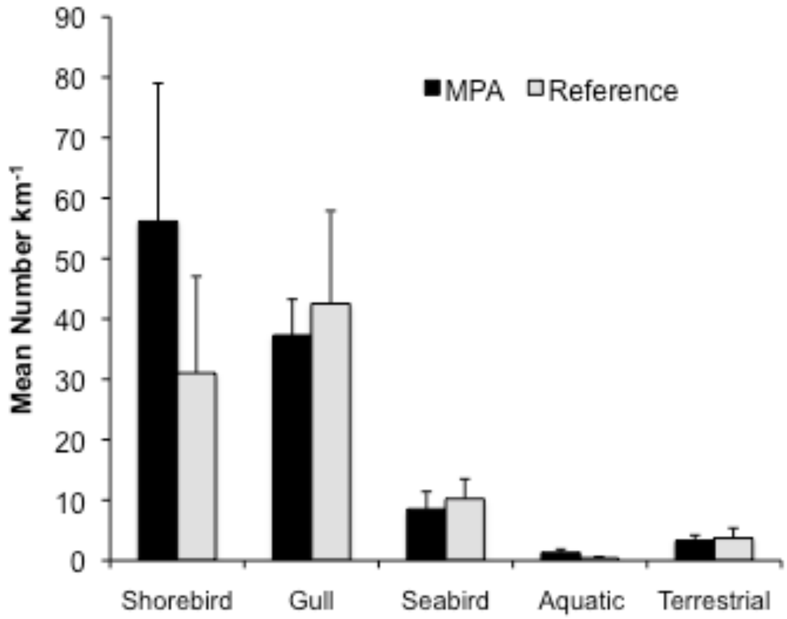

Figure 17. Mean values (+ std. errors) of the abundance of birds observed on beaches located inside MPAs and on reference beaches.

Birds: Species Richness of Shorebirds

Twenty-four species of shorebirds were observed in the 288 surveys of the study beaches (Table 4). Besides the federally listed Western Snowy Plover, many of the shorebird species observed on the 12 study beaches in the baseline study (Table 4) are listed on the Yellow Watch List in the 2014 State of the Birds Report (http://www.stateofthebirds.org/newsroom/2014_State_of_the_Birds_Release.pdf). These include Black Oystercatcher, Willet, Whimbrel, Long-billed Curlew, Marbled Godwit, Black Turnstone, Short-billed Dowitcher, Dunlin, and Pectoral Sandpiper. Species on the Yellow Watch List are either range restricted (small range and population), or are more widespread but with troubling declines and high threats. This indicates the potential importance of sandy beaches and MPAs in shorebird conservation efforts.

Peak average species richness (mean richness $\geq$ 4 species) of shorebirds occurred in the fall and winter surveys (Figure 18) and lowest average richness was observed in June (mean richness of 0.7 species) on the study beaches. Total species richness also varied among months ranging from five to 19 species observed in a month on the 12 study beaches. The average total number of shorebird species observed was 14 species per month in the two year study.

Strong spatial variation among the study beaches was evident in the species richness of shorebirds in the baseline study. The average number of shorebird species observed varied over 6 fold among beaches ranging from 1.3 species at Gaviota and San Clemente to 8.2 species at Isla Vista (Figure 20). The total number of species observed during the study also varied more than six fold among the beaches, ranging from three species at Blacks to 20 species at East Campus and averaging nine species per study beach. Other beaches with high total species richness (> 16 species) for shorebirds included Isla Vista (MPA) and Crystal Cove (MPA). The maximum number of species of shorebirds observed on a single 1 km survey date was fifteen species at East Campus in October 2013. The average species richness of shorebirds was significantly correlated with the average abundance of shorebirds across the study beaches (r^2 = 0.975, p <0.001).

Beaches where greater numbers of shorebird species were observed generally had high habitat heterogeneity and contained some rocky outcrops. Relatively low total species richness (three species) occurred on beaches with high cliffs at Dume Cove, Leo Carrillo and Blacks (Figure 20). The latter two beaches have creek mouths and rocky habitat but there are tall cliffs overlooking the beach habitat. These landscape features can provide perches for raptors that prey on shorebirds and affect bird distributions on beaches.

Gulls

Overall, abundance varied greatly among individual species of gulls, ranging over two orders of magnitude from 0.01 birds km^{-1} to 13.1 birds km^{-1} for total monthly observations (Table 5). The average monthly abundance of four species of gulls and of unidentified gulls exceeded 1 individual km^{-1} during the baseline study (Table 5, Figure 18). Based on average abundance observed over the study, the most abundant gull species were Western Gull (13.1 birds km^{-1}), Heerman's Gull (4.0 birds km^{-1}), California Gull (2.7 birds km^{-1}), and Herring Gull (2.2 birds km^{-1}) (Table 5). Western Gulls comprised 27%, Heerman's Gulls comprised 8.3%, California Gulls comprised 5.7% and Herring Gulls comprised 4.5%, of the total gulls observed in the study. Unidentified gulls were generally immature individuals, were likely of the species recorded as adults in the surveys. Gulls were frequently observed with three species of gulls and unidentified gulls recorded in 20 or more of the monthly surveys (Table 5). Species richness of gulls was lowest in May and June (Figure 18).

Seabirds

Grebes, terns, loons and ducks that feed in the ocean in migration and winter seasons are included as seabirds. The most common of these birds was the Western Grebe (3.9 birds km^{-1}) with 1123 individuals (4.0% of birds observed, eighth most common overall) and almost all were recorded in the surf zone (Table 5). The majority of the remaining seabirds observed were loafing (resting, sunning, etc., but definitely not feeding) on the shore. Overall, abundance varied greatly among individual species of seabirds, ranging over three orders of magnitude from 0.007 birds km^{-1} to 3.9 birds km^{-1} for total monthly observations (Table 5). The average abundance of four species of seabirds exceeded 1 individual km^{-1} during our study. Based on average abundance observed over the study, the most abundant seabird species were Western Grebe (3.9 birds km), Double-crested

Cormorants 2.2 birds km^{-1} (628), Royal Terns 1.2 birds km^{-1} (346), and Brown Pelicans 1.1 birds km^{-1} (316) (Table 5). Western grebes comprised 41%, Double Crested Cormorants comprised 23.1%, Royal Terns comprised 12.7%, and Brown Pelicans comprised 11.6 % of the total seabirds observed in the study. Seabirds were regularly observed with four species of seabirds and unidentified cormorants observed in 25 or more of the individual surveys (Table 5). Species richness of seabirds was highest in Fall and Winter (Figure 18) and in the northern bioregion of the SC (Figure 20).

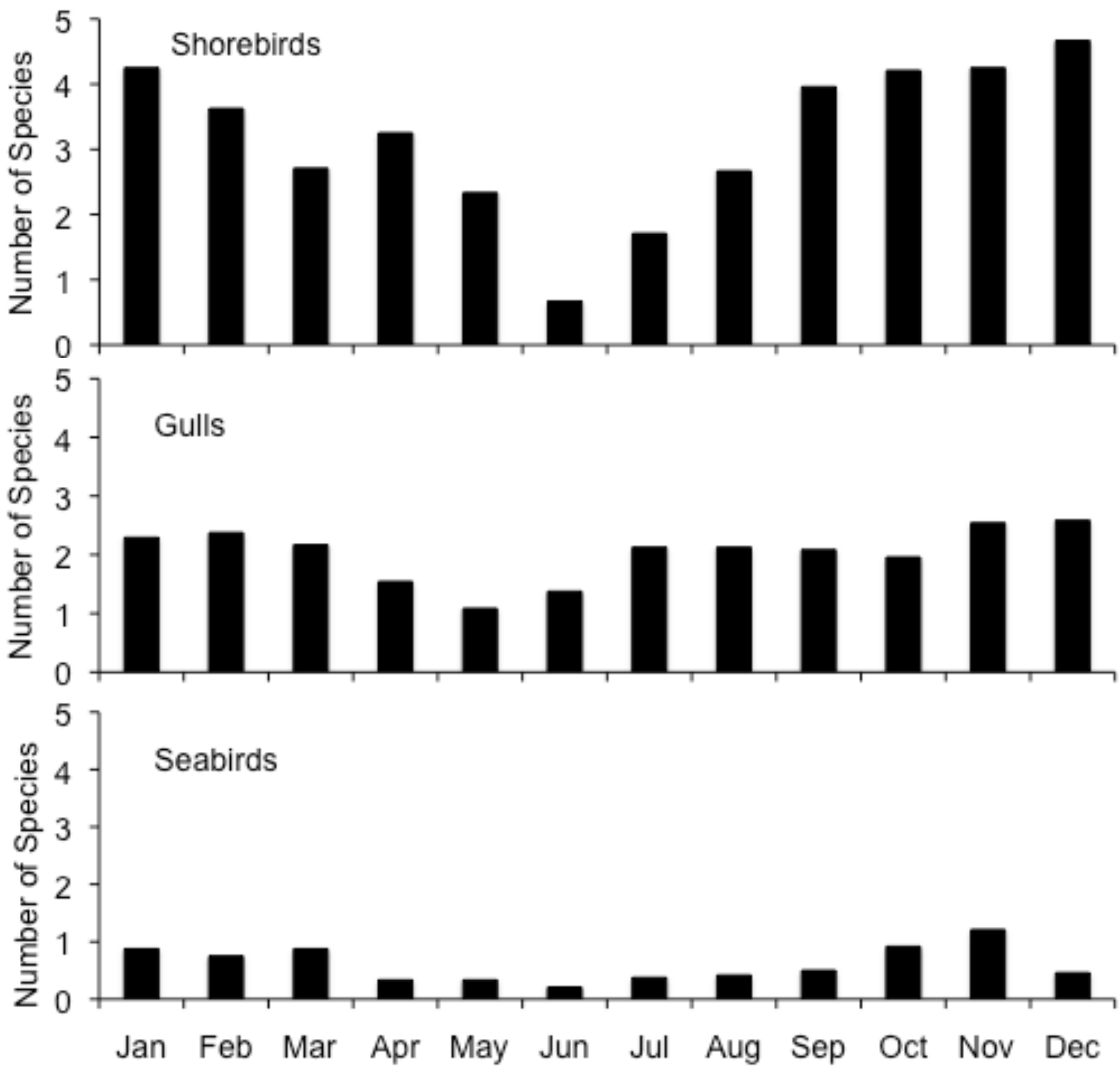

Figure 18. Monthly mean values of species richness of shorebirds, gulls and seabirds observed on the 12 study beaches expressed as mean number of species km^{-1} (n = 24). Surveys were conducted once a month for 2 years from December 2011 to November 2013. All observations were made along a standard 1 km transect.

Aquatic and Wading Birds

Aquatic and wading birds were commonly observed foraging in the intertidal on the study beaches. During the study, we observed 215 aquatic/wading birds of seven species (0.8% of all birds) (Table 5). This group included egrets, herons, coots, Mallards, and Pied-billed Grebes using intertidal pools, creek mouth lagoons and other shore habitats. No aquatic/wading bird species occurred in densities exceeding 1 bird km^{-1} in our study and monthly species richness varied from 0.2 to 0.5 species in the baseline study (Figure 19). The most abundant species were Snowy Egret (79 individuals, 0.27 birds km^{-1}), Mallard (57 individuals, 0.20 birds km^{-1}), and American Coot (43 individuals, 0.15 birds km^{-1}). Species richness of aquatic and wading birds was greatest on beaches in the northern bioregion (Figure 20). These birds were >3 times more abundant in MPAs than on the reference beaches but that difference was not significant (Figure 17).

Terrestrial Birds

Terrestrial birds contributed considerably to the total diversity of the bird surveys (29 of 73 species, 40%), but much less to the total abundance (997 individuals, 3.6%) (Table 6). However, monthly species richness of terrestrial birds was not high, varying from 0.9 to 2.0 species in the baseline study (Figure 19) suggesting high turnover of these species. This group includes migratory and resident species, local nesting (e.g. Black Phoebe, Song Sparrow, California Towhee, American Crow, and Peregrine Falcon) and introduced forms (e.g. European Starling, Rock Pigeon). Birds of prey were included in counts when their flights over the survey transects influenced the distribution of other birds on the shore. Terrestrial birds were commonly observed foraging on the study beaches and were generally recorded using upper shore habitats. The feeding modes of terrestrial birds using the beaches vary widely from aerial insect catchers (Black Phoebe, swallows, kingbirds, pipits) to urban generalists (Rock Pigeon, House Finch, Brewer’s Blackbird, European Starling), scavengers and carrion feeders (American Crow, Common Raven, Turkey Vulture), to birds of prey (American Kestrel, Northern Harrier, Peregrine Falcon). The most common and widespread terrestrial bird species observed was the Black Phoebe, (264 individuals, 0.9 birds km^{-1}), a flycatcher, that foraged on wrack-associated insects and crustaceans and was observed on 130 of the surveys. American Crows (248 individuals, 0.9 birds km^{-1}) were the most abundant scavenging and carrion feeding birds and were observed on the study beaches in 63 individual surveys. Cliff swallows were observed foraging seasonally on some beaches but only recorded on 10 individual surveys. House Finches were the most abundant passerine species observed (81 individuals, 0.28 birds km^{-1}) but were only recorded in 14 individual surveys (Table 6). Species richness of terrestrial birds followed shorebird species richness across the study with peak richness at Isla Vista, East Campus and Crystal Cove (Figure 20).

Corvids, including American Crows and Common Ravens, are known to prey upon nesting shorebirds and can cause decreased reproductive success in Western Snowy Plover, a beach nesting species listed as threatened. A total of 248 American Crows were observed in the baseline study and the overall average abundance was 0.9 birds km^{-1} (Table 6). American Crow is a resident breeding species that accounted for 24.8% of the terrestrial birds and was observed in 63 of the 288 surveys.

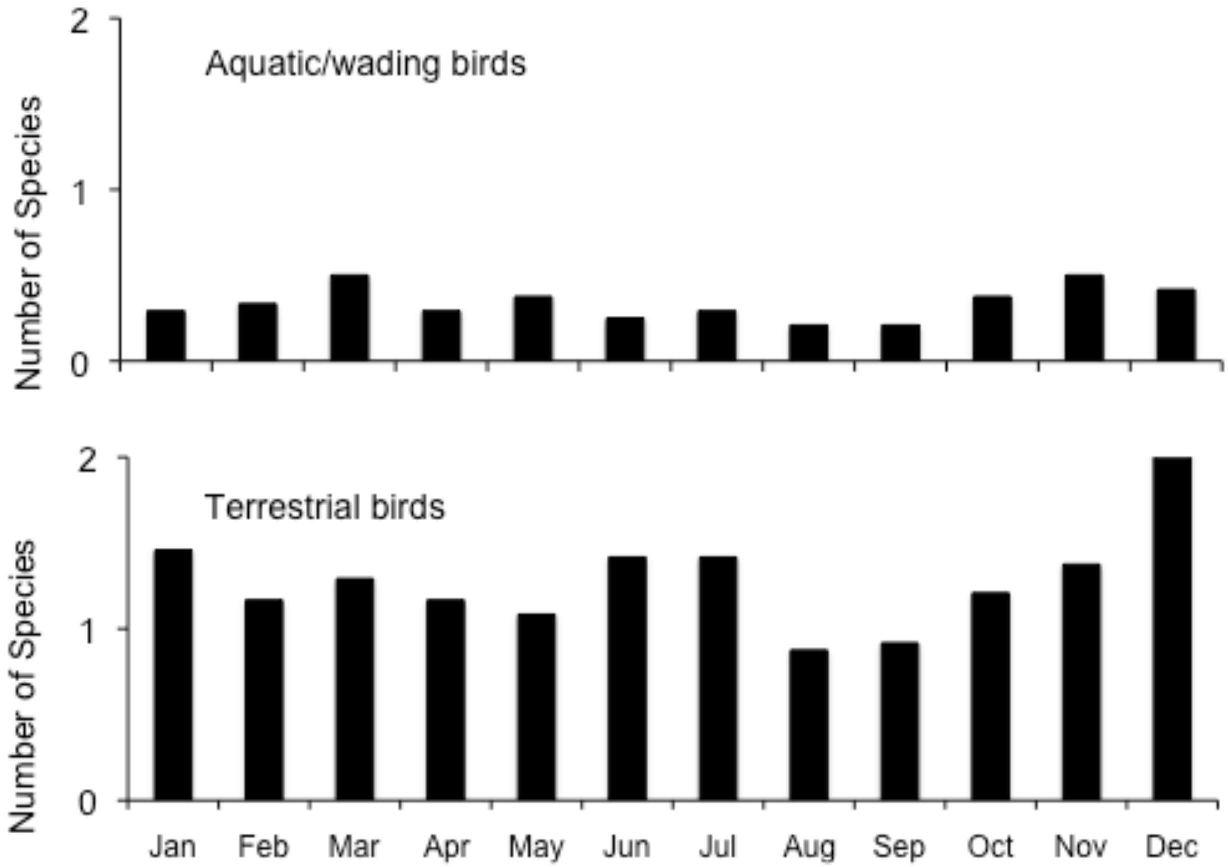

Figure 19. Monthly mean values of species richness of aquatic/wading birds and terrestrial birds observed on the 12 study beaches expressed as mean number of species km^{-1} ($n = 24$). Surveys were conducted monthly from December 2011 to November 2013. All observations were made along a standard 1 km transect at each study beach.

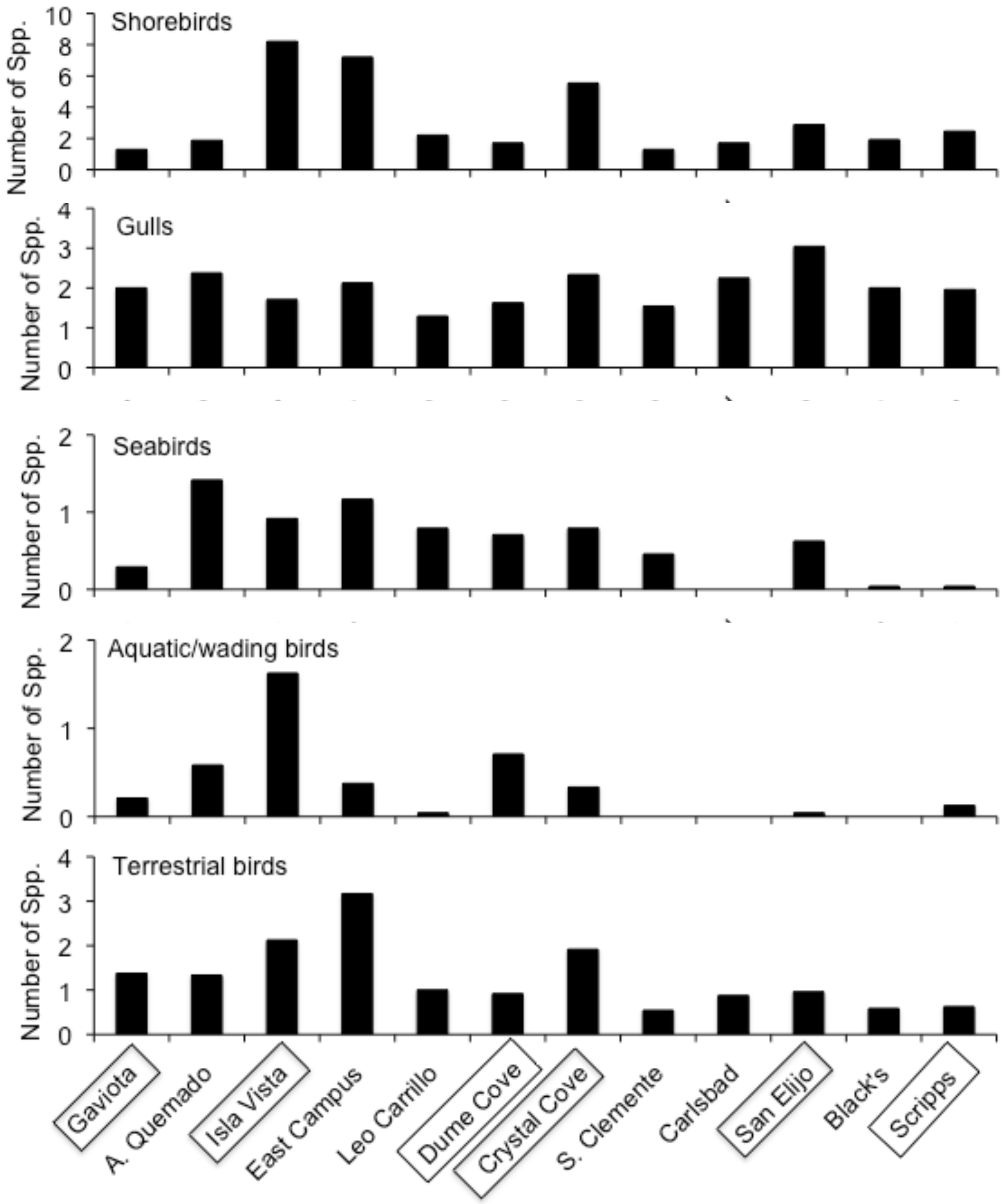

Figure 20. Values of average species richness of shorebirds, gulls, seabirds aquatic/wading and terrestrial birds observed at the 12 study beaches during 24 monthly surveys between December 2011 and November 2013. All observations were made along a standard 1 km transect. Beaches are listed from north to south. Names of sites located in MPAs are in boxes. Note-the Y-axis scales vary.

Table 4 Shorebirds observed in 288 monthly surveys at the 12 study beaches. Boldface indicates species with mean abundance $\geq$ 1 km^{-1}.

	Mean abund. ind. km^{-1}			Max count km^{-1}			Times observed		
SPECIES	All	MPA	Ref	All	MPA	Ref	All	MPA	Ref
Sanderling	17.77	27.52	8.01	266	266	214	88	56	32
Black-bellied Plover	4.36	5.63	3.10	65	65	60	104	66	38
Whimbrel	4.08	3.60	4.56	76	58	76	163	85	78
Western Sandpiper	3.47	2.05	4.90	500	98	500	33	19	14
Marbled Godwit	3.35	4.83	1.88	68	68	64	83	52	31
Willet	3.10	4.25	1.96	55	55	20	131	69	62
Semipalmated Plover	2.50	4.13	0.87	60	60	31	46	33	13
Least Sandpiper	1.29	0.08	2.50	75	5	75	17	4	13
Black Turnstone	0.95	1.77	0.13	31	31	8	42	38	4
Greater Yellowlegs	0.59	0.31	0.88	26	10	26	25	10	15
Killdeer	0.53	0.28	0.77	24	7	24	42	17	25
Black-necked Stilt	0.32	0.15	0.49	23	12	23	10	3	7
Spotted Sandpiper	0.26	0.23	0.29	5	5	4	42	21	21
Dunlin	0.25	0.49	0.01	17	17	2	14	13	1
Snowy Plover	0.21	0.39	0.03	14	14	3	13	10	3
Long-billed Curlew	0.17	0.15	0.18	5	4	5	27	12	15
Long-billed Dowitcher	0.14	0.03	0.26	14	1	14	11	4	7
Short-billed Dowitcher	0.069	0.000	0.139	9	0	9	3	0	3
Surfbird	0.052	0.097	0.007	5	5	1	6	5	1
Ruddy Turnstone	0.049	0.090	0.007	3	3	1	8	7	1
Wilson's Plover	0.028	0.021	0.035	4	3	4	3	1	2
Pectoral Sandpiper	0.024	0.007	0.042	5	1	5	3	1	2
Wandering Tattler	0.014	0.021	0.007	2	2	1	3	2	1
Black Oystercatcher	0.007	0.014	0.000	2	2	0	1	1	0
Lesser Yellowlegs	0.003	0.007	0.000	1	1	0	1	1	0

Table 5 Gulls, seabirds and aquatic/wading birds observed in 288 monthly surveys at the 12 study beaches. Boldface indicates species with mean abundance ≥ 1 km^{-1}.

	Mean density ind. km^{-1}			Max count km^{-1}			Times observed		
SPECIES	All	MPA	Ref	All	MPA	Ref	All	MPA	Ref
Western Gull	18.52	17.93	19.12	875	297	875	239	131	108
California Gull	10.80	8.54	13.06	791	701	791	89	41	48
Heerman's Gull	5.55	5.56	5.53	66	64	66	141	74	67
Ring-billed Gull	4.79	4.93	4.65	190	178	190	90	45	45
Mew Gull	0.11	0.13	0.10	8	8	6	12	7	5
Glaucous-winged Gull	0.08	0.15	0.01	21	21	1	4	2	2
Herring Gull	0.02	0.03	0.01	4	4	2	3	2	1
Bonaparte's Gull	0.02	0.01	0.03	4	1	4	3	1	2
Thayer's Gull	0.00	0.01	0.00	1	1	0	1	1	0
Western Grebe	3.90	4.93	2.87	230	209	230	28	15	13
Double-crested Cormorant	2.18	0.38	3.99	69	15	69	41	14	27
Royal Tern	1.20	1.88	0.53	35	35	30	35	22	13
Brown Pelican	1.10	0.97	1.23	55	49	55	37	17	20
Elegant Tern	0.69	0.14	1.24	126	13	126	11	4	7
Snowy Egret	0.27	0.51	0.04	6	6	2	42	37	5
Mallard	0.20	0.20	0.19	16	11	16	13	6	7
Forster's Tern	0.18	0.17	0.20	16	16	10	9	3	6
American Coot	0.15	0.29	0.01	42	42	1	2	1	1
Brant	0.09	0.06	0.12	10	6	10	7	3	4
Great Egret	0.06	0.09	0.03	1	1	1	17	13	4
Great-blue Heron	0.045	0.083	0.007	2	2	1	11	10	1
Red-throated Loon	0.042	0.000	0.083	8	0	8	4	0	4
Caspian Tern	0.031	0.007	0.056	8	1	8	2	1	1
Red-breasted Merganser	0.024	0.042	0.007	2	2	1	6	5	1
Pied-billed Grebe	0.014	0.014	0.014	1	1	1	4	2	2
Brandt's Cormorant	0.010	0.000	0.021	3	0	3	1	0	1
Black-crowned Night Heron	0.007	0.014	0.000	2	2	0	1	1	0

Table 6 Terrestrial birds observed in 288 monthly surveys at the12 study beaches. Boldface indicates species with overall mean abundance $\geq$ 1 km^{-1}.

	Mean abund ind. km^{-1}			Max count Ind. km^{-1}			Times observed		
SPECIES	All	MPA	Ref	All	MPA	Ref	All	MPA	Ref
Black Phoebe	0.92	1.00	0.83	9	6	9	130	73	57
American Crow	0.86	1.07	0.65	26	26	17	63	37	26
Cliff Swallow	0.28	0.07	0.50	62	5	62	10	3	7
House Finch	0.28	0.02	0.54	18	2	18	14	2	12
Brewer's Blackbird	0.16	0.28	0.05	10	10	7	8	7	1
Common Raven	0.15	0.14	0.15	8	5	8	19	10	9
American Pipit	0.13	0.12	0.14	5	5	3	20	9	11
Savannah Sparrow	0.11	0.00	0.22	11	0	11	10	0	10
Eurasian Starling	0.10	0.11	0.08	12	12	4	10	4	6
Song Sparrow	0.09	0.15	0.03	4	4	4	12	10	2
Rock Pigeon	0.08	0.05	0.12	5	5	5	9	3	6
Say's Phoebe	0.08	0.07	0.10	2	2	2	22	9	13
Yellow-rumped Warbler	0.07	0.04	0.09	5	5	4	7	2	5
Rock Wren	0.03	0.04	0.01	1	1	1	8	6	2
Barn Swallow	0.02	0.01	0.03	4	2	4	3	1	2
Turkey Vulture	0.01	0.01	0.01	1	1	1	4	2	2
Anna's Hummingbird	0.01	0.01	0.01	2	1	2	2	1	1
Cassin's Kingbird	0.01	0.00	0.02	2	0	2	2	0	2
California Towhee	0.01	0.01	0.01	1	1	1	3	2	1
White-crowned Sparrow	0.01	0.02	0.00	2	2	0	2	2	0
American Kestrel	0.01	0.01	0.01	1	1	1	2	1	1
Osprey	0.01	0.01	0.01	1	1	1	2	1	1
Loggerhead Shrike	0.01	0.01	0.00	1	1	0	2	2	0
Red-winged Blackbird	0.01	0.00	0.01	2	0	2	1	0	1
Peregrine Falcon	0.003	0.000	0.007	1	0	1	1	0	1
Northern Harrier	0.003	0.007	0.000	1	1	0	1	1	0
Western Kingbird	0.003	0.007	0.000	1	1	0	1	1	0
Northern Mockingbird	0.003	0.000	0.007	1	0	1	1	0	1
House Sparrow	0.003	0.007	0.000	1	1	0	1	1	0

Birds: Species Accounts

Shorebirds

Overall, abundance varied greatly among individual species of shorebirds, ranging over 3 orders of magnitude from 0.003 birds km^{-1} to 17.8 birds km^{-1} for total monthly observations (Table 4). The average abundance of eight species of shorebirds exceeded 1 individual km^{-1} during the baseline study. Based on average observed abundance over the 2 years of the study, the most abundant shorebird species were Sanderling (17.8 birds km^{-1}), Black-bellied Plover (4.4 birds km^{-1}), Whimbrel (4.1 birds km^{-1}), Western Sandpiper (3.5 birds km^{-1}) Marbled Godwit (3.4 birds km^{-1}) and Willet (3.1 birds km^{-1}), all of which breed outside the study region. Other important species included Semipalmated Plover (2.5 birds km^{-1}), Least Sandpiper (1.3 birds km^{-1}), and Black Turnstone (0.9 birds km^{-1}). Two species that nest in the study region, Western Snowy Plover (0.2 birds km^{-1}) and Killdeer (0.5 birds km^{-1}) were observed regularly on some of the study beaches. Although Black Oystercatchers nest in a few mainland areas of the SC study region, they were scarce (0.007 birds km^{-1}) on the study beaches and were only observed once in 288 surveys. Seventeen species of shorebirds were observed in 10 or more of the individual monthly surveys (Table 3). Sanderlings, Black-bellied Plovers, and Whimbrels, which use SC beaches as migration and wintering habitat, were observed in 88, 104 and 163 of the individual surveys, respectively. Western Snowy Plovers, which nest on beaches in the SC region, were observed in thirteen individual surveys. Killdeer also nest on beaches in the SC region, including several of the focal beaches during the baseline study and were observed in 42 individual surveys. Black Oystercatchers, which are resident and nest in the study area, were observed in only 1 survey.

Sanderling

Sanderlings were the most abundant shorebird observed in the baseline study and accounted for 40.8% of the shorebirds observed. A total of 5126 Sanderlings were observed in 288 surveys of study beaches. The average total abundance of Sanderlings was 17.8 birds km^{-1} (Table 4). Sanderlings were observed in 88 individual surveys and average abundance varied among months ranging from 0 to 42.3 birds km^{-1}. The abundance of Sanderlings showed strong seasonal patterns corresponding to fall and spring migration and wintering with average abundance exceeding 20 birds km^{-1} in from October thru December and in February, April and May then dropping to 0 birds km^{-1} in June on the study beaches.

Although they were the most abundant shorebirds we observed, Sanderlings only occurred at eleven of the 12 beaches. Sanderlings were never observed on the transect at San Clemente Beach. The average abundance of Sanderlings varied over an order of magnitude among beaches, ranging from 0 to 66.4 birds km^{-1}. The study beach with the highest average numbers of Sanderlings (66.4 birds km^{-1}) was Crystal Cove Beach. The average abundance of Sanderlings also exceeded 20 birds km^{-1} at Isla Vista, East Campus and San Elijo beaches. Sanderlings are gregarious and tend to occur in flocks. The abundance of Sanderlings observed exceeded 100 birds km^{-1} in 18 individual surveys and the peak abundance observed during the study was 266 individuals at San Elijo in February 2012.

Black-bellied Plover
A total of 1256 Black-bellied Plovers were recorded in the baseline study. Black-bellied Plovers made up 10% of the total shorebirds and were observed in 104 surveys (Table 4). The overall average abundance of Black-bellied Plovers was 4.36 birds km^{-1}. Black-bellied Plovers were observed in every month of the year and average abundance varied among months, ranging from 0.5 to 7.3 birds km^{-1}. Peak abundance of this species was observed during fall and winter.

Black-bellied Plovers were observed on nine of the 12 study beaches. The average abundance of Black-bellied Plovers varied more than four fold among sites, ranging from 0.0 to 19.3 birds km^{-1}. The highest average abundance of Black-bellied Plovers (19.3 birds km^{-1}) occurred at Isla Vista Beach. The peak abundance of Black-bellied Plovers observed during our study was 65 individuals at Isla Vista in January 2012.

Whimbrel
A total of 1175 Whimbrels were recorded in the baseline study. Whimbrels accounted for 9.3% of the total shorebirds and were observed in 163 surveys (Table 4). The overall average abundance of Whimbrels was 4.08 birds km^{-1}. Whimbrels were observed in every month and average abundance varied among months, ranging from 1 to 10.4 birds km^{-1}. Peak abundance of this species was observed in July and in April and May.

Whimbrels were widely distributed, occurring on all of the study beaches. The average abundance of Whimbrels varied more than four-fold among sites, ranging from 0.5 to 16 birds km^{-1}. The highest average abundance of Whimbrels (16 birds km^{-1}) occurred at Blacks Beach. The peak abundance of Whimbrels observed during our study was 76 individuals at Blacks Beach in July 2012.

Western Sandpiper
A total of 999 Western Sandpipers were observed in the study. Western Sandpipers made up 8% of the total shorebirds and were observed in 33 surveys (Table 4). The overall average abundance of Western Sandpipers was 3.5 birds km^{-1} (Table 4). Western Sandpipers were observed in 11 months of the baseline surveys and average abundance varied among months, ranging from 0.5 to 26 birds km^{-1}. Peaks in the abundance of this species occurred during spring migration (April).

Although they were the fourth most abundant shorebirds we observed, Western Sandpipers only occurred at five of the study beaches during our baseline study. Average abundance of Western Sandpipers varied over an order of magnitude among beaches, ranging from 0 to 29.1 birds km^{-1}. The study beach with the highest average numbers of Western Sandpipers (29.1 birds km^{-1}) was East Campus. The peak abundance of Western Sandpipers observed during our study was 500 individuals at East Campus in April 2013, coincident with a spring migration peak.

Marbled Godwit
A total of 965 Marbled Godwits were observed in the study. Marbled Godwits accounted for 7.7% of the total shorebirds and were observed in 83 surveys (Table 4). The overall average abundance of Marbled Godwits was 3.4 birds km^{-1} (Table 4). Marbled Godwits were observed in 11 months of the baseline surveys and average abundance varied

strongly among months, ranging from 0 to 6.1 birds km^{-1}. Peaks in the abundance of this species coincided with fall and spring migration and wintering.

Marbled Godwits occurred at nine of the 12 study beaches during our baseline study. Average abundance of Marbled Godwits varied over an order of magnitude among beaches, ranging from 0 to 11.6 birds km^{-1}. The study beach with the highest average numbers of Marbled Godwits (11.6 birds km^{-1}) was Scripps Beach. The peak abundance of Marbled Godwits observed during our study was 68 individuals at Scripps in March 2013.

Willet
A total of 893 Willets were observed in the baseline study. Willets accounted for 7.1% of the total shorebird abundance and were observed in 131 surveys (Table 4). The overall average abundance for Willets was 3.1 birds km^{-1} during the study. Willets were observed in eleven months of the baseline surveys and the average number observed on the study beaches varied among months, ranging from 0.3 to 7.5 birds km^{-1}. The peak in the total abundance of Willets occurred in April during spring migration.

Willets were widely distributed occurring on all of the study beaches. The average abundance of Willets varied five fold among the study beaches, ranging from 0.1 to 8.9 birds km^{-1}. The highest average number of Willets occurred at Isla Vista Beach. The peak abundance of Willets observed during our study was 55 individuals at Isla Vista in March 2013.

Western Snowy Plover
Western Snowy Plovers are federally listed as a threatened species. These shorebirds nest on beach, river bar, salt flat and estuarine habitats in the study region. On beaches, both adults and chicks depend largely on prey resources associated with macroalgal wrack making them important species to consider as potential indicators of ecosystem condition and connectivity in MPA baseline evaluation. None of the 12 study beaches currently support nesting of Western Snowy Plovers although nesting occurs within the Campus Point MPA and Isla Vista beach is adjacent to nesting area. A total of 61 Western Snowy Plovers were observed in the baseline study. Western Snowy Plovers accounted for 0.5% of the total shorebirds and were observed in nine surveys (Table 4). The overall average abundance for Western Snowy Plovers was 0.21 birds km^{-1} (Table 4). Western Snowy Plovers were recorded in 5 months of the baseline surveys and peak abundance of this species occurred during fall and winter at wintering/staging sites.

Western Snowy Plovers had a restricted spatial distribution, and were observed at only four of the study beaches during our baseline surveys (Isla Vista, East Campus, Leo Carrillo and Crystal Cove). The peak number of Snowy Plovers observed in a single survey, 14 birds, was at Crystal Cove in November 2013, where a roost site may occur during wintering and post-breeding dispersal.

Killdeer
Killdeer also nest in the study area and were commonly observed on some of the beaches making this plover species a potential indicator of ecosystem conditions. A

total of 152 Killdeer were observed in the baseline study with an average abundance of 0.53 birds km^{-1} (Table 4). Killdeer were observed in eleven months of the study with average abundance ranging from 0 to 2.1 birds km^{-1}. The largest numbers of Killdeer on the study beaches were recorded in October after the nesting season.

Killdeer were observed on five of the study beaches and average abundance ranged from 0 to 3.4 birds km^{-1} with the highest average abundance at East Campus Beach. The peak abundance of Killdeer observed during our study was 24 individuals at East Campus in October 2012.

Black Oystercatcher

Black Oystercatchers are a shorebird of high conservation concern, although they are not a listed species. These shorebirds nest in the study area and on beaches, making them important species to consider as potential indicators of ecosystem condition and connectivity in MPA baseline evaluation. However, this species was only observed on one survey during the baseline study of beaches. A total of 2 Black Oystercatchers were observed at Crystal Cove in November of 2013 (Table 4). The overall average abundance of Black Oystercatchers was very low (0.007 birds km^{-1}) (Table 4).

Human use & activities

Visitor use of the study beaches was high and diverse including walking, jogging, dog-walking, surfing, sunbathing, socializing, fishing, and beach sports or play. We also observed photo shoots and filming of movies and commercials on several occasions on the two study beaches in Los Angeles County. We observed a total of 11,893 people in the 288 surveys of the 12 study beaches. The monthly average number of people observed on the beach and in the surf zone was 34.3 individuals km^{-1}. The peak number of visitors observed exceeded 500 people km^{-1} during one summer survey at San Clemente State Beach. The mean number of visitors observed on the study beaches varied seasonally ranging from 13.9 to 85.5 individuals km^{-1} for January and July, respectively. A similar seasonal pattern was observed in the average numbers of people in the surf zone, which ranged from 2.0 to 19.1 individuals km^{-1} for January and July, respectively. The average total number of people observed on the study beaches and in the surf zones varied by nearly two orders of magnitude among beaches, ranging from 1.3 to 112 individuals km^{-1} (Figure 21) of which 0.2 to 32.3 individuals km^{-1} were in the surf zone at Arroyo Quemado and San Elijo, respectively.

Dogs (leashed and unleashed) were regularly observed on most of the study beaches. We observed a total of 183 dogs in the study and monthly average abundance of dogs was 0.9 dogs km^{-1} of which 0.6 dogs km^{-1} were off leash. The average number of dogs observed on the study beaches varied by more than an order of magnitude among beaches, ranging from 0.0 to 3.9 dogs km^{-1} of which 0.0 to 2.1 individuals km^{-1} were off leash at Blacks and Leo Carrillo, respectively. Dog abundance was also low (0.1-0.2 dogs km^{-1}) at Crystal Cove, Carlsbad and San Elijo State Beaches, all of which appeared to have high compliance with restrictions on dogs.

Total human density on the beaches increased from north to south in the region (r^2 = 0.697, $p < 0.001$) in a way that was broadly consistent with populations of nearby communities but that also followed that pattern of increasing air temperatures (r^2 =

0.771) and wind chills (r^2 = 0.751, $p < 0.001$) in the study region. Mean human densities at the study sites were correlated with mean air temperatures (r^2 = 0.408, $p < 0.05$). The mean density of people in the surf and mean density of dogs did not exhibit spatial trends across the region. The average number of visitors and dogs on the study beaches did not vary consistently inside and outside MPAs (Figure 22) and differences were not significant (ANOVA p=0.302, p=0.489, respectively).

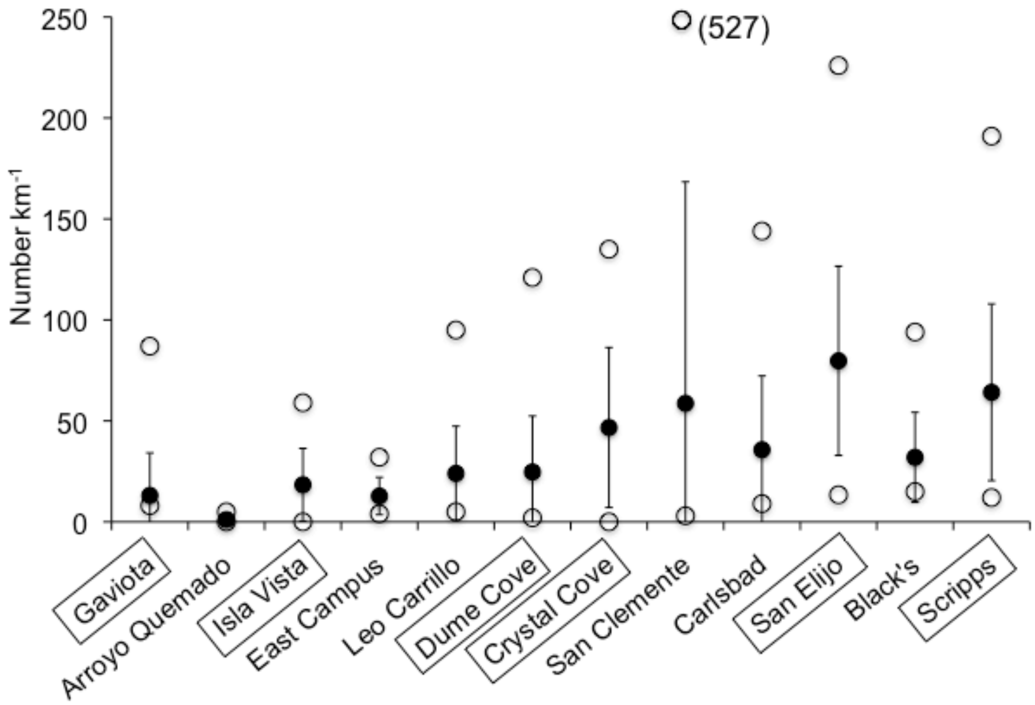

Figure 21. Mean (•) (+ one std dev), maximum (o) and minimum (o) numbers of visitors observed at the 12 study beaches in monthly surveys. All observations are for a standard 1 km transect at each study beach. Beaches are listed from north to south. Names of sites located in MPAs are in boxes

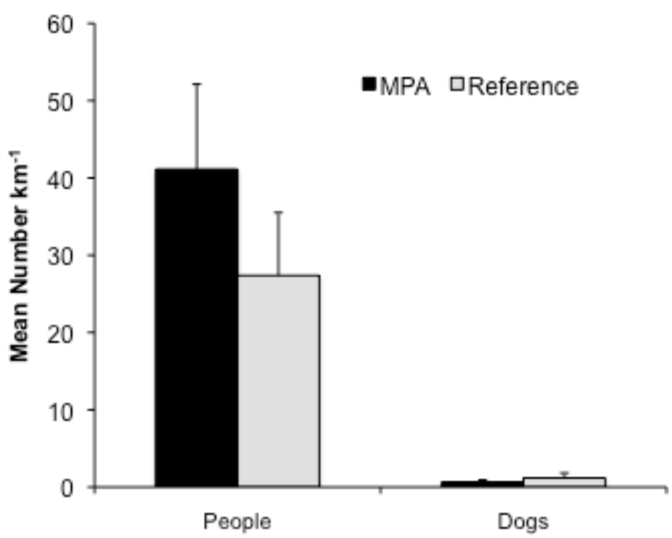

Figure 22. Mean numbers (+ std. errors) of people and dogs observed on beaches inside MPAs and on reference beaches.

Beach Wrack

Wrack Cover

Macrophyte wrack is an important subsidy for invertebrates living on the beach, which are potential prey for birds and fish. The cover of marine macrophytes (macroalgae, surfgrasses *Phyllospadix* spp. and eelgrasses [*Zostera* spp.]) was used to estimate the standing crop of drift macrophytes or wrack at each study beach during the rapid monthly surveys as well as during biodiversity and target species sampling. The macrophyte wrack observed on the study beaches consisted primarily of the kelps, *Macrocystis pyrifera*, *Egregia menziesii* and surfgrass, *Phyllospadix* spp. Other brown and red algae and eelgrass, *Zostera marina,* also occurred as wrack on the study beaches, usually in small quantities and cover.

The composition of marine macrophyte wrack varied among the study beaches. Kelp and other brown macroalgae made up 9 to 96% of total cover and giant kelp alone made up 40% or more of the marine wrack at six of the 12 study beaches (Figure 23). Surfgrass, *Phyllospadix* spp., made up 3 to 90% of the total cover of marine wrack and alone surfgrass made up >50% of the wrack cover at seven of the 12 study beaches. The dominance of surfgrass at some beaches may be associated with the rapid turnover and processing of kelp wrack by beach consumers, such as talitrid amphipods (Lastra et al 2008).

The mean cover of marine macrophyte wrack was high in the region but varied over eight fold among the study beaches, ranging from 0.56 to 4.76 m^2 m^{-1} at San Clemente and East Campus, respectively (Figure 23). Average cover of wrack exceeded 2.5 m^2 m^{-1} at four of the study beaches. Low average cover of marine wrack, < 0.90 m^2 m^{-1}, occurred at two beaches, San Clemente and Carlsbad (Figure 23). The average cover of brown macroalgal wrack, primarily kelps, varied over an order of magnitude among the study beaches ranging from 0.11 to 1.62 m. and was > 0.9 m at five of the study beaches. The average cover of *Macrocystis* wrack varied over an order of magnitude among the study beaches ranging from 0.10 to 1.28 m (Figure 23). Average cover of *Macrocystis* exceeded 0.5 m^2 m^{-1} at nine of the beaches and at four of those beaches exceeded 1 m^2 m^{-1} of cover. The average cover of *Phyllospadix* wrack varied over two orders of magnitude among study beaches, ranging from 0.02 to 2.91 m^2 m^{-1} (Figure 23). Average cover of *Phyllospadix* was >1.0 m^2 m^{-1} at eight of the study beaches and cover exceeded 2.0 m^2 m^{-1} at two of those beaches (Isla Vista and East Campus).

Overall the monthly average cover of marine macrophyte wrack was high in the SC study region, with mean values exceeding 1 m^2 m^{-1} in every month (Figure 24). Seasonal variation in marine wrack cover was greater than 2 fold, ranging from 1.25 m^2 m^{-1} to 3.17 m^2 m^{-1} with peak values generally observed in the winter surveys (Figure 24). The cover of *Macrocystis* wrack ranged from 0.46 to 1.24 m^2 m^{-1} and peaked in the October and November on the study beaches.

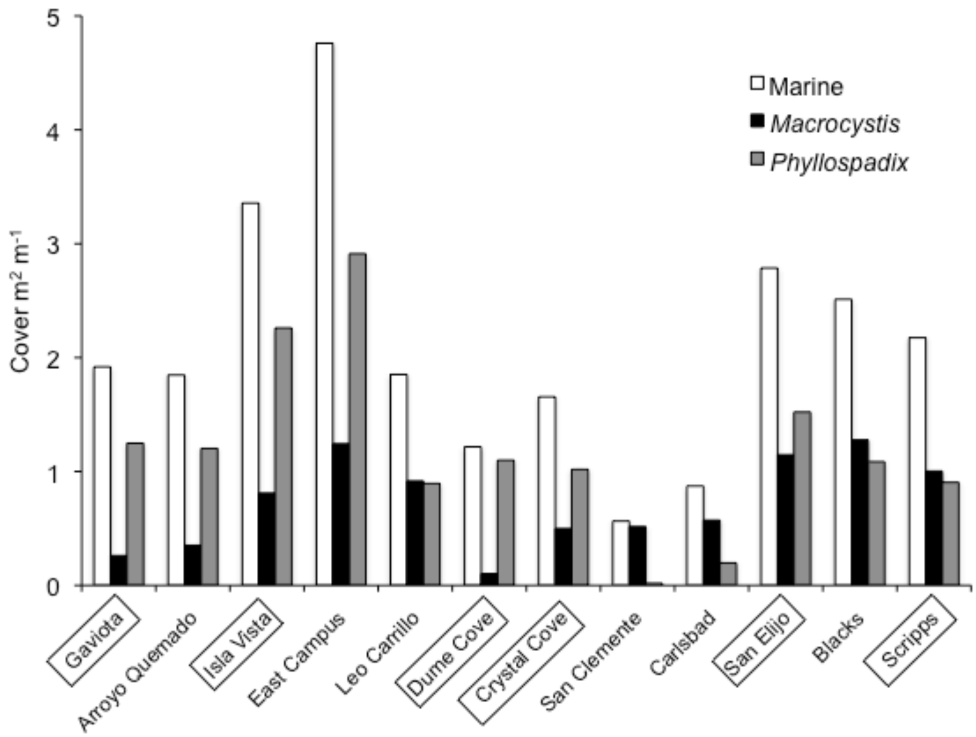

Figure 23. Mean values of cover of marine macrophyte wrack (total marine, *Macrocystis pyrifera* and *Phyllospadix* spp.) expressed as mean cover m^2m^{-1}, for monthly surveys of the 12 study beaches from December 2011 to November 2013 (n = 24). Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

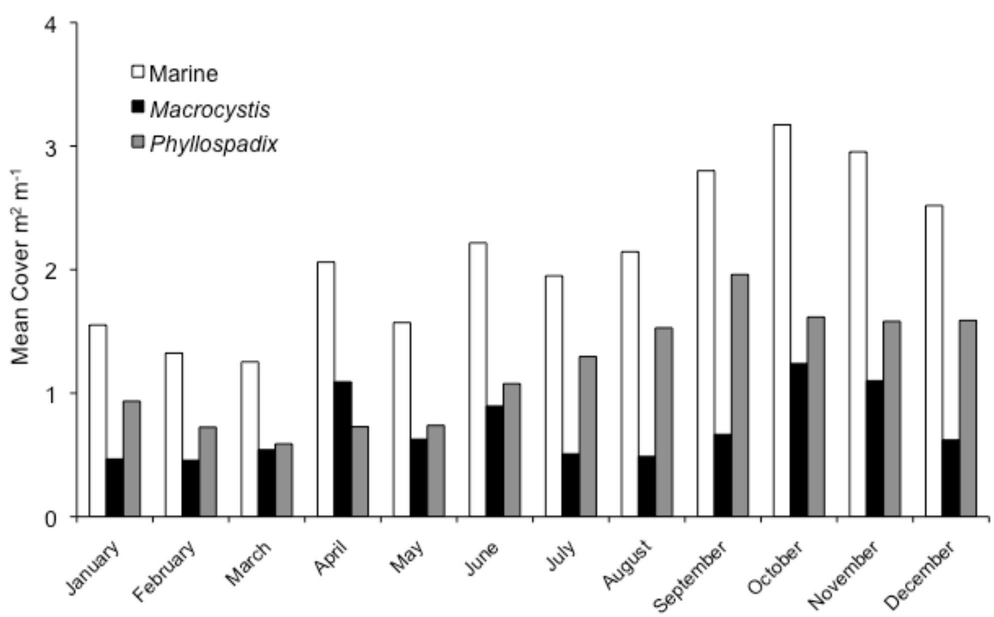

Figure 24. Monthly mean values of the cover of macrophyte wrack (total marine, *Macrocystis pyrifera* and *Phyllospadix* spp.) expressed as mean cover m^2m^{-1} observed on the 12 study beaches (n = 24). Surveys were conducted monthly from December 2011 to November 2013.

Fresh Kelp Plants

The average total abundance of fresh beach-cast kelp plants and holdfasts (*Macrocystis pyrifera*) quantified in the 1 km alongshore surveys varied over an order of magnitude (from 4.8 to 151 plants km^{-1}) among sites and averaged 44 plants km^{-1} overall (Figure 25). The peak number of kelp plants and holdfasts observed was 516 plants km^{-1} in January 2012 at Isla Vista. Two bluff-backed beaches, Isla Vista and East Campus, had average values of >70 plants km^{-1} year round. Counts of more than 200 plants and holdfasts km^{-1} were observed on individual surveys at Arroyo Quemado, Isla Vista, East Campus, Crystal Cove and San Elijo. The two beaches with the lowest mean values for abundance of fresh kelp plants were Dume Cove and San Clemente (5.0 and 5.2 plants km^{-1}, respectively). The latter beach is not proximal to major kelp forests. Our Scripps study beach located in the Scripps SMCA and the Matlahuayl SMR also had a surprisingly low abundance of fresh kelp plants (9.8 km^{-1}). This result appeared to be related to the regular beach grooming in the SMR and SMCA conducted by the City of San Diego on a large part of the 1 km transect on this beach. Carlsbad beach is ungroomed yet also had a low abundance of fresh kelp plants (10.5 plants km^{-1}). This result may be related to the highly eroded condition of Carlsbad beach during much of our 2 year study. There were no consistent or statistically significant differences in the abundance of fresh kelp plants (ANOVA p=0.341) or holdfasts (ANOVA p=0.905) among beaches located inside MPAs and the reference beaches (Figure 26).

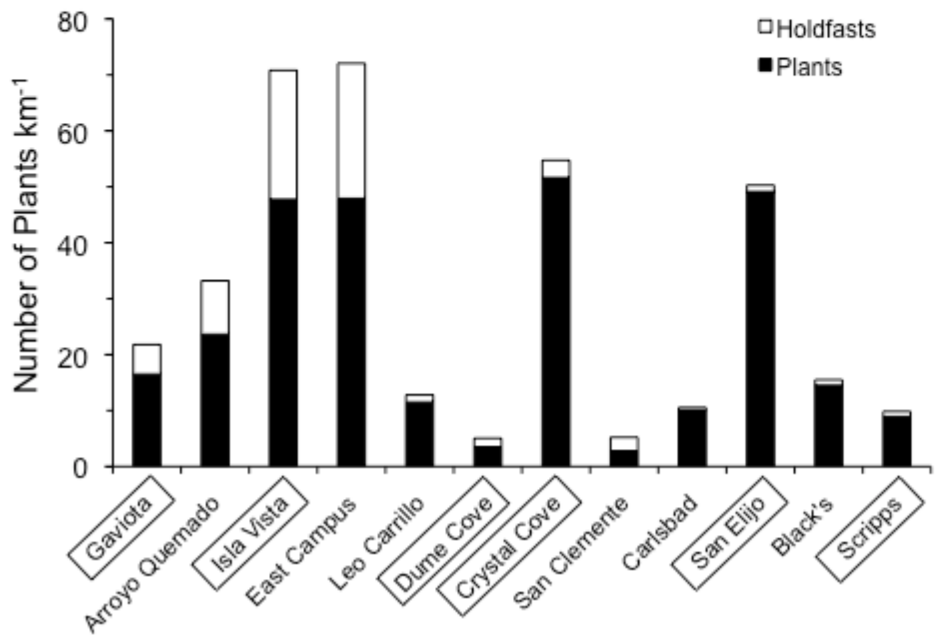

Figure 25. Mean numbers of fresh kelp plants and holdfasts (*Macrocystis pyrifera*) counted in monthly surveys at the 12 study beaches. All observations were made along a standard 1 km transect at each study beach. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

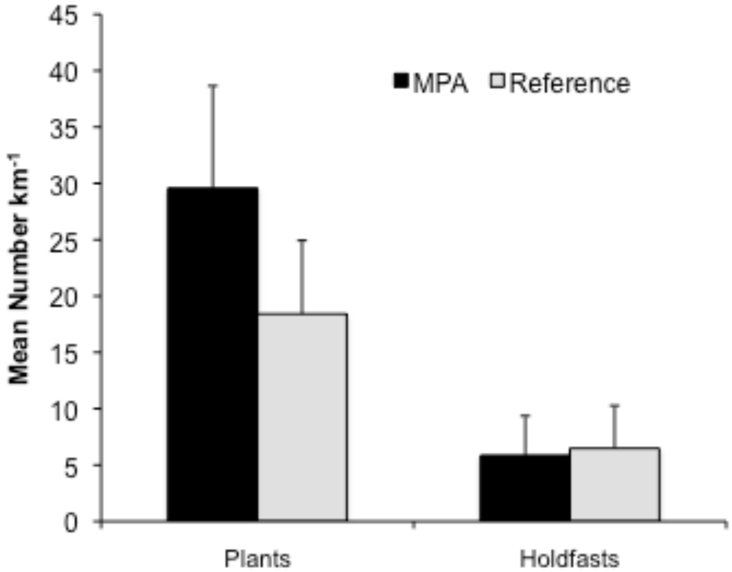

Figure 26. Mean numbers (+ std. errors) of fresh kelp plants and holdfasts observed on beaches inside MPAs and on reference beaches

The average cover of marine macrophyte wrack across the entire width of the beach was highly correlated with average abundance of fresh kelp plants per km ($r^2 = 0.61$, $p < 0.001$), suggesting that fresh kelp plant surveys may be a useful proxy for estimating standing crop of marine wrack on a beach. However, the average cover of *Macrocystis* wrack was not correlated with the average abundance of fresh kelp plants in our study, again potentially indicating the role of turnover of kelp resources by the abundant kelp wrack consumers, primarily talitrid amphipods, on many of the study beaches (Lastra et al. 2008).

The large spatial differences observed in macrophyte wrack accumulation and composition at the study beaches are likely related to the proximity of rocky reefs and prevailing swell exposure and wind patterns (e.g. Cavanaugh et al. 2011), beach grooming, and the presence of suitable upper beach zone for deposition and retention of wrack (Revell et al. 2011). The abundance of primary consumers of macrophytes, such as talitrid amphipods, influences the turnover rates and affects the standing crop of macrophyte wrack observed on beaches (Lastra et al. 2008) a process that is likely to be reflected in our results on wrack.

Temporal variation in the abundance of fresh kelp plants ranged from 10.8 to 66.3 plants km^{-1} with highest average abundance observed in the months of January, November and April and lowest in July and August (Figure 27). The winter peak in abundance of kelp plants matched patterns observed for kelp wrack on beaches in the Santa Barbara Channel (Revell et al 2011). However the spring increase in kelp plant abundance does not and may be related to other factors, such as very mild winter conditions followed by strong spring winds that occurred during the baseline study.

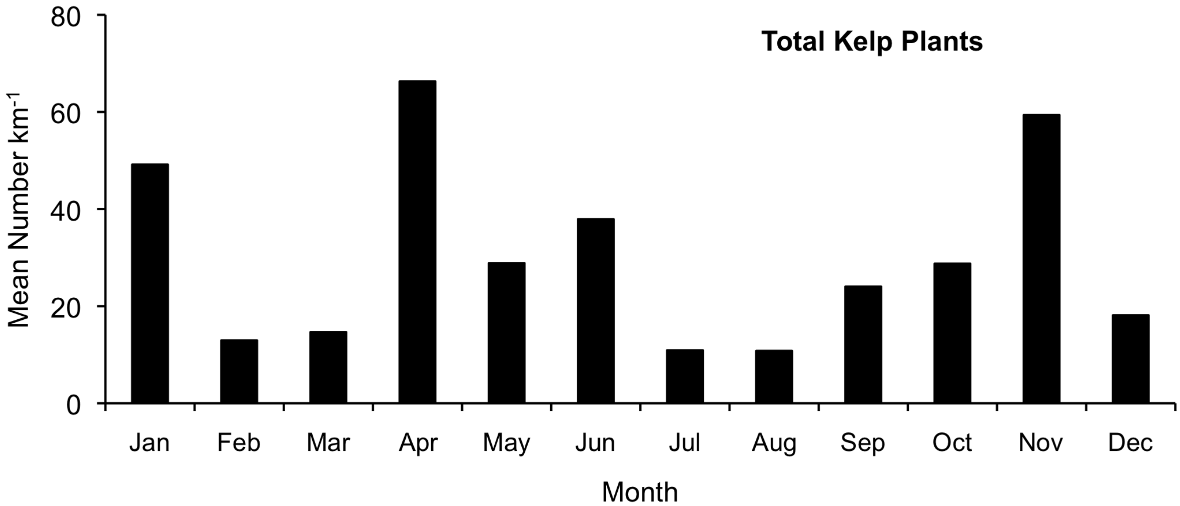

Figure 27 Monthly mean values of the abundance of fresh *Macrocystis pyrifera* plants observed on the 12 study beaches expressed as mean number km^{-1} (n = 24). Surveys were conducted once a month for 2 years from December 2011 to November 2013 on standard 1 km transects.

Macroinvertebrates

Species richness of intertidal macroinvertebrates varied more than 3 fold among study beaches, ranging from 12 to 45 species during our 2011 biodiversity surveys. Twenty-five or more species of invertebrates were found at all but two of the study beaches in the biodiversity surveys (Table 7, Figure 28). This represents very high richness for open coast beaches compared to other parts of the world. A total of over 83 different macroinvertebrate taxa were observed in our biodiversity surveys across all the study beaches in the SC region (Table 7). Isla Vista (MPA) and East Campus (reference) beaches really stood out with respect to their total species richness (40 and 39 species, respectively, followed by Leo Carrillo (37 species). San Clemente Beach had the lowest total species richness (12 species) observed in the biodiversity surveys of the 12 study beaches. When the results of indicator surveys were included in the species counts, the total species richness was greater at many of the beaches (Table 7) and the total number of macroinvertebrate taxa observed in our study increased to 89.

Wrack-associated invertebrate species, (talitrid amphipods, isopods, insects and arachnids) (Table 7), which depend on subsidies of drift macroalgae from nearshore kelp forests and reefs, made up an important component of the diversity and abundance of the intertidal community at all of the beaches, representing a diversity of trophic levels and ecological roles. A total of 37 wrack-associated invertebrate taxa were found in our surveys, making up 45% of the total macroinvertebrate species observed in our study. The number of wrack-associated species in the biodiversity samples varied 7 fold, ranging from three at Carlsbad to 22 species at Isla Vista. The proportion of wrack-associated species varied over 4 fold among beaches, ranging from 14% at Carlsbad to 68% at Dume Cove and these taxa made up an average of 46% of the total number of invertebrate species found on the study beaches. Wrack-associated species made up 50% or more of the species at five of the 12 study beaches.

There were no consistent or statistically significant differences in the species richness of invertebrates (ANOVA $p = 0.516$) or wrack-associated invertebrates (ANOVA, $p = 0.257$) between MPA and reference beaches in the baseline study (Figure 29).

The two taxa of invertebrates, *Emerita analoga* and *Megalorchestia* spp., that were observed in biodiversity surveys at all 12 study beaches were also our proposed indicator taxa confirming their potential suitability as indicators (Table 7). The taxon, *Megalorchestia* spp., was remarkably diverse in the SC region, with five species represented, including: *M. benedicti*, M. californiana, *M. columbiana*, *M. corniculata* and *M. minor*. The kelp fly, *Fucellia* spp. was the next most widespread taxa, occurring in the biodiversity surveys at 11 of the 12 study beaches. Four taxa of macroinvertebrates occurred in the biodiversity surveys at ten of the 12 study beaches: including two polychaetes, *Nephtys californiensis* and *Hemipodia simplex* and two beetles, *Emphyastes fucicola* and *Cercyon fimbriatus*. A polychaete, *Scololepis bullibranchia*, and a staphylinid beetle, *Bledius fenyesi,* were found in the biodiversity surveys at nine of the 12 study beaches. A deposit- feeding polychaete *Thoracophelia mucronata* and a scavenging cirolanid isopod, *Excirolana chiltoni* occurred in the biodiversity surveys at eight of the 12 study beaches (Table 7).

Macroinvertebrate abundance and biomass were high but varied considerably among the study beaches in the SC region in our biodiversity surveys (Figure 28). Macroinvertebrate abundance and biomass were not correlated with each other. Total abundance varied over an order of magnitude from a minimum of 8575 individuals m^{-1} at San Clemente Beach to a peak of 134,649 individuals m^{-1} at East Campus Beach in the 2011 biodiversity surveys. Total mean abundance of macroinvertebrates also exceeded 100,000 individuals m^{-1} at Isla Vista Beach. The overall mean abundance of invertebrates was very high in the SC region, exceeding 30,000 individuals m^{-1} at all but one of the study beaches (San Clemente) in the biodiversity surveys. Values of macroinvertebrate abundance >10,000 animals m^{-1} are considered high for open coast beaches (McLachlan et al. 1996) and particularly for intermediate type beaches like those in the SC region. Outside of California values of abundance exceeding 10,000 animals m^{-1} have been reported primarily on wide dissipative or high intermediate type beaches (McLachlan et al., 1996, Dugan et al. 2003). The estimated mean abundances of six individual macroinvertebrate taxa (*Meglaorchestia* (7 sites), *Emerita* (3 sites), *Fucellia* (2 sites), *Thoracophelia* (2 sites), *Excirolana* (1 site), and *Donax* (1 site) were also very high, exceeding 10,000 individuals m^{-1} at one or more of the study beaches in the 2011 biodiversity surveys.

There were no consistent or statistically significant differences in the abundance or biomass of macroinvertebrates (ANOVA, $p = 0.685$, $p = 0.595$, respectively) or of wrack-associated macroinvertebrates (ANOVA, $p = 0.733$ and $p = 0.070$, respectively) between MPA and reference beaches (Figure 30).

Wrack-associated invertebrates were a very important component of overall community abundance. The abundance of wrack-associated invertebrates was remarkably high, exceeding 20,000 individuals m^{-1} at four and 10,000 individuals m^{-1} at 5 more of the 12

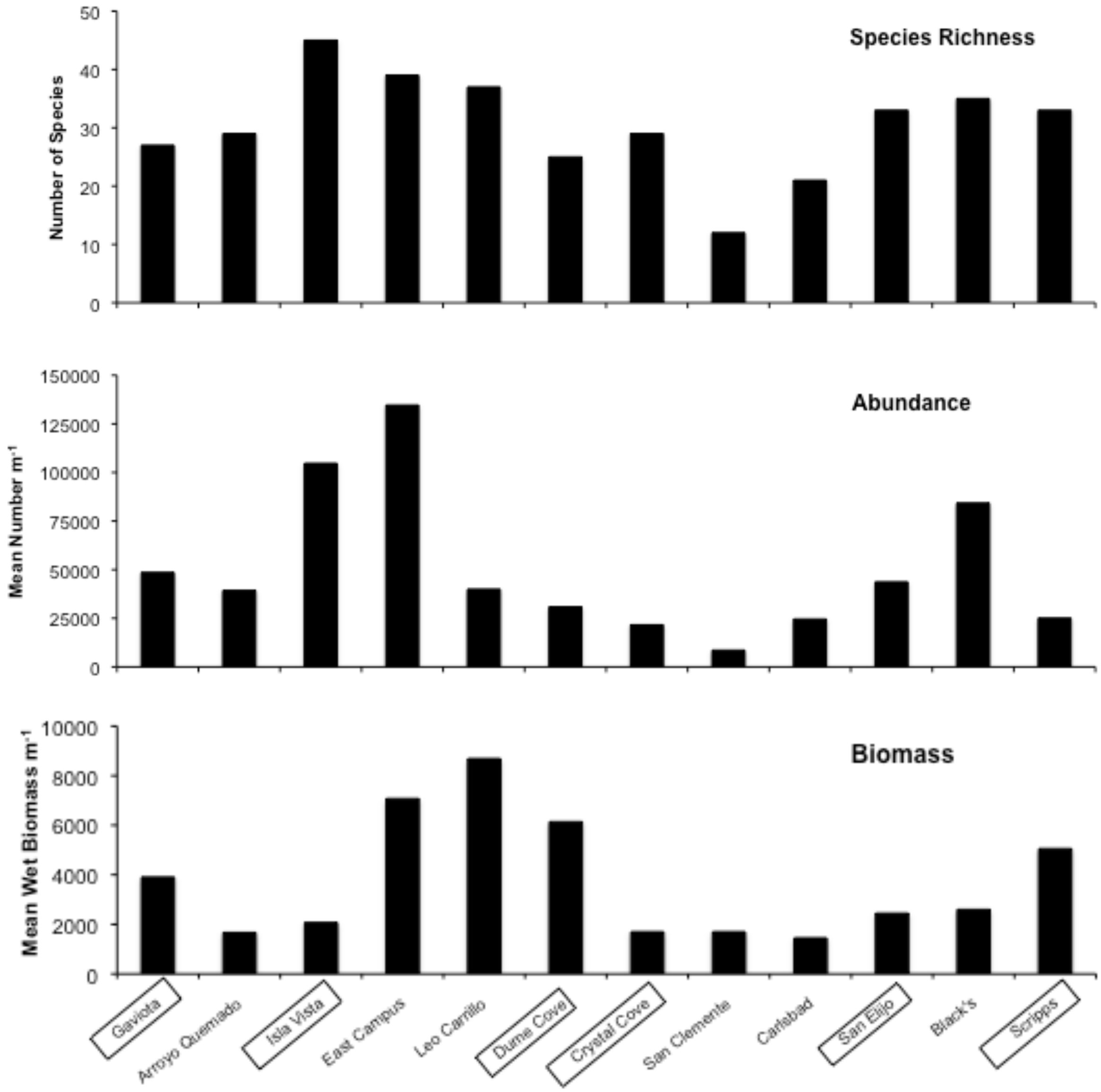

Figure 28. Total species richness and mean values of abundance and biomass of macroinvertebrates for biodiversity surveys of the 12 study beaches conducted in Fall 2011. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

study beaches in the biodiversity surveys. Wrack-associated invertebrates were more abundant than sand crabs at all but two of the study sites (Dume Cove and Blacks) in the biodiversity study (Figure 31).

Total mean biomass of macroinvertebrates varied nearly six fold among the study beaches ranging from 1450 g m^{-1} at Carlsbad Beach to 8685 g m^{-1} at Leo Carrillo Beach (Figure 28). Values of wet biomass exceeded 5000 g at four of the study beaches (East Campus, Leo Carrillo, Dume Cove and Scripps). At Leo Carrillo and Dume Cove, this high biomass was primarily due to high abundance of *Emerita analoga* (Figure 32).

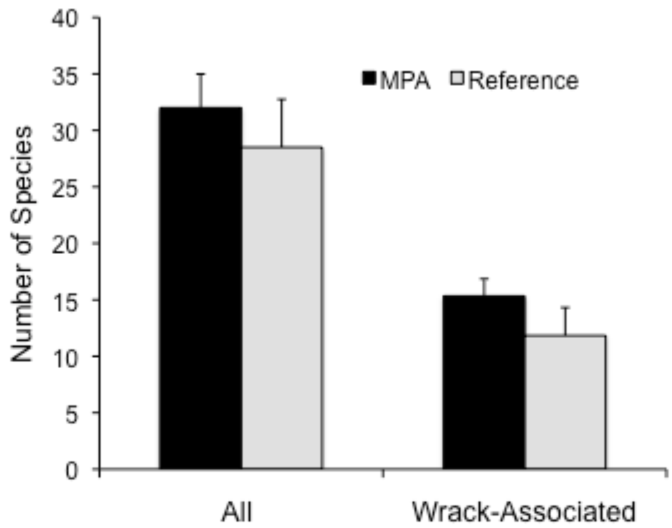

Figure 29 Mean numbers (+ std. errors) of species of invertebrates and wrack-associated invertebrates observed on beaches inside MPAs and on reference beaches in biodiversity surveys in Fall 2011**.**

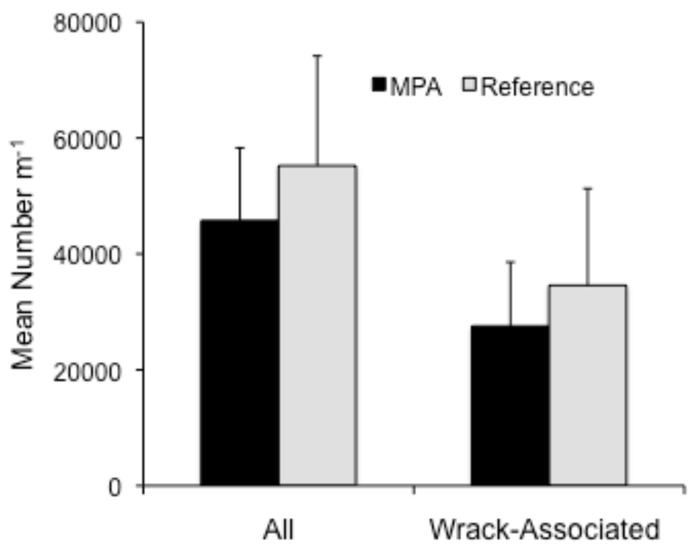

Figure 30. Mean abundance (+std. errors) of invertebrates and wrack- associated invertebrates observed on beaches inside MPAs and on reference beaches in the biodiversity surveys in Fall 2011.

Mean macroinvertebrate biomass (wet) was generally high in the SC region relative to that reported for beaches elsewhere in the world (McLachlan *et al.* 1996; 1993). A dry biomass of >1000 g m^{-1} is considered high and 5000 g m^{-1} a ceiling value for macroinvertebrate communities of exposed sandy beaches by McLachlan et al. (1996, 1993). Outside of California dry biomass values exceeding 1000 g m^{-1} have been reported only for high intermediate to dissipative beach types (McLachlan et al. 1996). Using a conversion of 25% of wet biomass as an estimate for dry biomass (McLachlan, personal communication), we estimated mean dry biomass values >1000 g m^{-1} at four of the 12 study beaches and a high value of 2171 g m^{-1} (Leo Carrillo) in the current study. Community biomass was dominated by *Emerita,* which averaged 51% of the total biomass. However, the proportion of community biomass composed of *Emerita* varied among the study beaches, ranging from 5% at Isla Vista to 96% at San Clemente.

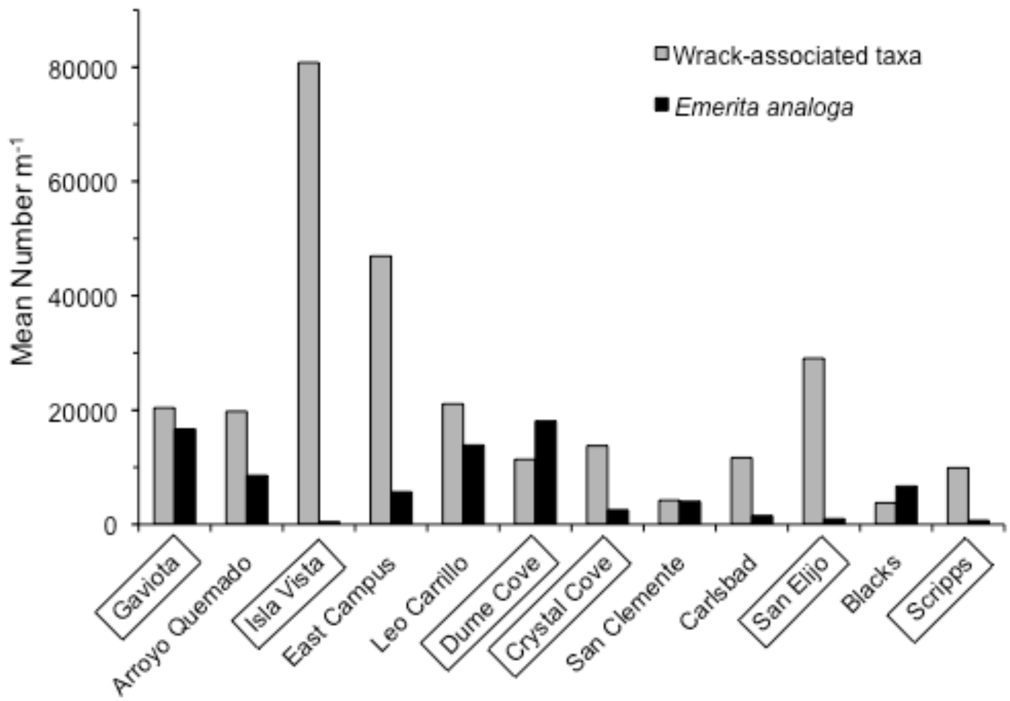

Figure 31. Average values of abundance for wrack-associated taxa and sand crabs, *Emerita analoga,* at the 12 study beaches during the 2011 biodiversity surveys. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

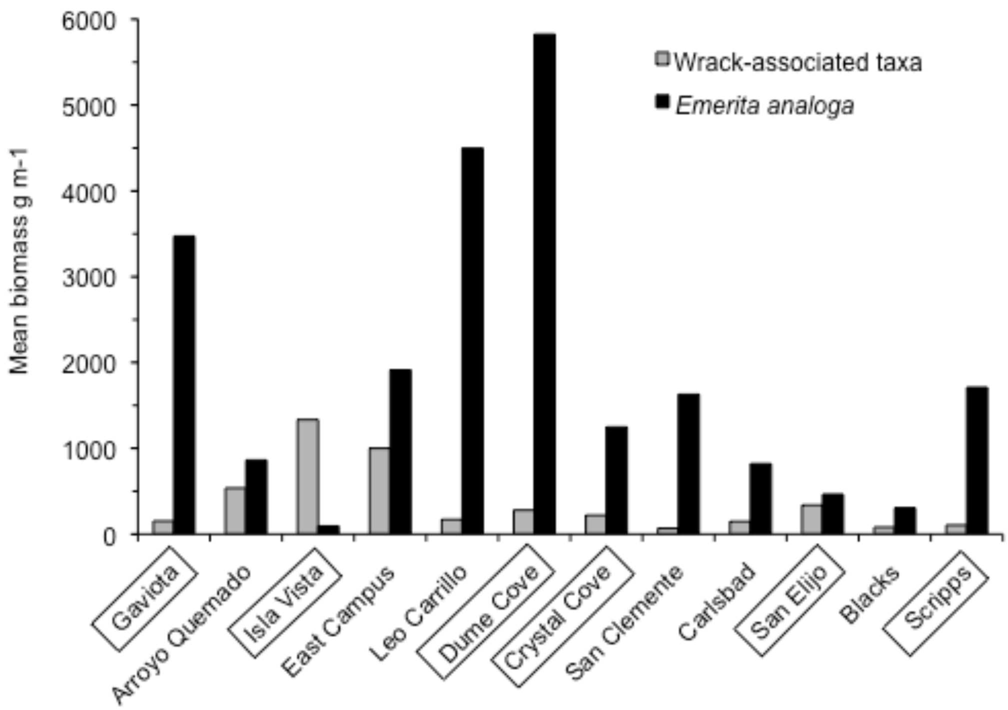

Figure 32. Average values of biomass for wrack-associated taxa and sand crabs, *Emerita analoga,* at the 12 study beaches during the 2011 biodiversity surveys. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Table 7 List of macroinvertebrate species collected in surveys of the 12 study beaches. Names of sites located in MPAs are underlined. X indicates the species was found in biodiversity surveys, p indicates the species was found only in other surveys at that site. A gray highlight indicates abundance > 10,000 individuals m^{-1} in any survey.

	Gaviota	Arroyo Quemado	Isla Vista	East Campus	Leo Carrillo	Dume Cove	Crystal Cove	San Clemente	Carlsbad	San Elijo	Blacks	Scripps
PLATYHELMINTHES									X		X	
NEMERTEA												
Unid. Nemertean		X	X	X	X			X	X	X	X	X
Paranemertes californica				X	X		X		X	X	X	X
Paranemertes peregrina			X									
MOLLUSCA												
Bivalvia												
Donax gouldii				p					X	X	**X**	**Xp**
Tivela stultorum			p	X							X	X
*Mysella pedroana**					X							X
Gastropoda												
Callianax biplicata	p		p	p	X	p			X	X	X	
ANNELIDA												
POLYCHAETA												
Arabella iricolor	X		X	X	X	X	X		X			
Arenicola sp.				X								
Paraonella platybranchia					X		X					
Capitellidae											X	
Amastigos acutus				X								
Notomastus sp.			X	X								
Notomastus sp. D							X					
Cirriformia sp.							X					
Eteone dilatae			X									
Thoracophelia dillonensis						X					X	X
Thoracophelia mucronata	X	X	**X**	**X**	X		p		X		X	**X**
Glycera macrobranchia			X	X								
Hemipodia simplex		X	X		X	X	X	X	X	X	X	X
Nephtys caecoides			X	X					X	X		X
Nephtys californiensis	X	X	X	X	X	X	X		X	X	X	X
Nephtys sp.	X								X	X	X	
Orbinia johnsoni												X
Scoloplos armiger		X	X	X	X		X		X	X	X	X
Dispio uncinata			X	X	X				X	X	X	X
Scolelepis bullibranchia		X		X	X	X	X		X	X	X	X
Scolelepis squamata		X	X	X		X	X			X		
Spionidae		X		p	p					X	X	
Scoletoma zonata		X	X	X	X	X	X		X	X	X	X

Table 7. List of macroinvertebrate species collected in surveys of the 12 study beaches continued.

	Gaviota	Arroyo Quemado	Isla Vista	East Campus	Leo Carrillo	Dume Cove	Crystal Cove	San Clemente	Carlsbad	San Elijo	Blacks	Scripps
ARTHROPODA												
CRUSTACEA												
MYSIDACEA												
Archaeomysis grebnitzkii											X	
Archaeomysis maculata						X		X			X	
Archaeomysis sp.											X	
AMPHIPODA												
Americhelidium sp	X	X					X			X	X	
Eohaustorius sawyeri	X	X	X	X	X							
Eohaustorius washingtonianus							X		X	X	X	X
Gibberosus devaneyi									X		X	X
Gibberosus myersi										X	X	
Mandibulophoxus gilesi							X					
Megalorchestia benedicti	X	X	X	X	X	X	X	X		X	X	X
Megalorchestia californiana			X		X	X	X	X		X		
Megalorchestia columbiana						X						
Megalorchestia corniculata	X	X	**X**	X			X	X	X	X	X	X
Megalorchestia minor					X	X		X				
TOTAL *Megalorchestia* spp.	X	**X**	**X**	**X**	**X**	X	**X**	X	X	**X**	**Xp**	**Xp**
Paraphoxus sp.			X	X			X			X	X	X
ISOPODA												
Alloniscus perconvexus	p	X	X	X	X	X	X	p			p	
Tylos punctatus		p			X	X	X				X	X
Excirolana chiltoni	**X**	X	X	X			p		X	X	X	X
Excirolana linquifrons	X	X	X	X	X							
Excirolana sp.	X	X		p								
Gnorimosphaeroma noblei	X	X	X			X	X					
DECAPODA												
Emerita analoga	**X**	**Xp**	**Xp**	**Xp**	**X**	**X**	**Xp**	X	X	**Xp**	**Xp**	**Xp**
Blepharipoda occidentalis	p		p	X*	X					X	p	X
Lepidopa californica			X		X		p		X	X	X	X
Isocheles pilosus												p
ARACHNIDA										p		
Garypus californicus		p	X		p	p						
Neomolgus littoralis						X						

Table 7. List of macroinvertebrate species collected in surveys of the 12 study beaches continued.

	Gaviota	Arroyo Quemado	Isla Vista	East Campus	Leo Carrillo	Dume Cove	Crystal Cove	San Clemente	Carlsbad	San Elijo	Blacks	Scripps
INSECTA												
COLEOPTERA		p	p									
Aleochara sulcicollis	X	X	X	X	p	p	X	p	p	X	X	p
Unid. Aleocharinae						p						
Bledius fenyesi	X	X	X	X	X		X	p	X	X	p	X
Bledius ornatus	p			X								
Cafius canescens	X	p	X	X	X	X	p				p	
Cafius decipiens				p								
Cafius lithocharinus	p	X	p	X	p		p	p		p	p	p
Cafius luteipennis					X		p	p		p		
Cafius seminitens	X		X	W	X		p				p	
Cafius sulcicollis					X		p					
Cafius sp.	X	X	X	X	X	X						X
Hadrotes crassus		p	X									
Pontamalota opaca	X	p	X	p	X	X	p					
Tarphiotia fucicola	p		X		p	p	p	p				
Tarphiotia geniculata	X	p	X	X	X		p	p		p		p
Thinopinus pictus	X	X	X	X	X	p	p				X	
Unid. Staphylinidae				p		X				X		
Cercyon fimbriatus	X	X	X	X	X	p	X	X	p	X	X	X
Akephorus marinus		X	X	X			p				p	
Elassoptes marinus										p		
Emphyastes fucicola	X	X	X	X	X	X	X			X	X	X
Phycocotes testaceus		p										
Sitona sp.	p											
Unid. Curculionidae		p				p						
Euspilotus scissus	p		p		p		p	p			p	
Hypocaccus bigemmeus											p	
Hypocaccus gaudens	p		X	p			X			p	p	X
Neopachylopus aeneipunctatus	X				X		p				p	X
Neopachylopus sulcifrons		p			X	p	p	p		X	p	
Neopachylopus sp.		X			X	X						
Histeridae			p			p		X		p		
Coelus ciliatus	X			X	X	X						
Coelus globosus						X		X				
Coelus sp.			X			X				X		

Table 7. List of macroinvertebrate species collected in surveys of the 12 study beaches continued.

	Gaviota	Arroyo Quemado	Isla Vista	East Campus	Leo Carrillo	Dume Cove	Crystal Cove	San Clemente	Carlsbad	San Elijo	Blacks	Scripps
INSECTA												
COLEOPTERA		p	p									
Phalaria rotunda	p		X	p	p	X	X	X		X	X	X
Epantius obscurus			X	p	p	p				X	p	
Tenebrionidae larva						p				X	p	
Amblyderus sp.				p								
Phyconomous marinus		p	p									
DIPTERA		p	p									p
Dolichopodidae	X											
Empididae	X	X	X	X		p	p	p		X	X	X
Fucellia sp.	**X**	X	X	X	X	X	**Xp**	p	X	X	X	X
Coelopa vanduzeei	X	X	X	X	X	p	p	p	p			p
Thoracochaeta johnsoni												X
FISH												
Leuresthes tenuis (eggs)						p	**p**					
Total Species Observed	36	36	51	59	44	55	48	24	24	42	46	51

Indicator taxa

Biodiversity surveys

Although the two ecologically important taxa we are evaluating as potential indicators of the ecological state of sandy beaches (*Emerita analoga* and talitrid amphipods in the genus *Megalorchestia*) were present on all 12 beaches their abundance and biomass varied substantially among the study beaches (Figures 31, 32) in the biodiversity surveys. The abundance of *E. analoga* varied more than two orders of magnitude among beaches ranging from 675 to 18,067 individuals m^{-1} at Scripps and Dume Cove, respectively (Figure 31). Sand crabs made up an average of 19% of the total invertebrate abundance but this proportion varied more than 25 fold across beaches (2.2% at Carlsbad to 58% at Dume Cove). The biomass of sand crabs varied over an order of magnitude among beaches ranging from 94 to 5825 g m^{-1} at Isla Vista and Dume Cove, respectively (Figure 32). This crab species made up an average of 50% of the total macroinvertebrate biomass across the beaches but that proportion varied more than 8 fold across beaches (11.7% at Blacks to 96% at San Clemente).

Wrack associated taxa, made up a very important component of the abundance of invertebrates on the study beaches in the biodiversity surveys with mean values exceeding 20,000 individuals m^{-1} at five of the 12 study beaches and peak values of 80,780 individuals m^{-1} at Isla Vista and 46,934 individuals m^{-1} at East Campus (Figure 31). A mean abundance of wrack associated invertebrates of < 4500 individuals m^{-1} was observed at only two beaches during the biodiversity surveys (San Clemente and San Elijo). The mean biomass of wrack invertebrates only exceeded 1000 g m^{-1} at two beaches, Isla Vista and East Campus, in the biodiversity surveys (Figure 32).

Talitrid amphipods, *Megalorchestia* spp., dominated the abundance of all wrack-associated macroinvertebrates, including Coeloptera, Diptera and other insects both numerically and by weight in the biodiversity surveys. Talitrids made up between 27 and 99 % (average [SD] = 69 [28] %) of the numerical abundance and between 78 and 99 % of the biomass (average [SD] = 71 [33] %) of all wrack-associated macroinvertebrates in the biodiversity surveys.

The abundance of talitrid amphipods, *Megalorchestia* spp., varied more than an order of magnitude across the study beaches ranging from 1019 to 62,294 individuals m^{-1} at Blacks and Isla Vista, respectively, in the biodiversity surveys. The abundance of talitrid amphipods exceeded 10,000 individuals m^{-1} at seven of the 12 study beaches. Talitrid amphipods made up an average of 35% of the total invertebrate abundance but this proportion varied more than 64 fold across beaches (1% at Blacks to 64% at San Elijo). The biomass of talitrids also varied over an order of magnitude among beaches ranging from 6 to 1239 g m^{-1} at Blacks and Isla Vista, respectively. This species made up an average of only 12% of the total macroinvertebrate biomass across the beaches but that proportion varied more than 8 fold across beaches (0.2% at Blacks to 60% at Isla Vista).

There were no consistent or statistically significant differences in the abundance of *Emerita analoga* (ANOVA $p = 0.968$) or of talitrid amphipods (ANOVA $p = 0.691$) between MPA and reference beaches in the biodiversity surveys (Figure 33).

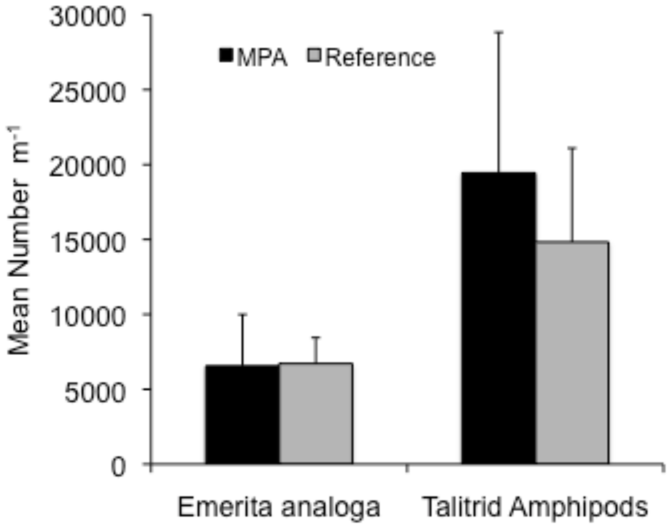

Figure 33. Mean abundance (+ std. errors) of *Emerita analoga* and talitrid amphipods observed on beaches inside MPAs and on reference beaches in the Fall 2011 biodiversity surveys.

Targeted sampling of potential indicator species

The four surveys of potential macroinvertebrate indicator taxa conducted in Spring (May/June) and Fall (September/October) of 2012 and 2013 yielded estimates of abundance and biomass of these taxa at the 12 study beaches in two seasons. These surveys focused on two major macroinvertebrate indicator taxa, which are important food sources for higher trophic levels: swash zone fauna focusing on *Emerita analoga* and wrack-associated fauna focusing on *Megalorchestia* spp. We also surveyed aerial invertebrates focusing on dipterans of several species.

Overall spatial patterns in the abundance and biomass of the two macroinvertebrate indicator taxa in fall surveys were generally similar to those observed in biodiversity samples of Fall 2011. However, large differences between spring and fall abundance of the indicator taxa were evident in our surveys at many of the study beaches. This was particularly evident for sand crabs, *Emerita analoga*, where populations swelled by many orders of magnitude at some sites, driven by strong spring recruitment then declined to much lower levels by the Fall surveys.

The average abundance of *Emerita analoga* varied over an order of magnitude among the study beaches, ranging from 4074 to 115,365 individuals m^{-1} in the Spring surveys and 484 to 26,021 individuals m^{-1} in the Fall surveys (Figure 34). The highest fall abundance values for sand crabs were observed on beaches with relatively steep slopes and harsh swash climates. This reflects the ability of highly mobile sand crabs to survive and grow in a wider range of intertidal swash regimes and sand types than other suspension feeders, such as clams (Dugan et al. 2000). The Gaviota, Leo Carrillo and Dume Cove beaches stood out in terms of the abundance and biomass of *E. analoga* in Fall surveys (Figures 31, 32). However, peak numbers of sand crabs were observed and average abundance was generally higher in Spring than in Fall reflecting the strong influence of the spring recruitment period on population abundance. The abundance of *E. analoga* in the September surveys was not correlated with that of the preceding June surveys, suggesting survival varies and that predation may operate strongly on these populations at some beaches, sharply reducing young of the year abundance. Very high abundances of *E. analoga* (>100,000 individuals m^{-1}), composed primarily of recently recruited young of the year, were observed in Spring surveys on several beaches, specifically Gaviota (2012 & 2013), Leo Carrillo (2013), Blacks and Scripps (both 2012) in the baseline study. Abundances exceeding 30,000 crabs m^{-1}, primarily young of the year, were also observed in Spring 2012 at Arroyo Quemado and Dume Cove and in Spring 2013 at Arroyo Quemado, East Campus, Dume Cove, Blacks and Scripps.

The mean biomass of *E. analoga* measured in the indicator taxa surveys varied >3 orders of magnitude among the beaches ranging from 0.42 g m-1 to 17,553 g m^{-1} in Spring and 48.8 to 6804 g m^{-1} in Fall (Figure 35). Mean biomass was lower in Fall

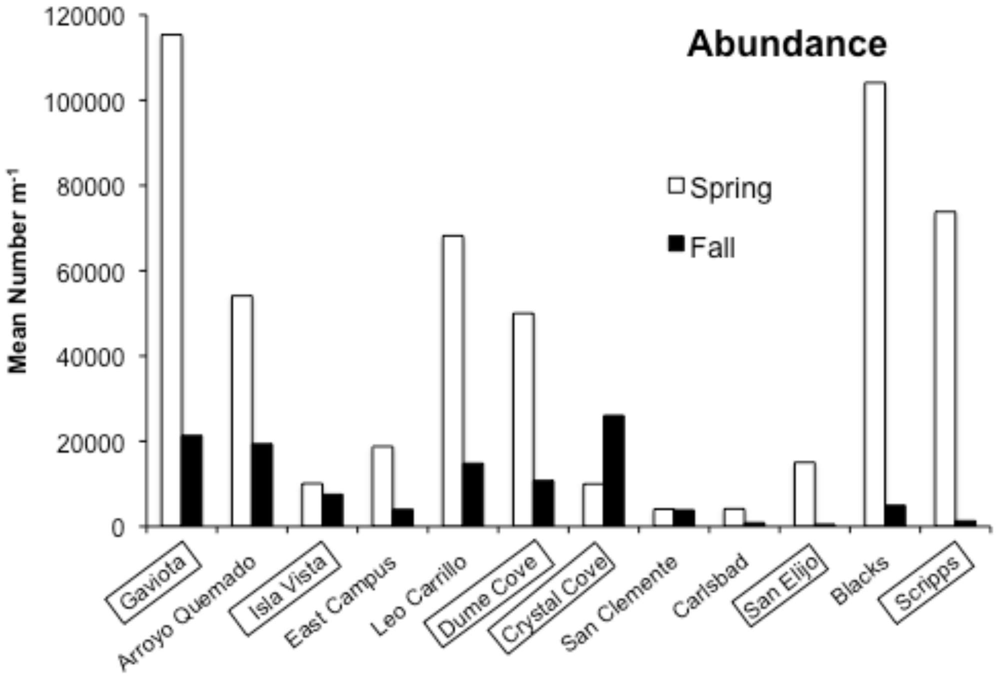

Figure 34. Mean values of abundance of *Emerita analoga* for Spring and Fall surveys of the 12 study beaches (2 surveys per season). Names of sites in MPAs are in boxes.

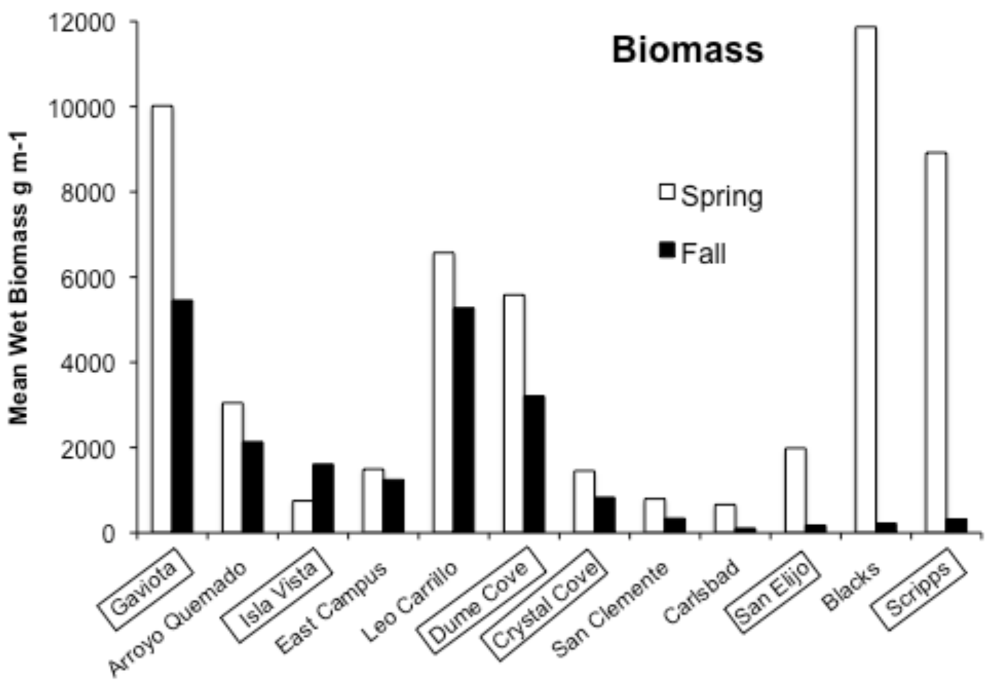

Figure 35. Mean values of wet biomass of *Emerita analoga* for Spring and Fall surveys of the 12 study beaches (2 surveys per season). Names of sites in MPAs are in boxes.

surveys than in Spring surveys at 10 of the 12 beaches, matching the abundance pattern (Figure 35). The biomass of *E. analoga* in the Fall 2013 survey was significantly correlated with that of the preceding Spring survey in 2013 but this was not the case in 2012. Very high mean biomass values for *E. analoga* (>10,000 g m^{-1}) were observed in spring surveys at Blacks and Scripps Beach in 2012 and at Gaviota in 2013. Mean biomass values exceeded 5,000 g m^{-1} at Gaviota and Leo Carrillo in Spring and Fall of 2012, and at Blacks in Spring 2013.

There were no consistent or statistically significant differences in the abundance or biomass of *Emerita analoga* between MPA and reference beaches in the Spring (ANOVA p = 0.888 and 0.776 respectively or the Fall indicator taxa surveys (ANOVA p p= 0.546 and p = 0.751, respectively) (Figure 36).

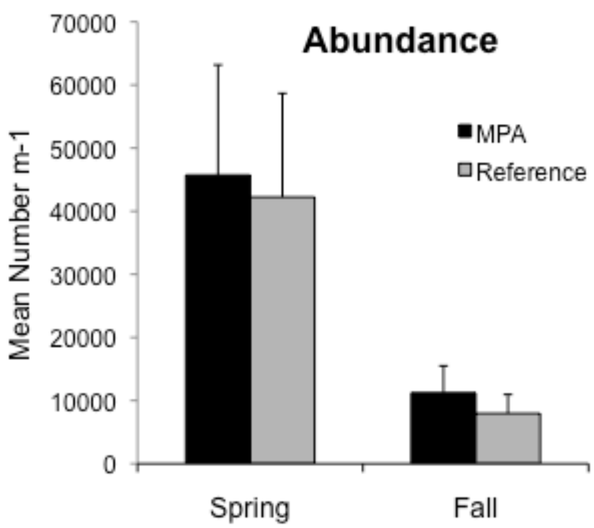

Figure 36. Mean abundance (+ std. errors) of *Emerita analoga* observed on beaches inside MPAs and on reference beaches in Spring and Fall surveys.

For the indicator taxa surveys, overall mean abundance of talitrid amphipods varied by >2 orders of magnitude among study beaches in 2012 and 2013 (Figure 37). As in the biodiversity surveys, talitrids reached highest abundance on beaches with high wrack abundance, particularly Isla Vista and East Campus. Average mean abundance for the two years ranged from 134 to 40,125 individuals m^{-1} in Spring surveys and 2224 to 61,707 individuals m^{-1} in Fall surveys (Figure 37). Strong seasonal variation in abundance was evident at several sites but no consistent pattern in overall mean abundance of this taxon was apparent between Spring and Fall surveys, suggesting populations are responding to site specific factors. However, mean values of abundance of *Megalorchestia* spp. were positively and significantly correlated in Spring and Fall surveys each year.

The overall mean biomass of *Meglaorchestia* spp. in the indicator taxa surveys varied by >2 orders of magnitude among beaches, ranging from 4 to 811 g m^{-1} in Spring and 3 to 1246 g m^{-1} in Fall surveys (Figure 38). No consistent pattern in overall mean biomass was evident between Spring and Fall surveys, again suggesting the influence of site specific factors. However, as seen for abundance, mean biomass of *Megalorchestia* spp. was significantly correlated across Spring and Fall surveys each year.

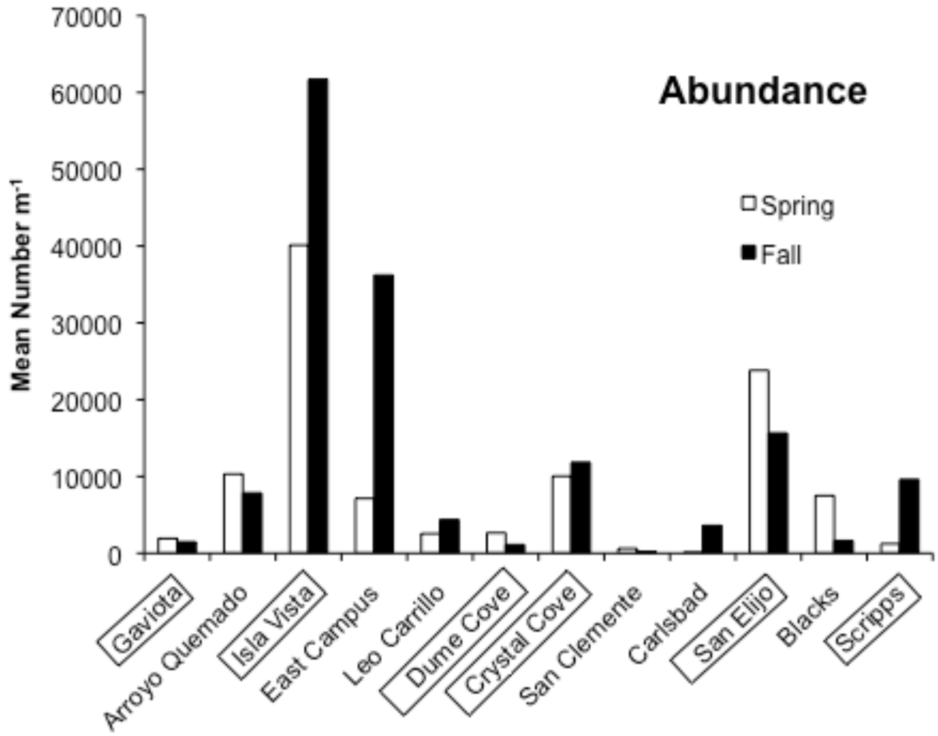

Figure 37. Mean values of abundance of *Megalorchestia* for Spring and Fall surveys of the 12 study beaches (2 surveys per season). Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

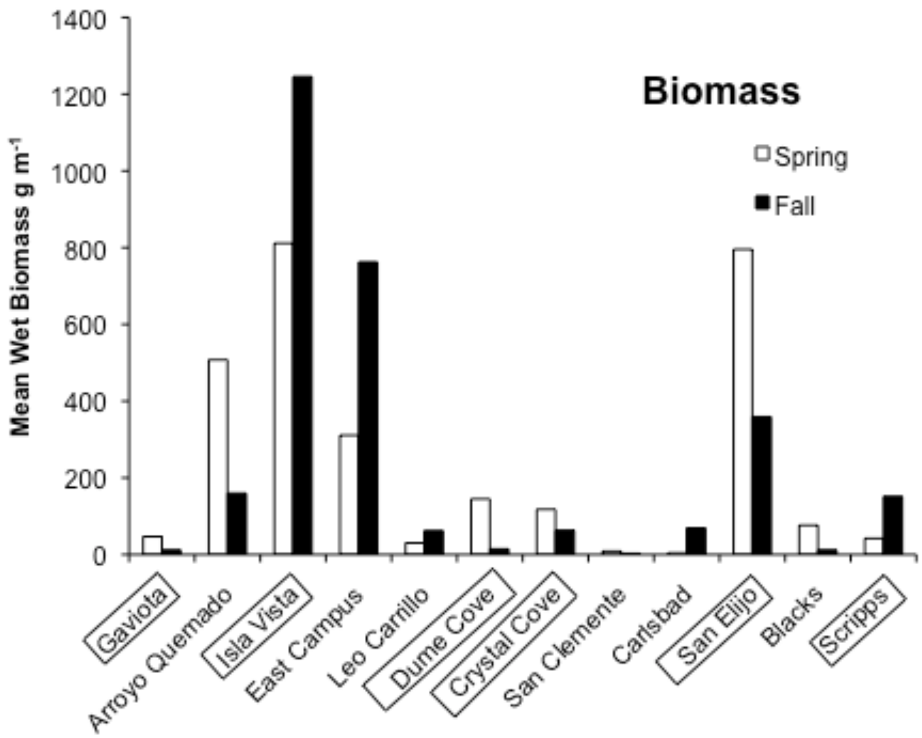

Figure 38. Mean values of wet biomass of *Megalorchestia* for Spring and Fall surveys of the 12 study beaches (2 surveys per season). Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

There were no consistent or statistically significant differences in the abundance or biomass of talitrid amphipods between MPA and reference beaches in the Spring (ANOVA $p = 0.224$ and 0.351 respectively or the Fall indicator taxa surveys (ANOVA p $p = 0.481$ and $p = 0.583$, respectively) (Figure 39).

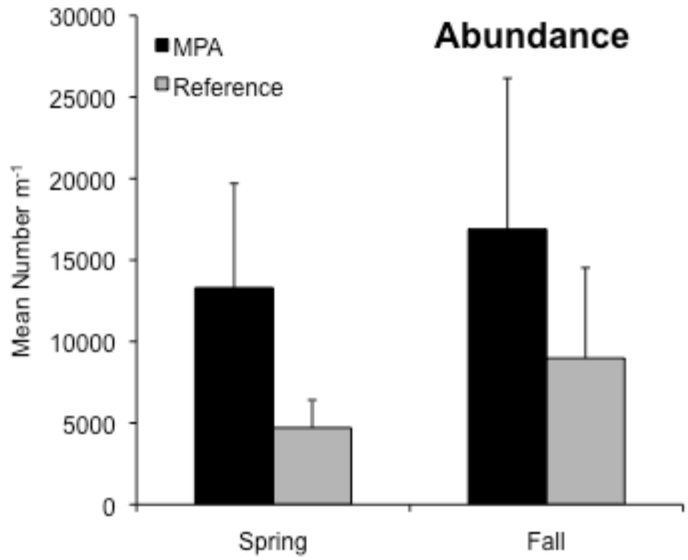

Figure 39 Mean abundance (+ std. errors) of talitrid amphipods observed on beaches inside MPAs and on reference beaches in Spring and Fall indicator surveys.

Aerial invertebrates

The catch of aerial invertebrates on sticky traps varied >2 orders of magnitude among the study beaches, ranging from 4 to 878 flies trap^{-1} (Figure 40). Along with the larger species of *Fucellia* and *Coelopa*, several smaller species of flies were collected on these traps including species of Dolichopodidae, Empididae and Sphaeroceridae. Identification of the smaller species of flies on sticky traps was limited by the adhesive used in the collection technique. Talitrid amphipods and Coleoptera (primarily Staphylinidae) were also collected on the sticky traps.

In general, there were strong regional patterns in the abundance of flies on the study beaches and no consistent patterns with MPA status (Figures 40, 41). High overall abundance of flies (>500 flies trap^{-1}) occurred at Gaviota, Isla Vista and East Campus beaches. Fly abundance was very low (<35 flies trap^{-1}) at Dume Cove, Crystal Cove and San Clemente. These spatial patterns generally followed those observed for fly larvae and pupae in the biodiversity core samples with peak mean abundance exceeding 10,000 flies m^{-1} at Gaviota and Isla Vista (Figures 40, 41). Kelp fly larvae feed on kelp and require an ~ 2 week development time, which is linked spring/neap tide cycles, in moist aging deposits of kelp wrack on the beach. Where kelp wrack is scarce, dries too quickly or is consumed rapidly by other consumers, such as talitrid amphipods, kelp fly populations can be depressed. Competition for wrack resources among consumers is likely important in affecting community structure only on beaches and at times when kelp wrack inputs are limited. At beaches, such as Isla Vista, where kelp wrack is plentiful, both flies and talitrid amphipods can attain high population abundance.

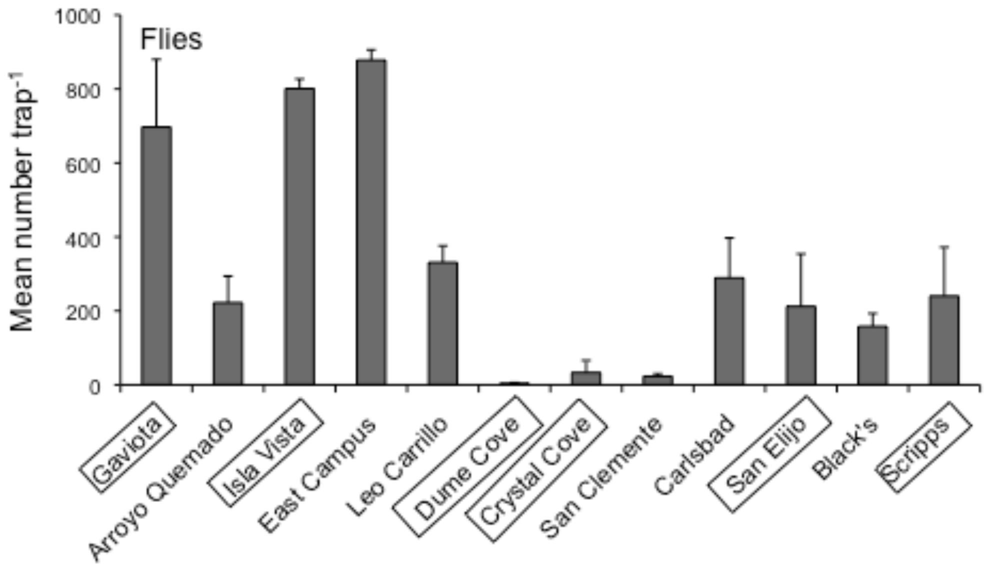

Figure 40. Average numbers (+ 1 std error) of flies caught on sticky traps in biodiversity surveys of the study beaches in Fall 2011. Names of sites located in MPAs are in boxes.

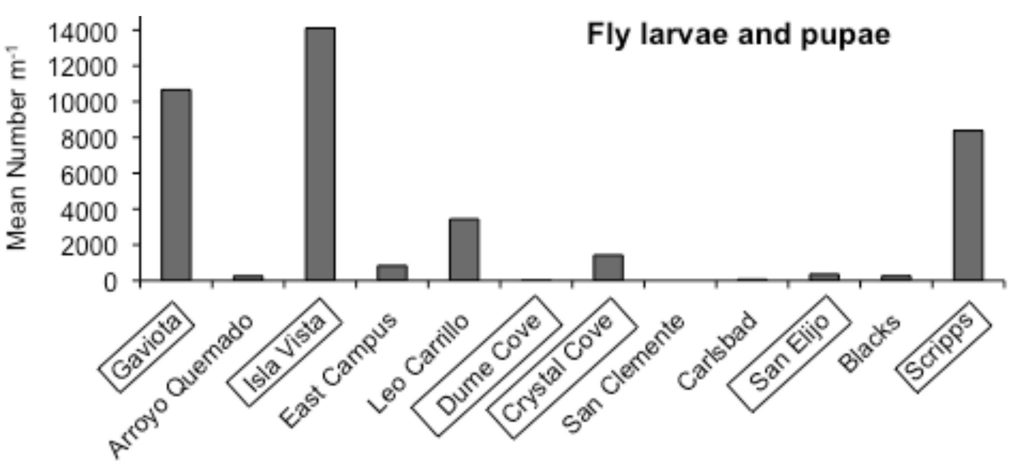

Figure 41. Mean abundance of fly larvae and pupae in biodiversity surveys of the study beaches in Fall 2011. Names of sites located in MPAs are in boxes.

Clams

Two free-living bivalve species, the Pismo clam, *Tivela stultorum*, and the bean clam, *Donax gouldii*, occurred in our biodiversity surveys from three and four of the study beaches, respectively (Table 7). *Tivela stultorum* and *D. gouldii* co-occurred in samples from two of the study beaches. When present, *D. gouldii* occurred in high abundance at some sites 3,769 - 42,017 clams m^{-1} in the biodiversity surveys with highest abundance at Blacks (Figure 42). Estimated abundances in the biodiversity surveys were relatively low for *T. stultorum*, ranging from 38 - 59 clams m^{-1} (Figure 42). In the four subsequent indicator species surveys, *T. stultorum* and *D. gouldii* were found at one additional site each in Santa Barbara County in low abundance, 13 and 102 clams m^{-1}, respectively. Overall, values of average abundance of *D. gouldii* in the biodiversity and indicator surveys ranged from 20 to 12,037 clams m^{-1} at East Campus and Scripps, respectively (Figure 42). For *T. stultorum*, values of average abundance in the biodiversity and indicator surveys ranged from 3 to 107 clams m^{-1} at Isla Vista and Scripps, respectively (Figure 42).

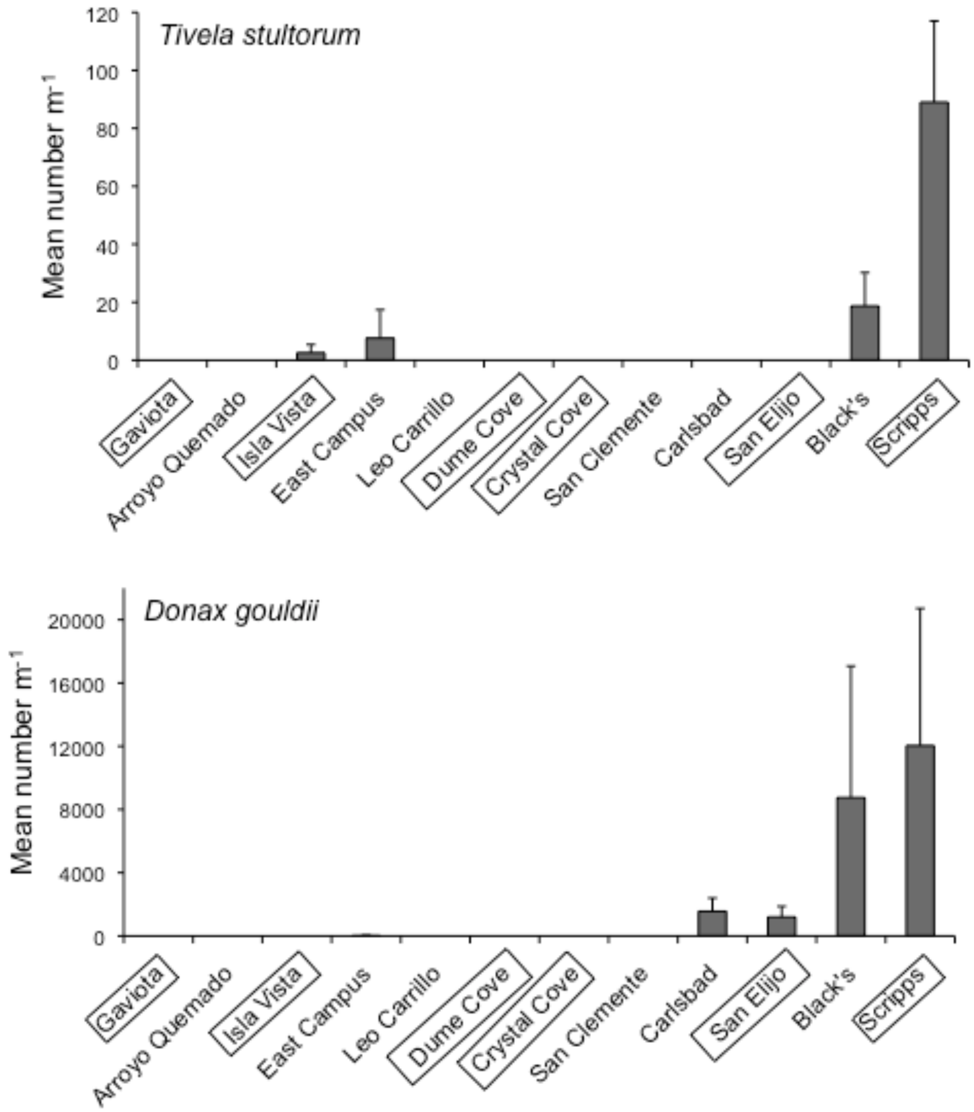

Figure 42. Average abundance (+ 1 std error) of clams in biodiversity and indicator surveys of the 12 study beaches during the two years of the baseline study. Beaches are listed from north to south. Names of sites located in MPAs are in boxes.

Results of winter surveys of Pismo clams using the Dept of Fish and Wildlife protocols at paired MPA and reference beaches yielded similar values of abundance for *T. stultorum* to those in our biodiversity and indicator surveys (Figure 43) The abundance of clams of legal harvest size was very low with no clams of legal size found in the two MPAs and a mean values of 3.3 and 1.3 legal size clams m^{-1} at the two reference beaches in 2012 and 2013. No consistent pattern in overall abundance of Pismo clams between MPA and reference beaches was apparent (Figure 43) but clam abundance was significantly greater on the reference beaches in the Winter 2012 surveys.

Pismo clams are a classic example of the impacts of fishing on long-lived large intertidal species around the world (McLachlan et al. 1996) Commercial fishing of Pismo clams ceased in 1948 in the face of declining landings. Recreational fishing continues to the present. Despite rolling closures, transplants, and changes in regulations on size and bag limits, populations of this highly desirable clam have not recovered to harvestable levels in many areas.

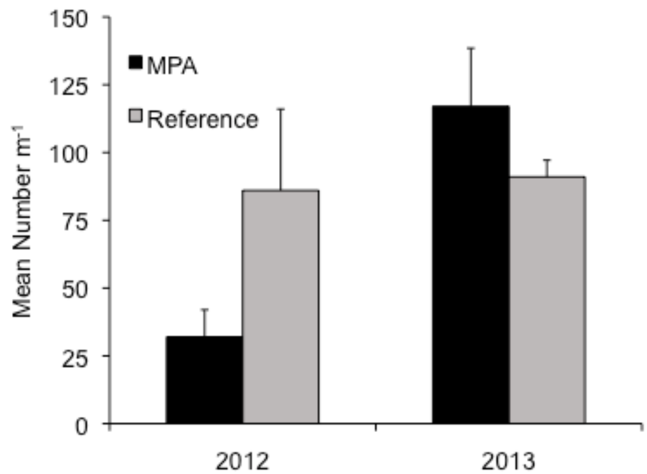

Figure 43. Values of mean abundance (+ std. errors) for *Tivela stultorum* on beaches located inside MPAs and on reference beaches in Winter surveys conducted in 2012 (four sites) and 2013 (two sites).

Hypothesis testing

Beaches are closely linked with other coastal ecosystems, such as kelp forests and reefs and the nearshore ocean (Figure 44). Press and pulse environmental drivers and human activities can strongly influence this critical connectivity and the structure and function of beach ecosystems (McLachlan & Brown 2006, Revell et al. 2011, Dugan et al 2003). Our study design allowed us to examine a number of hypotheses concerning functional relationships and linkages that may respond directly or indirectly to MPA implementation on the South Coast region (Figure 44).

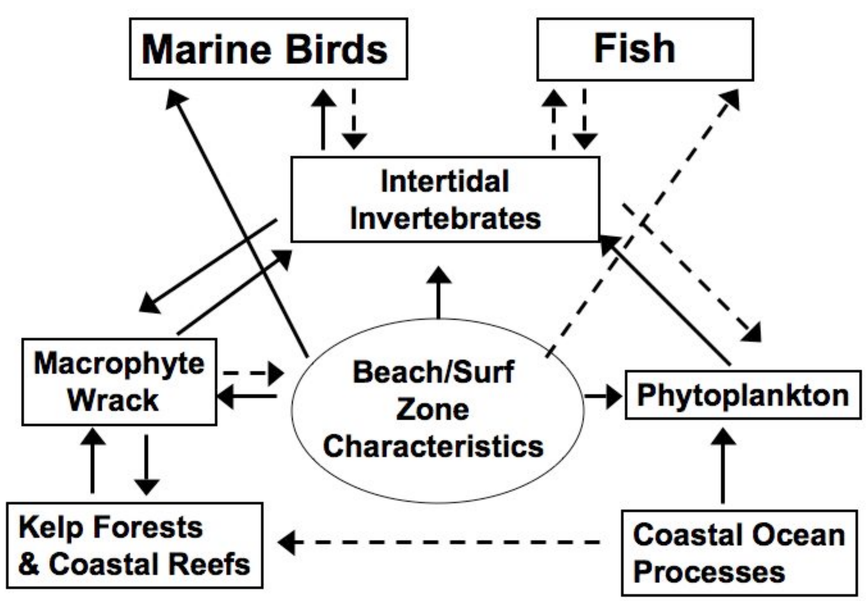

Figure 44. Hypothesized functional relationships among shorebirds, fish, macroinvertebrates, macrophyte wrack, beach characteristics and associated ecosystems for open coast sandy beach ecosystems. Solid arrows indicate relationships supported by results to date in California. Dashed arrows refer to relationships still in need of investigation.

We used the results from our baseline surveys of exposed sandy beaches in the SC region including data from 2 years of monthly shorebird, wrack and physical characteristics surveys, biodiversity surveys of macroinvertebrates and twice a year surveys of indicator taxa to examine possible relationships between shorebirds, invertebrates, macrophyte wrack, and the physical attributes of sandy beaches. We examined several hypotheses, including:

1. The structure of intertidal macroinvertebrate communities including species richness, abundance, and biomass on sandy beaches are related to:

- physical characteristics, such as beach morphodyanamics, beach width, swash climate, sediment characteristics,
- factors related to connectivity such as the abundance of subsidies of macrophyte wrack from reefs and kelp forests

2. The distribution, abundance and species richness of shorebirds on sandy beaches are related to:

- physical characteristics, such as beach morphodyanamics, beach width, swash climate, sediment characteristics,
- factors related to connectivity such as the abundance of subsidies of macrophtye wrack
- human use of beaches

3. The distribution, abundance and species richness of shorebirds on sandy beaches are related to:

- the overall structure of intertidal macroinvertebrate communities including diversity, abundance, biomass and mean individual size
- the abundance and biomass of individual taxa of intertidal invertebrates

Hypothesis group 1: Relationships between intertidal invertebrates and beach characteristics, including macrophyte wrack abundance.

<u>Macroinvertebrate communities and beach characteristics</u>
Beach characteristics provided some predictions of overall macroinvertebrate community structure. However, beach morphodynamics as estimated by Dean's parameter and other attributes such as swash climate, were not correlated with intertidal community structure (species richness, abundance or biomass) at our study beaches in the SC region.

Sand grain size was the most important physical factor we identified for intertidal community structure on the study beaches. Sand grain size can be affected by sediment sources, erosion/accretion dynamics and human activities, such as dredge spoil disposal and beach filling. The species richness of the macroinvertebrate community was negatively correlated with sand grain size at the WTO ($r = 0.775$, $p <$

0.005) (Figure 45), illustrating the strong influence that grain size can exert on the diversity of burrowing animals, with a greater number of species able to inhabit beaches with fine sand compared to those with coarse sand. Species richness was also negatively correlated with beach slope at the HTS ($r = 0.677$, $p < 0.02$). Beach slopes are generally correlated with grain size (Bascom 1980) with coarser sand able to repose at steeper angles than fine sand. This suggests that beaches with flatter upper shore slopes, and by extension finer sand, can support greater biodiversity. Species richness trended positively with overall beach width, active intertidal width and the width of the saturated sand zone but these correlations were not significant ($r =0.506$, $p >0.05$), ($r =0.518$, $p > 0.05$) and ($r = 0.569$, $p> 0.05$), respectively. Species richness was positively correlated with the location of the high swash line ($r= 0.596$, $p < 0.05$) suggesting an influence of beach width on species diversity.

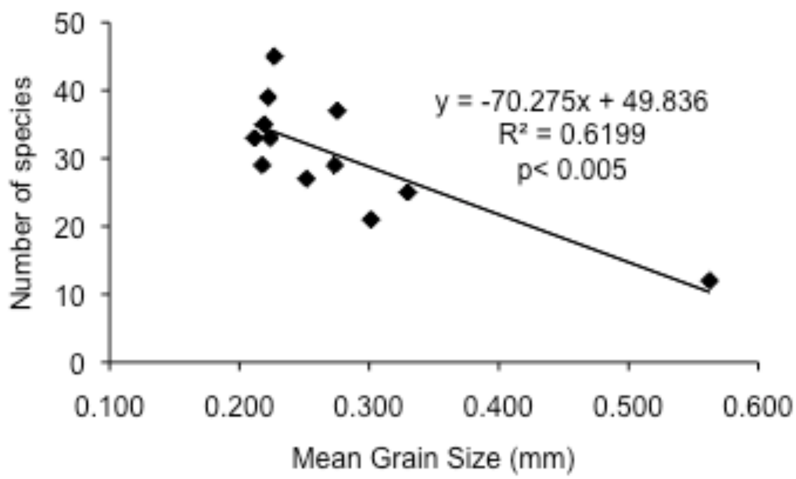

Figure 45. Relationship between species richness of intertidal invertebrates and mean grain size at the WTO for the study beaches.

The abundance (log-transformed) of the intertidal macroinvertebrate community was also negatively and significantly correlated with mean grain size at the WTO ($r =0.738$, $p < 0.02$). This result again illustrates the strong influence of grain size on burrowing invertebrates and its role as a key physical variable in beach ecosystems. This result means that fine sand beaches support higher abundance of macroinvertebrates than coarse sand beaches. Log-transformed abundance was negatively correlated with the mean beach slope at the HTS ($r = 0.643$, $p <0.05$) for the study beaches.

The mean biomass ($g\ m^{-1}$) and log mean biomass of the macroinvertebrate community were not correlated with Dean's parameter or any of the zone widths. The mean biomass and log mean biomass were also not correlated with grain size at the WTO or the beach slope at the HTS.

Overall our results for macroinvertebrate community structure and Dean's parameter are not consistent with patterns reported by McLachlan (1990) and McLachlan et al. (1993, 1996), for beaches in other parts of the world where richness, abundance and biomass were positively correlated with beach morphodynamic state as estimated by Dean's parameter. Our results for the baseline study are consistent with our earlier results for the northern bioregion of the SC region (Dugan et al. 2000, 2003) and support the ideas that 1) important taxa characteristic of the region, such as sand crabs *E. analoga*, (Dugan and Hubbard 1996 Dugan et al. 2000) do not respond strongly to morphodynamics and 2) that connectivity, in the form of subsidies, such as macrophyte wrack, with nearshore ecosystems, can strongly influence community structure on sandy beaches (Dugan et al. 2003).

<u>Macroinvertebrates and macrophyte wrack</u>

Macrophyte wrack exerted a strong influence on macroinvertebrate communities of the study beaches in the south coast region. Overall species richness of the macroinvertebrate community was positively and significantly correlated with the mean standing crop of marine (Figure 46) and of brown macroalgal wrack ($r = 0.646$, $p < 0.05$) and with the number of stranded kelp plants ($r = 0.629$, $p <0.05$). These results are in full agreement with our earlier results for beaches in Ventura and Santa Barbara and San Luis Obispo counties (Dugan et al. 2003, Dugan et al. 2000, 2004, Dugan 1999) and baseline results from the North Central Coast region (Nielsen et al. 2013). This strong and consistent result appears to be related to the presence of a number of species of insects and crustaceans that are functionally associated with stranded drift algae and macrophytes. The importance of these endemic insects to intertidal biodiversity is an important result of this study. The South Coast region may represent a biodiversity hotspot for these poorly studied and highly vulnerable animals. Wrack-associated beetles were a diverse group with more than 34 species recorded in our samples in the South Coast region (Table 7). These included a carabid, *Dyschirius marinus*, two tenebrionids, *Phalaria rotundata* and *Epiantius obscurus*, a hydrophilid, *Cercyon luniger*, five species of curculionids e.g. *Emphyastes fucicola, Phycocetes testaceus*, five species of histeriids and seven genera and 14 species of staphylinids, including *Thinopinus pictus*, *Hadrotes crassus*, *Aleochara* spp. *Bledius* spp., *Cafius* spp., *Pontomalota* spp. and *Tarphiota* spp. Larvae and pupae of two species of kelp wrack-dependent flies, *Fucellia costata*, and *Coelopa vanduezei* occurred in association with macrophyte wrack at all and ten of the study beaches, respectively. Small flies in the family Empididae were also widespread, occurring at ten of the study beaches. Five species of wrack-consuming talitrid amphipods, *Megalorchestia* spp. were often abundant on study beaches with accumulated macrophyte wrack. Two species of

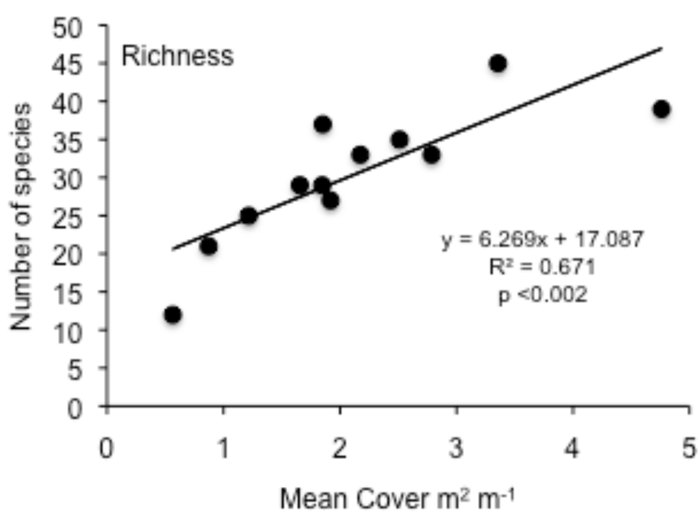

Figure 46 Relationship between species richness of macroinvertebrates and mean abundance (cover) of marine wrack on the study beaches.

wrack-feeding isopods, *Alloniscus perconvexus* and *Tylos punctata*, were found at nine and six of the study beaches, respectively, at times in high abundance. Populations of these direct developing upper beach dwelling isopods have declined significantly in the south coast region over the last 50 years with only a few extant populations in some major littoral SC cells (Hubbard et al. 2013). All of these wrack-associated species are potential prey for invertebrate predators and for birds at all tidal stages.

The overall abundance of macroinvertebrates was positively and significantly correlated with the standing crop of marine (Figure 47) ($r = 0.909$, $p < 0.001$) and of brown macroalgal wrack ($r = 0.673$, $p < 0.02$) and the abundance of stranded kelp plants ($r = 0.675$, $p < 0.02$). However the overall biomass (g m^{-1}) of macroinvertebrates was not correlated with our measures of wrack abundance. The latter is not surprising given the small average individual size of wrack-associated macroinvertebrates, such as insects and talitrid amphipods.

The standing crop of macrophyte wrack was an excellent predictor of the abundance of wrack-associated taxa and of talitrid amphipods on the study beaches. The mean abundance of *Megalorchestia* spp. was significantly and positively correlated with the mean cover of marine macrophyte wrack on the study beaches in the 2011 biodiversity surveys ($r = 0.732$, $p < 0.01$) and with the abundance of fresh kelp plants ($r = 0.730$, $p < 0.01$). The abundance of talitrid amphipods in the fall surveys was also significantly correlated with mean wrack abundance ($r = 0.730$, $p < 0.01$) and number of kelp plants ($r = 0.831$, $p < 0.001$) (Figure 48). For the spring surveys talitrid abundance was significantly correlated with the number of kelp plants ($r = 0.730$, $p < 0.01$) but not with mean wrack cover. The mean abundance of flies (larvae and pupae) was significantly correlated with the mean cover of marine macrophyte wrack on the study beaches in the 2011 biodiversity surveys ($r = 0.735$, $p < 0.01$).

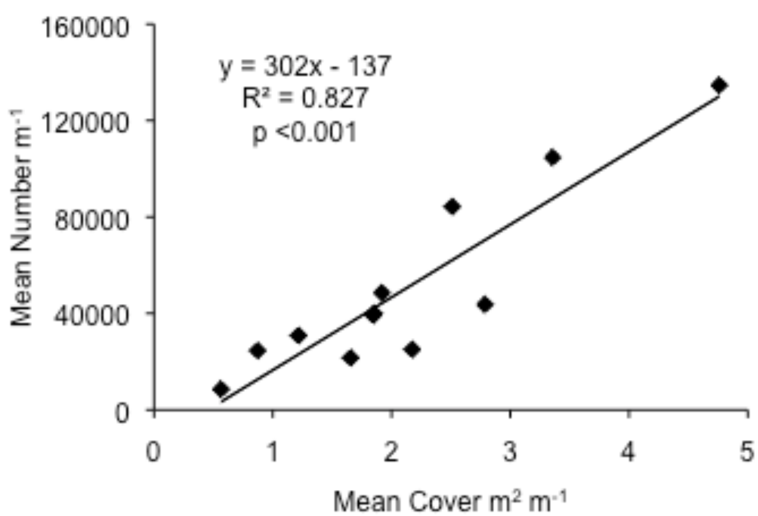

Figure 47. Relationship between the mean abundance of macroinvertebrates and the mean abundance (cover) of marine macrophyte wrack on the study beaches.

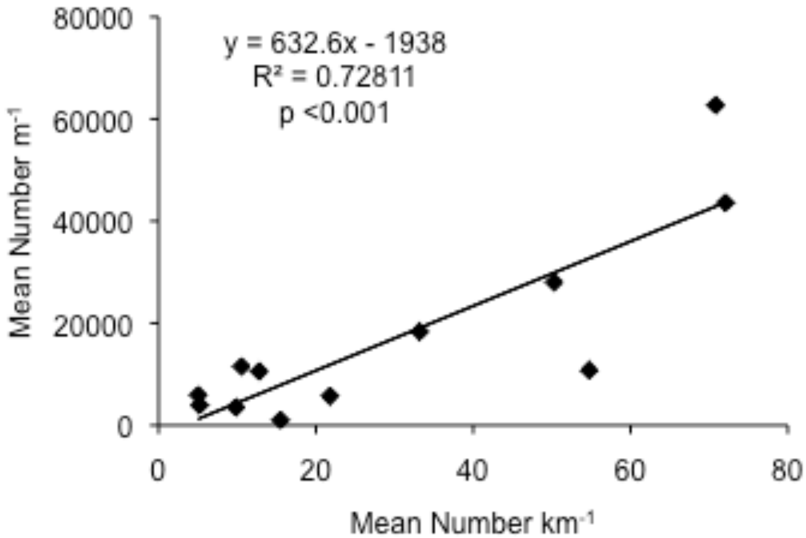

Figure 48 Relationship between the mean abundance of talitrid amphipods and the mean abundance of kelp plants on the study beaches**.**

<u>Hypothesis group 2:</u> *The distribution, abundance and species richness of shorebirds on a beach are related to physical factors, such as beach morphodynamics, beach width, swash climate, sediment characteristics, and other factors such as macrophtye wrack cover.*

<u>Shorebirds and beach characteristics</u>
The species richness and abundance of shorebirds was not correlated with any physical measures of the study beaches, including zone widths, slopes, grain size, swash regime or Dean's parameter.

<u>Shorebirds and wrack</u>
The species richness and abundance of shorebirds were highly correlated with the abundance of macrophyte wrack including wrack cover and drift kelp plants (Figures 49, 50). This result indicates that higher trophic levels represented by shorebirds respond strongly to connectivity to kelp forests and reefs, which drives the influence of bottom up subsidies on the diversity and abundance of intertidal prey resources on beaches in the South Coast region. This result agrees strongly with earlier results for California beaches (Dugan et al. 2003, 2004).

<u>Shorebirds and human use</u>
Humans and dogs can disturb shorebirds on beaches (McCrary and Pierson 2000) and in other coastal settings. However, despite heavy human use of the study beaches, we found no relationships or trends between the species richness and abundance of shorebirds with any component of human or dog use of the study beaches. This result suggests that visitor use was not strongly affecting the distribution and abundance of shorebirds on the study beaches. The one kilometer length of shoreline transects used in our baseline study design appeared to provide sufficient space for people, dogs and birds to co-occur on the study beaches. A transect of shorter length would likely yield different results with respect to dogs and humans (See Nielsen et al. 2013 for pocket beaches). The fact that human visitors tend to concentrate near the access points on many beaches often leave many 100's of meters of beach open to birds.

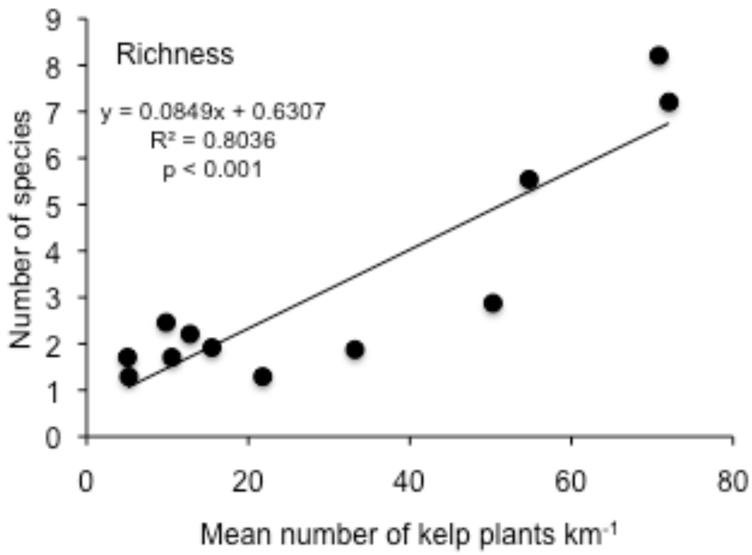

Figure 49. Relationship between the mean species richness of shorebirds and the number of drift kelp plants on the study beaches.

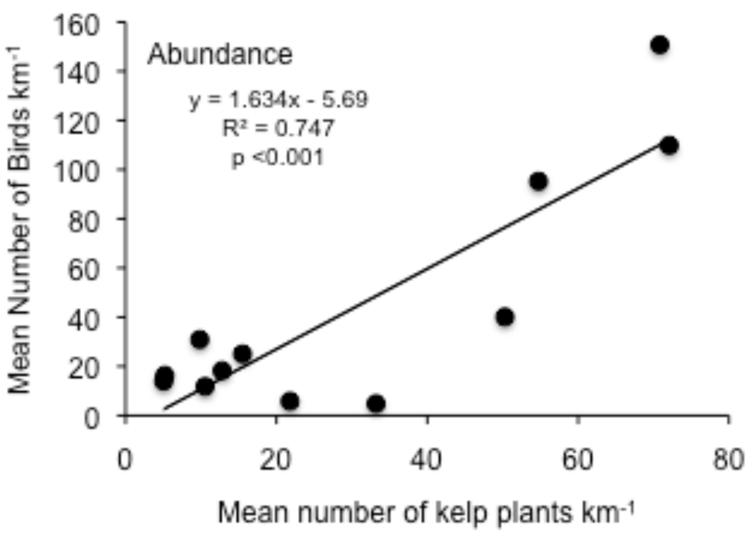

Figure 50. Relationship between mean abundance of shorebirds and the abundance of drift kelp plants on the study beaches.

<u>Hypothesis group 3</u>: Relationships between shorebirds and macroinvertebrate prey on the study beaches.

Shorebirds and <u>macroinvertebrate communities</u>
We found important significant relationships between the distribution and abundance of shorebirds and the structure and characteristics of the intertidal macroinvertebrate community on the study beaches in the SC region. Overall, the mean species richness of shorebirds was significantly and positively correlated with species richness of the macroinvertebrate community at the study beaches ($r = 0.671, p < 0.02$) (Figure 51). The species richness of shorebirds on the study beaches was also significantly correlated with the abundance of the macroinvertebrate community (individuals m^{-1}) ($r = 0.633$, $p < 0.05$) but not with biomass (g m^{-1}), or mean individual size (g) of the overall macroinvertebrate community.

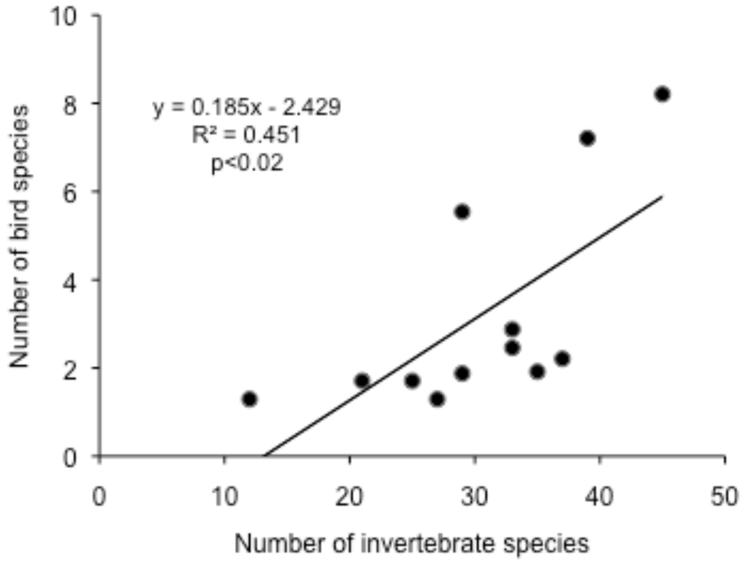

Figure 51 Mean species richness of shorebirds as a function of the species richness of macroinvertebrate prey for the study beaches**.**

The mean abundance of shorebirds on the study beaches was also significantly correlated with some overall measures of the macroinvertebrate prey community, including species richness ($p < 0.05$) and abundance ($p < 0.05$) (Figure 52) as estimated in our biodiversity surveys but not with the mean biomass of invertebrates. However, we found negative non-significant relationships between the mean overall abundance of shorebirds and the mean individual body size (g) of macroinvertebrates suggesting the potential importance of smaller prey, such as wrack-associated invertebrates to foraging shorebirds in the South Coast study region.

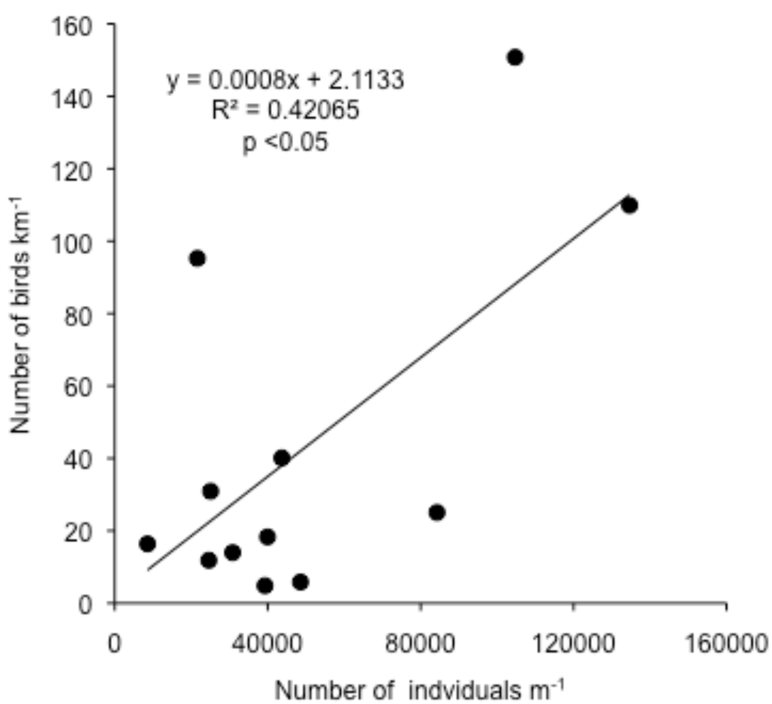

Figure 52 Mean abundance of shorebirds as a function of the mean abundance of macroinvertebrates for the study beaches

<u>Shorebirds and selected taxa of macroinvertebrates</u>
Relationships between the species richness and abundance of shorebirds and the abundance, biomass, and mean size of selected prey species/taxa, particularly the indicator taxa, *Emerita analoga* and *Megalorchestia* spp. were not consistent. Interestingly, shorebird abundance was not correlated with the abundance or biomass of sand crabs, *Emerita analoga*. We found significant positive relationships between the overall mean species richness (Figure 53) and abundance of shorebirds at the study beaches and the mean abundance and biomass of *Megalorchestia* spp. (Figures 54, 55) highlighting the strong links between these higher trophic levels and the macrophyte wrack-subsidized component of the intertidal macroinvertebrate community on the SC study beaches.

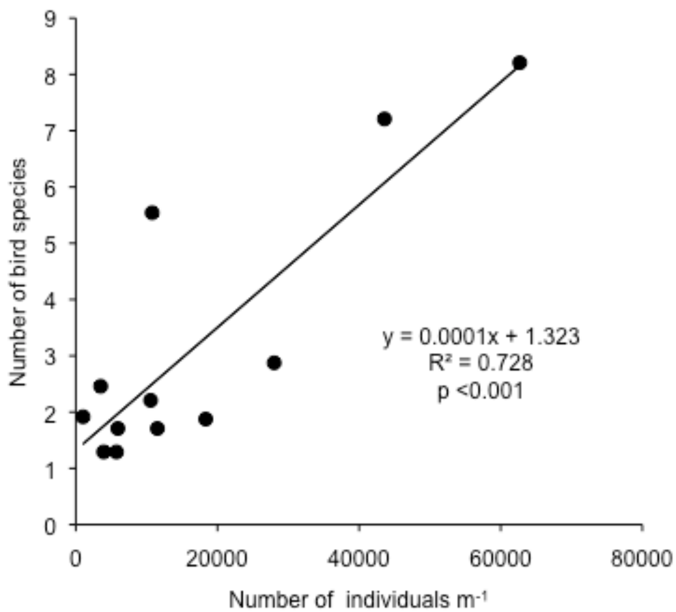

Figure 53 Relationship between the species richness of shorebirds and the mean abundance of talitrid amphipods on the study beaches.

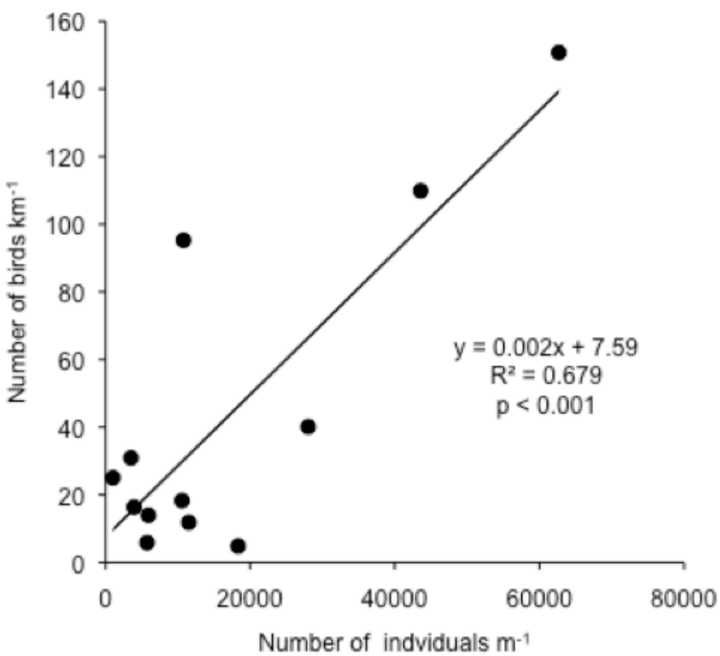

Figure 54 Relationship between the mean abundance of shorebirds and the mean abundance of talitrid amphipods on the study beaches.

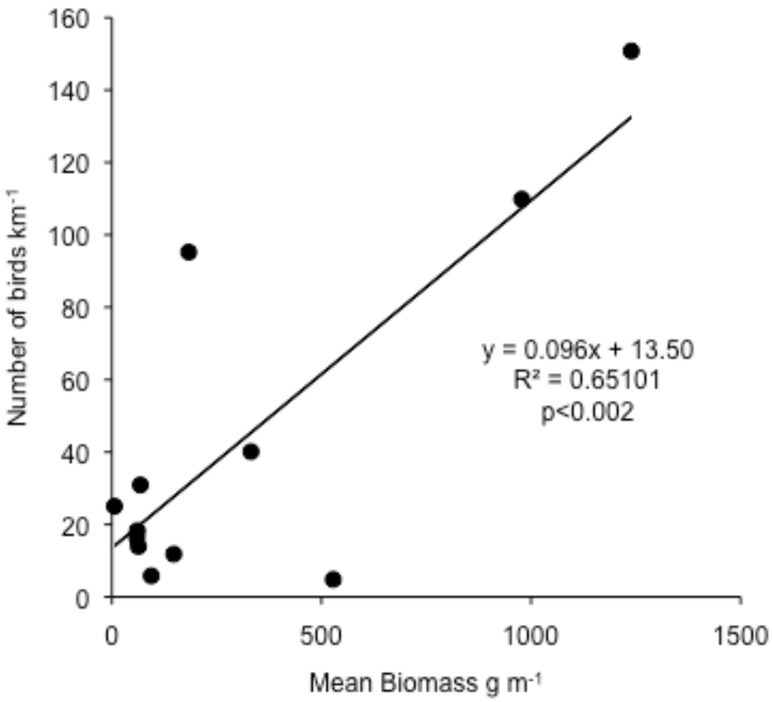

Figure 55 Relationship between the mean abundance of shorebirds and the mean biomass of talitrid amphipods on the study beaches.

These univariate analyses of results from our baseline study found compelling evidence supporting hypotheses concerning connectivity with other coastal ecosystems through wrack subsidies and functional relationships affecting sandy beach ecosystems and food webs (Dugan et al. 2003, 2008) (Figures 2, 44). Macroinvertebrate communities on beaches responded to factors associated with beach condition, particularly sediments and beach width. The strong influence of subsidies of drift macrophytes on community structure and resulting responses in the abundance and distribution of higher trophic levels represented by shorebirds represent critical linkages among coastal ecosystems through which the direct and indirect effects of MPAs may be realized.

Shorebirds appear to be sensitive indicators of ecosystem conditions on beaches in the South Coast region. This strong regional scale result agrees with the suggestion that shorebirds (sandpipers, plovers, etc) could be sentinels of coastal ecosystems that integrate environmental conditions on a hemispheric scale (Piersma & Lindstrom (2004). The loss of migration staging, foraging, and wintering habitats has been implicated in the declines of populations of many species of shorebirds in North America and is a major concern for shorebird conservation planning and management (Howe et al. 1989, Brown et al. 2001, Bart et al. 2007; Morrison et al. 2001, 2006) as are the effects of climate change (e.g. Kendall et al. 2004). As shown by our results, the south coast of California represents a very important area for shorebirds, many of whom spend most of their year on the California coast, departing in May for breeding sites and returning by August. Further, as coastal wetlands in California have declined to less than 10% of their historic extent, sandy beaches have likely become increasingly more important as foraging habitat for shorebirds (Hubbard & Dugan 2003).

II. Rocky Shore Birds

Introduction

To pilot methods and provide a baseline description of the use of rocky intertidal sites by higher order predators represented by birds, we recorded patterns of bird use at rocky intertidal sites on the mainland coast in the late fall and winter of 2013-2014. The goal of these surveys was to collect data on mobile avian predators suitable for use in integrative comparisons of data on the community structure and composition of rocky intertidal biota collected by Blanchette et al. (2015) at these sites during the SCMPA baseline program. We will use this data integration to 1) investigate potential relationships between the distribution and abundance of birds and habitat characteristics and intertidal communities and 2) compare to results from sandy beaches in the South Coast Region.

Methods

We developed protocols and conducted surveys of the distribution and abundance of all birds at 16 rocky intertidal monitoring/survey sites on the mainland South Coast during daytime low tides from December 2013 to February 2014.

The rocky intertidal monitoring sites in our study vary greatly in size (shoreline length and area). This required careful consideration to standardize sampling effort and area for the bird surveys. On each survey date, we collected data on the birds present in 100 m shoreline segments. These sampling units included focal segments that contained the rocky intertidal monitoring/survey sites and where present, up to two adjacent segments with suitable rocky intertidal habitat at each site.

In each 100 m segment of shoreline, we recorded the number of individual birds of each species present on rocky intertidal habitat that were recorded in categories as: on rocks, in tidepools or surge channels (rocky), on macroalgae or surfgrass on rocks, or on sand. We noted behavior (feeding: surface picking, probing, gleaning, flycatching, fishing, loafing, preening, alarmed) of each bird observed. We also counted the number of people and dogs on rocky substrate (see above) in each of the 100 m segments. We visited each of the 16 study sites at least three times during the 3 month study period (December 2013 to February 2014). Because the amount of rock exposed varied with tide levels, swell conditions and at some sites the degree of sand burial, we estimated the extent of rocky substrate in each segment to the nearest 500 m^2 on each survey using measurements along shore normal transects, and/or by reference to scaled aerial photographs.

Results are presented primarily as descriptive summaries with contrasts between MPA and reference sites. Multivariate analyses of community composition that consider the effects of covariates on basic patterns are part of ongoing integrative efforts.

Results and Discussion

Birds

We observed 1304 birds of 36 species in 132 surveys of one-hundred-meter segments (Table 8). This included 17 species of shorebirds, 6 species of gulls, 4 species of seabirds, 3 species of aquatic/wading birds and 6 species of terrestrial birds (categories same as used for sandy beaches). The overall mean abundance of birds in the surveys was 9.9 birds per 100 meters of shoreline. The majority of the birds observed were gulls (52.3%) and shorebirds (37.0%). Six species made up 76% of the total birds observed: Western Gull (33%), Black-bellied Plover (16%), California Gull (9%), Heerman's Gull (9%), Sanderling (5%), and Black Turnstone (4%). Gulls and shorebirds were observed using rocky intertidal habitat for feeding and for loafing during daytime low tides. Both groups of birds also were observed foraging in tidepools.

Table 8 Total birds observed in low tide surveys of 16 southern California mainland rocky intertidal monitoring sites between December 2013 and February 2014.

SHOREBIRDS		Times
Species	Number	observed
Black-belled Plover	208	24
Sanderling	63	7
Black Turnstone	52	16
Willet	41	21
Spotted Sandpiper	36	15
Whimbrel	24	18
Marbled Godwit	18	5
Semipalmated Plover	11	3
Long-billed Curlew	9	2
Killdeer	8	1
Ruddy Turnstone	3	2
Dunlin	3	1
Surfbird	2	1
Greater Yellowlegs	1	1
Wandering Tattler	1	1
Black Oystercatcher	1	1
Long-billed Dowitcher	1	1
Total	482	
GULLS		
Western Gull	435	30
California Gull	120	5
Heerman's Gull	113	7
Ring-billed Gull	11	4
Glaucous-winged Gull	2	1
Bonaparte's Gull	1	1
Total	682	

SEABIRDS		Times
	Number	observed
Brown Pelican	32	5
Double-crested Cormorant	26	5
Royal Tern	17	2
Red-breasted Merganser	1	1
Total	76	
AQUATIC/WADING		
Snowy Egret	14	13
Great Blue Heron	3	3
Great Egret	2	2
Total	19	
TERRESTRIAL		
American Crow	39	4
Yellow-rumped Warbler	2	2
Black Phoebe	1	1
American Pipit	1	1
Song Sparrow	1	1
Common Yellowthroat	1	1
Total	45	
Total for all birds	1304	

When combined the seabirds (5.8%), aquatic/wading birds (1.5%) and terrestrial birds (3.5%) accounted for about 10% of all birds observed in this study. Pelicans and cormorants recorded on rocky habitat were loafing, not feeding. Cormorants, mergansers, egrets and herons used tidepools and surge channels for fishing and foraging for invertebrates. Egrets and herons also foraged in rocky and vegetated rocky habitats. Terrestrial birds were not observed using tidepool habitats, but used rocky and vegetated rocky habitats. The mean abundance of birds in 100 m segments varied more than 100-fold among the 16 sites from 0.7 (Point Vicente) to 139 (Coal Oil Point) (Figure 56). The variation in mean shorebird abundance was similar ranging from 0.0 (Abalone Rocks) to 80.6 (Coal Oil Point) (Figure 56). The two northernmost sites had the extreme values for mean gull abundance 54.3 (Alegria) and 0.3 (Ellwood) (Figure 56). The mean abundance of other birds ranged from 0.0 (Pt. Vicente, Shaw's Cove, Windansea) to 13.2 (Carpinteria). The abundance estimates of the three major categories of birds (shorebirds, gulls and other birds) were significantly correlated across the 16 sites. Certain sites had high means for all categories (Coal Oil Point, Carpinteria) and others were consistently low (Pt. Vicente, Sea Caves, Windansea). This could be due to habitat quality, landscape features, such as high bluffs, that provide potential perches for raptors, disturbance or the direct influence of avian predators, such as raptors.

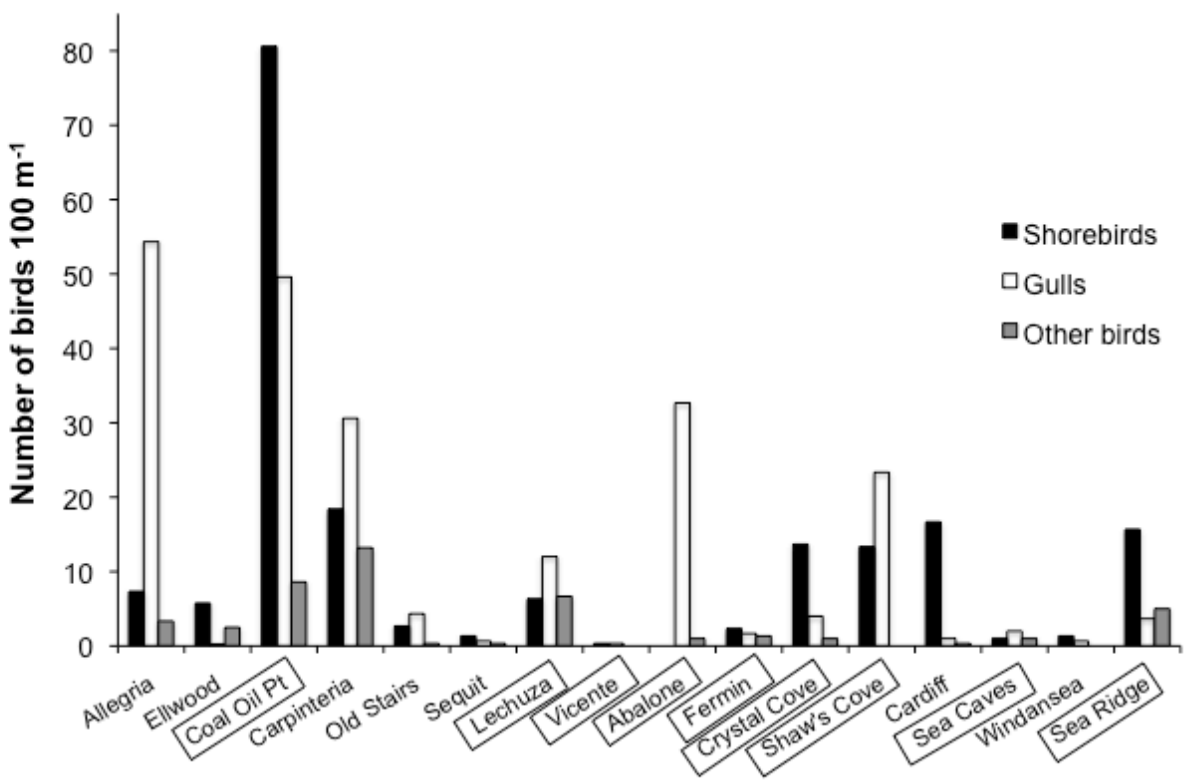

Figure 56 Mean numbers of shorebirds, gulls and other birds observed in surveys of 100 meter rocky intertidal shoreline segments at 16 SC mainland sites between December 2013 and February 2014. Sites are listed from north to south. Names of sites located in MPAs are in boxes

The overall mean species richness of birds for the 100 m survey segments varied more than 10-fold among the study sites, ranging from 0.7 species (Point Vicente) to 12.8 species (Coal Oil Point) (Figure 57). The overall species richness of shorebirds varied from 0 species (Abalone Rocks) to 8.6 species (Coal Oil Point). The species richness of gulls ranged from 0.3 species (Ellwood, Sequit, Pt. Vicente) to 2.0 species (Coal Oil Point). The mean species richness of other birds ranged from 0.0 species (Pt. Vicente, Shaw's Cove, Windansea) to 3.0 species (Carpinteria). The species richness estimates of the three major categories of birds (shorebirds, gulls and other birds) were significantly correlated across the 16 sites, suggesting these groups maybe responding to similar habitat, resource or disturbance characteristics.

We found no significant differences in the abundance of birds including shorebirds, gulls and other birds using rocky intertidal sites located inside and outside MPAs (Figure 58)

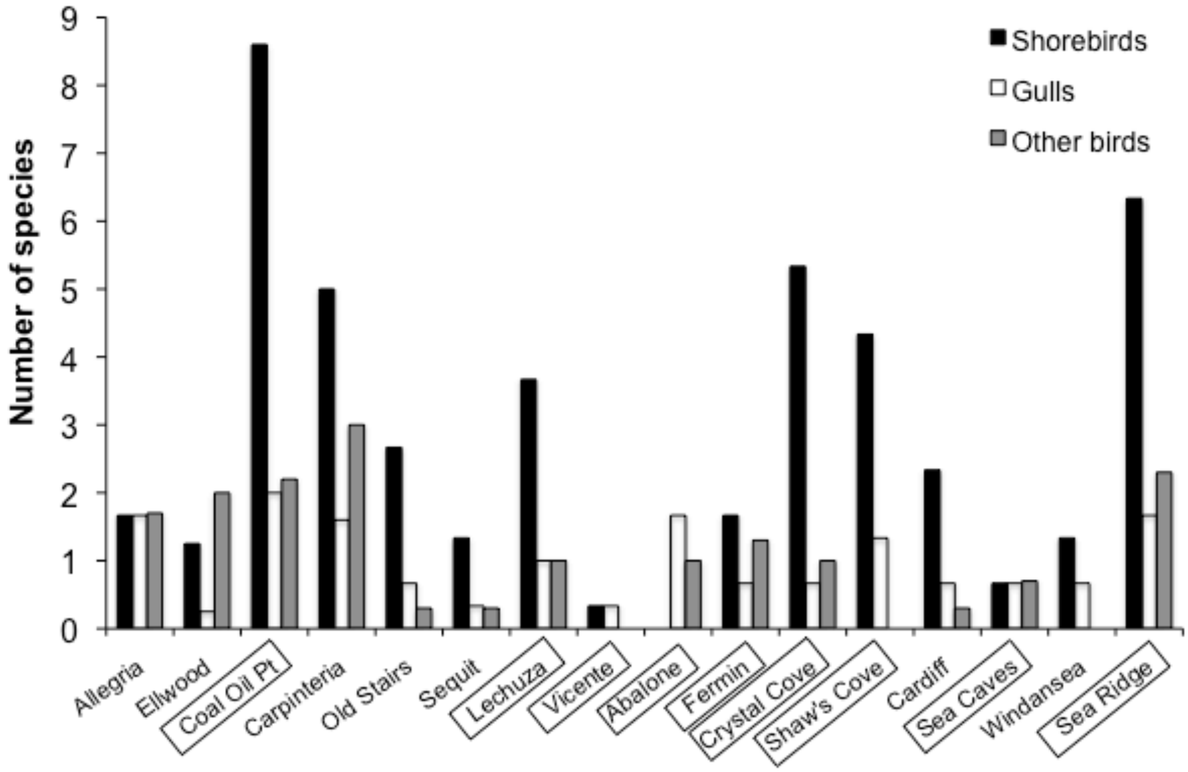

Figure 57 Mean numbers of species of shorebirds, gulls and other bird species in surveys of 100 meter rocky intertidal shoreline segments at 16 SC mainland sites between December 2013 and February 2014. Sites are listed from north to south. Names of sites located in MPAs are in boxes.

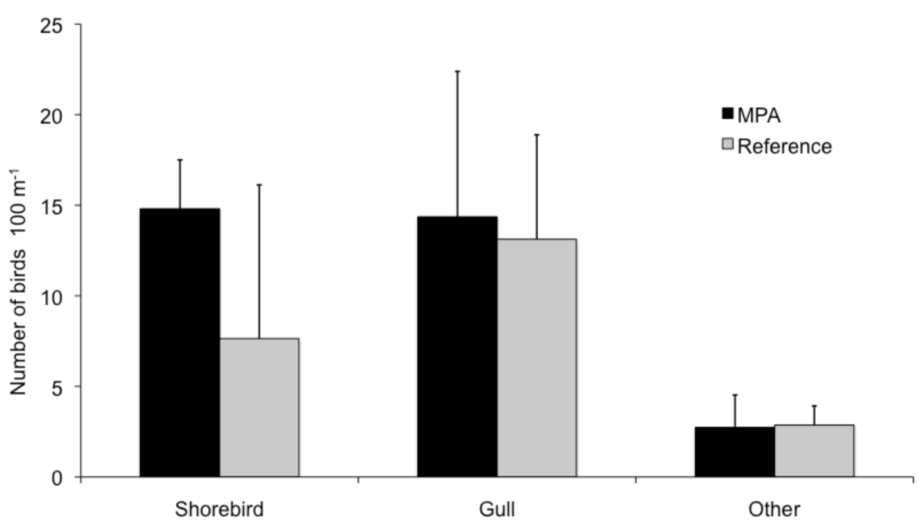

Figure 58 Mean abundance (+ std. errors) of birds observed on rocky intertidal habitat at sites located inside and outside of MPAs.

Shorebirds tend to spend much of their time foraging and can be good indicators of trophic connectivity. For this reason we used shorebirds to investigate the spatial consistency within sites (short distance). Both the diversity and the abundance of shorebirds stayed relatively similar over 100 to 200 m spatial scales. The species richness of shorebirds in the focal 100 m segments was significantly correlated with species richness in adjacent 100 m segments ($r^2 = 0.515$, $n = 75$, $p < 0.001$). The abundance of shorebirds in focal 100 m segments was significantly correlated with abundance in adjacent 100 m segments ($r^2 = 0.267$, $n = 75$, $p < 0.001$).

Humans and Dogs

During the surveys, people were observed in 30.7 percent of the 100 m plots at low tide. The number of visitors ranged from a minimum of 0 (69.3% of surveys) to a maximum of 37 people. Dogs were observed in 1.6% of the plots. Dog abundance ranged from 0 to 1 per 100 m of shoreline.

Rocky intertidal habitat patches in southern California can vary greatly in size and shoreline extent in the south coast region. Some patches of rocky intertidal habitat can be very small. Birds on small patches of rocky intertidal habitat appeared to be particularly sensitive to disturbance by humans and/or dogs, which can dramatically alter estimates of abundance and composition in low tide surveys. Numbers of birds on a 100 m segment can drop from high abundance to zero in an instant. If observers are not present at the time of the disturbance, the absence of birds in what appears to be quality rocky habitat can be puzzling. We expect that variance in bird distributions and abundance will be high at sites that are popular and readily accessible to human visitors.

The longer one km transects used for bird surveys on sandy beaches appear to be more robust to the influence of human visitors, because birds disturbed by visitors on beaches typically only move a few hundred meters at most and they usually remain in the survey area. One km transects would not be possible for the majority of rocky shores in the SC mainland region.

Temporal Considerations

Our observations suggested that the abundance of birds was often as high or higher during the falling phase of the tides, compared to during the lowest phase of the tides. Some of this variability appeared to be related to human use patterns with respect to tidal height at the rocky shore sites. Daylight fall and winter low tides attract large numbers of visitors to the rocky intertidal including school groups, citizen scientists, researchers and casual visitors. Many of these visitors typically arrive at the shore close to the time of the predicted low tide. We suggest that due to the small size of many of the rocky intertidal reef sites, future bird surveys should ideally be conducted independently of other rocky intertidal monitoring activities.

Our three-month survey period (December to February) was selected to focus on wintering birds and avoid migration periods when the distribution of birds can be highly variable (Hubbard and Dugan 2003). However, the distribution of sand and rock on the shoreline is dynamic at many sites on the south coast and this variation can strongly affect bird distributions. Late in the study period, erosion of accumulated sand revealed several rocky substrates in segments that had been purely sand early in the season. However, the newly exposed rock almost certainly had different (or no) prey resources for birds.

Comparison of birds on rocky shores and sandy beaches

Our results suggest that the bird community using rocky intertidal habitat at low tide in the late fall and winter was generally similar to the bird community observed in the 24-month study of sandy beaches in the South Coast Region (Figure 59). Generally, the bird communities on rocky shores and sandy beaches were similar. We found a statistically significant correlation, ($r^2 = 0.69$, $n = 81$, $p < 0.001$) between the log-transformed total abundance (adjusted to per km of shoreline) between the bird species observed on rocky shores and those on sandy beaches for the South Coast Region (Figure 59). That result indicated that bird species that were abundant on rocky shores were also abundant on sandy shores (e.g. Sanderling, Black-bellied Plover, Western Gull) and conversely bird species that were rare in one habitat were rare in the other.

There were, however, important differences within the larger pattern described above. Bird species that tended to specialize on rocky shore habitats appear far to the left of the 1:1 line illustrated in Figure 59 and sandy beach specialists appear far below the 1:1 line. Bird species that were more than twice as abundant on rocky shores than on sandy beaches included: Spotted Sandpipers, Black Turnstones, American Crows, and Snowy Egrets. Common bird species occurring in much higher abundances on sandy shores than on rocky shores included: Western Sandpipers, Least Sandpipers, and Semipalmated Plovers, Ring-billed Gulls and Black Phoebes.

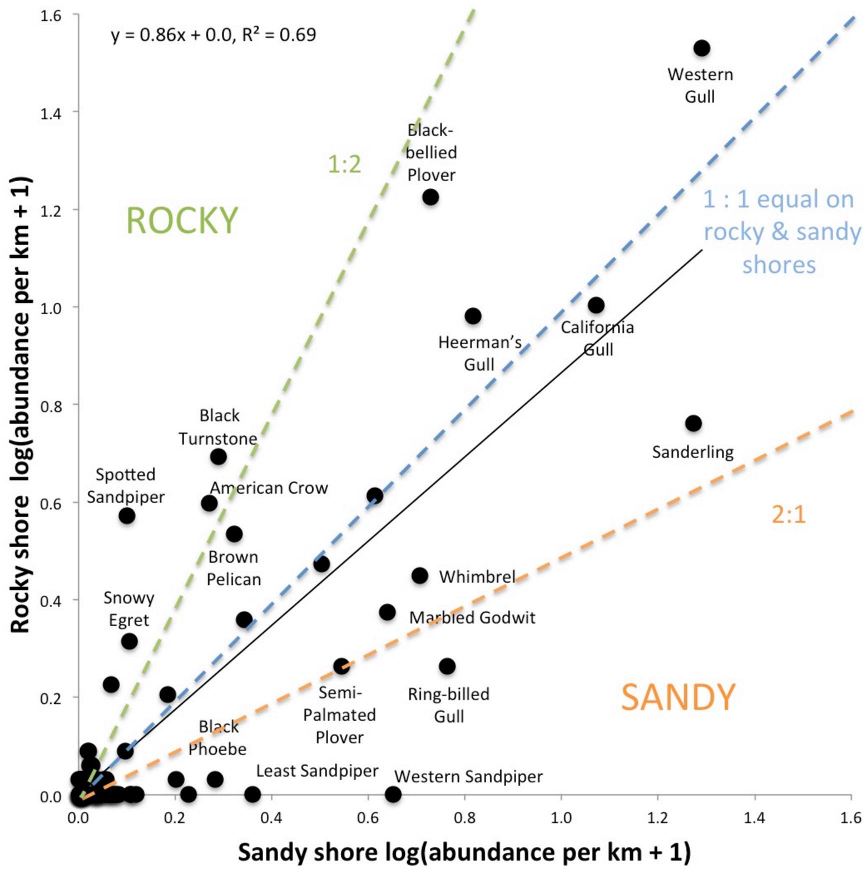

Figure 59 Comparison of the abundance of bird species observed on rocky and sandy shores on the SC mainland. Mean abundance per km of rocky intertidal (adjusted) vs. mean abundance per km of beach (southern California MPA study). Species that are increasingly far from the 1:1 (blue dashed line) are more characteristic of rocky (green dashed line) or sandy shores (orange dashed line) as indicated in the plot.

III. Partnerships

Academic and Agency Partnerships

The results presented in this report benefited from cooperation with a number of partners including academic institutions and state and federal agencies. We particularly want to thank the California Department of Fish and Wildlife, California State Parks, Channel Islands National Marine Sanctuary and the University of California Natural Reserve System for their assistance and cooperation in sampling beaches across the South Coast Region. The Santa Barbara Coastal Long Term Ecological Research (LTER) project and the UCSB Coastal Fund provided support for surveys of beaches on Santa Barbara County coastline. The Beach Metrics working group assisted greatly with the development and testing of new approaches to engaging local residents as citizen scientists on sandy beaches in the south coast region.

Citizen Science, Education and Outreach Partnerships

Sandy beach monitoring

Our project has largely focused on baseline characterization of sandy beach ecosystems with surveys over a two year period. However, consistent high quality long term monitoring over many years is required to describe and understand the range of natural variation in sandy beach ecosystems (e.g. Barnard et al. 2012, Hubbard and Dugan 2003). At this time we are aware of only two long term ecological monitoring programs for beach ecosystems conducted by qualified marine biologists in the state. Both are local scale programs conducted in the Santa Barbara Channel within the South Coast MPA region. The first of these is conducted by Channel Islands National Park (CINPS) and monitors wrack and several indicator taxa of the intertidal invertebrate communities on several beaches on Santa Rosa Island (Dugan 1990). This monitoring effort is conducted approximately annually. The second is conducted by the Santa Barbara Coastal LTER (SBC LTER) and monitors shorebirds and wrack abundance monthly and surveys wrack-associated taxa once a year at six beaches. The monitoring reports or data from both programs are available at http://science.nature.nps.gov/im/units/medn/monitor/beacheslagoons.cfm and http://sbc.lternet.edu, respectively. These two long term monitoring programs predate the MPA process in the region and were not designed to cover the new or existing MPAs. However, 2 of the CINPS monitoring sites and one of the SBC LTER monitoring sites are located within MPAs (Carrington Point SMR and Skunk Point SMR on Santa Rosa Island, and the Campus Point SMR, respectively).

Education and outreach

The educational benefits of public participation and engagement in science-based activities in coastal settings represent fundamental elements in enhancing the conservation of coastal ecosystems. We also recognize the importance of exploring and evaluating how different groups of users and stakeholders may contribute to the long term monitoring of California MPAs. However, to be useful the data collected needs to be comparable or at least compatible with that collected by practicing scientists. To succeed as citizen science efforts, monitoring protocols must be simple, robust and repeatable by a variety of observers with various levels of training, skills and experience. An active collaboration with practicing scientists can help to ensure consistency of protocols and the quality of data and its interpretation but this is not always possible or feasible, particularly on sandy beaches where scientific expertise is limited. Sandy beach ecosystems are physically accessible to public participation in scientific research (frequently characterized as 'citizen science') as they don't require SCUBA, boating or any additional special training certifications. However scientific collecting permits from California Department of Fish and Wildlife are required for monitoring activities inside and outside of MPAs.

LiMPETS

In this study we formally partnered with the southern California LiMPETS (Long-term Monitoring Program and Experiential Training for Students) program based at the Channel Islands National Marine Sanctuary and the Santa Barbara Coastal LTER Research Experience for Teachers (RET) Program funded by the National Science Foundation. LiMPETS (Long-term Monitoring Program and Experiential Training for Students) is an environmental education and monitoring program developed to engage students, educators, and volunteer groups. This hands-on program was developed to educate the public about the ocean and coastal ecosystems of California's National Marine Sanctuaries in order to increase awareness and stewardship of these important areas. LiMPETS fosters experiential learning, and in some cases, provides the first coastal visit for many students. LiMPETS trains primarily K-12 students, to conduct basic intertidal monitoring (rocky intertidal and sandy beach) along the coast of California. LiMPETS teams visit sandy beach and rocky intertidal sites throughout the South Coast region, and protocols, data and information are available at http://limpetsmonitoring.org. Through field-based monitoring using standardized protocols, students develop problem-solving skills, gain experience using tools and methods employed by field scientists, and learn to analyze data. The online data entry system on this website allows participants to archive their data electronically and to view and analyze program results over time. The LiMPETS program provides authentic, hands-on coastal monitoring experiences that seek to empower teachers, students and the community to conduct real science and serve as ocean stewards.

Protocol Development and Testing

On sandy beaches, LiMPETS uses a single protocol to quantify the abundance and size of sand crab populations. This protocol is described briefly below, and further detailed information about the methods and field data forms are available at http://limpetsmonitoring.org. Our collaboration with LiMPETS in the South Coast region was based on the three main areas as described in our proposal: analysis of LiMPETS data from the south coast region, development and testing of new protocols and Teacher training workshop and symposium. Below we describe our work in each of these three main areas, and present our results and recommendations.

Data Analysis

None of the current LiMPETS sandy beach sites overlapped with our 12 focal study sites in the SC region. Nonetheless we examined the datasets on sand crabs available online for the SC region. We found that in general that very few datasets for sand crabs had been uploaded. Of the datasets available, many samples consisted largely of zeros, suggesting that few or no sand crabs were collected on those dates at the sampling sites. For these reasons no formal analysis of existing LiMPETS data on sand crabs was feasible.

Protocol Development and Evaluation

Primary goals of this component included accurately identifying sand crab zones and distributions to inform the location and spacing of sampling effort, adding simple robust ancillary physical measurements to protocols, and developing efficient approaches for measuring size structure (especially for the young of the year crabs which can be collected in large quantities). We collaborated with UCSB undergraduates, LiMPETS and CINMS staff and two K-12 teachers who were participants in the NSF RET for the Santa Barbara Coastal LTER program in 2013.

Sandy beaches are one of the most challenging coastal habitats for animal life. The width, slope and shape of the beach are constantly responding to waves, tides and sand supply. The constantly moving sand making up beaches is too unstable to support attached plants or animals. To adapt to the harsh environment of waves and sand, most beach animals have high mobility and can burrow rapidly. As is typical for many sandy beach invertebrates, sand crabs are extremely mobile, changing position in the swash zone with every wave and tidal shift to adjust to their shifting beach habitat. Consequently, the width of the sand crab zone on a beach varies strongly with tide state, surf zone conditions and the beach profile, including the slope of beach (Dugan et al. 2013). As a result the locations of sand crab aggregations and their densities can vary markedly from hour to hour on a single beach and from beach to beach. Density of these mobile crabs can vary greatly on these scales even if population abundance is equivalent. Sand crab aggregations have been observed to move over 100 m following the swash zone across a wide flat beach during a single tide cycle (Jaramillo et al 1998). This high mobility and dynamic distribution fundamentally differs from rocky intertidal organisms that attach strongly to rocks and move very little on the scale of daily tides or waves. This means that any protocol that relies on standardized length or placement of transects or sampling units is completely unsuitable for intertidal monitoring in sandy beach ecosystems. Protocols based on such standardize placement will result in major errors in estimates of population abundance on beaches (Dugan et al. 2013).

In brief, the existing LiMPETS sandy beach protocol lays out a 50 m alongshore transect located above the high swash zone and selects five random locations on the alongshore transect to set up a number of 10 m long cross-shore transects (Figure 60). The LiMPETS protocol specifies each 10 m transect should start five meters above the top of the swash zone. From this starting point a single core sample is collected every one meter along each across-shore transect for a total of 10 core samples per transect. The current rigid protocol minimizes observation or decision making at the time of sampling, but critically does not take into account or adjust to the high mobility, changing position and dynamics of sand crabs in the intertidal zones of sandy beaches. In addition, students immediately measure any crabs collected in an individual core while they continue to stand on the transect, a disturbance that can cause any crabs in the vicinity to rapidly swim away from the transect, altering the results of subsequent cores. This flawed sampling approach likely contributes to the large number of zeros in the LiMPETS beach datasets for the south coast region and the lack of confidence in any resulting abundance estimates for sand crabs.

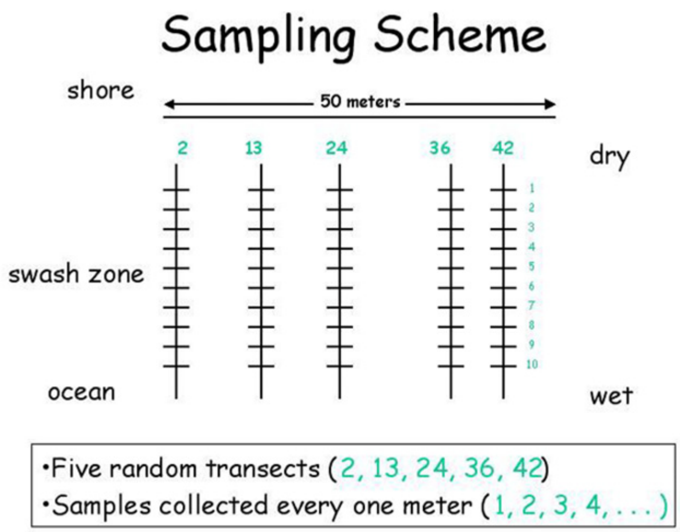

Figure 60 Schematic diagram of LiMPETS sampling grid from the program's web page: (http://limpetsmonitoring.org/sb_methods.php). Ten cores are collected on each transect.

To address this critical sampling issue, we developed and tested a modified protocol on the South Coast that first identifies the zone of sand crab occurrence and its width by making observations to determine the locations of the highest to lowest level of the beach where sand crabs are present. Once the crab zone width is identified and measured, the 10 cores are collected at uniform intervals across the width of the crab zone.

We collaborated with our NOAA CINMS and RET teacher partners to conduct a replicated, side-by-side comparison of sampling protocols for sand crabs at a single beach, located in the Campus Point MPA, on four survey dates during Summer 2013. This design complements and builds upon a similar comparison conducted during the NCC region baseline monitoring program with the Gulf of the Farallones LiMPETS sand crab sampling program (Nielsen et al. 2013).

Modified Sampling Protocol

The primary and critical modifications we developed for the LiMPETS protocol were intended to allow the protocol to adapt to the changing distributions of sand crabs and hence become more capable of adjusting to the high mobility of sand crabs in response to tides, waves and beach conditions without increasing sampling effort. A second important component was to increase accuracy of population sampling by reducing the disturbance of highly mobile and easily spooked sand crabs by sampling activities and minimize the influence of tide shifts on the distribution of crabs over the survey period. We rapidly collected the ten cores for each transect in series, then sieved and processed the core samples off transect. Crabs from each core were placed in plastic cups in a numbered grid drawn on the damp sand. Once all cores were collected for a transect the sizes of the crabs in each cup were measured. We predicted that use of the modified protocol could potentially greatly increase the number of sand crabs collected in each set of ten cores. For this reason, we also developed a calibration for carapace length and total body length of sand crabs that would allow a large reduction in handling time and crab injury and greatly increase the efficiency of measuring the sizes of large numbers of sand crabs in field conditions.

Protocol Comparisons

Replicated side by side comparisons of the two protocols were conducted on four dates in summer 2013, June 24, July 10, July 19 and August 30. To avoid confounding spatial variation in the beach that can affect sand crab distributions, the study design used pairs of transects, each pair consisted of one transect using standard protocols and a 2nd transect using the modified protocols. Each of the transect pairs was sampled simultaneously to avoid confounding results with high frequency temporal variation in sand crab distributions. A minimum of three pairs of transects were sampled on each survey date.

Results of Protocol Comparison

The use of the modified LiMPETS protocol resulted in greater numbers of sand crabs collected per transect than the standard LiMPETS protocol on every sampling date (Figure 61), ranging from 60% to 950% greater numbers of crabs. The inclusion of core spacing in the calculations, resulted in significantly higher estimates of sand crab abundance per meter of shoreline than did the standard LiMPETS protocol on the three sampling dates on falling tides (Figure 62), ranging from 5 to > 100 fold greater values for abundance (one way ANOVA for falling tide samples, $F = 63.56$, $p = 0.001$, $F = 40.68$, $p = 0.003$, $F = 12.02$, $p = 0.03$). The estimated abundance per meter for samples collected on the rising tide date did not differ significantly ($F = 5.235$, $p = 0.08$) (Figure 62), again highlighting how the sensitivity of sand crab distributions to tide, wave and beach condition strongly affects results of any survey of these mobile intertidal animals.

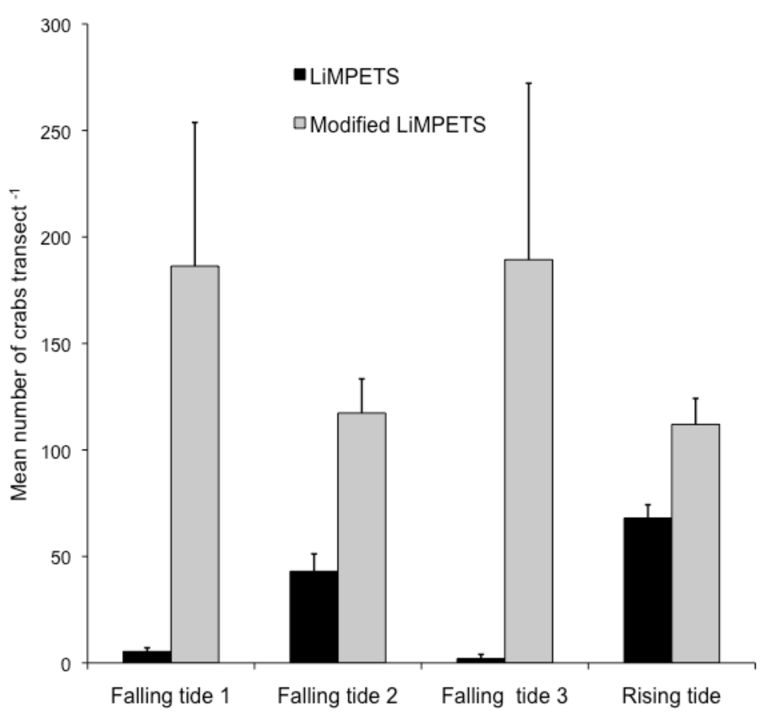

Figure 61. Mean numbers of sand crabs collected per transect (+ std. errors) in ten cores using standard LiMPETS and modified LiMPETS sampling protocols on paired transects at Campus Point MPA.

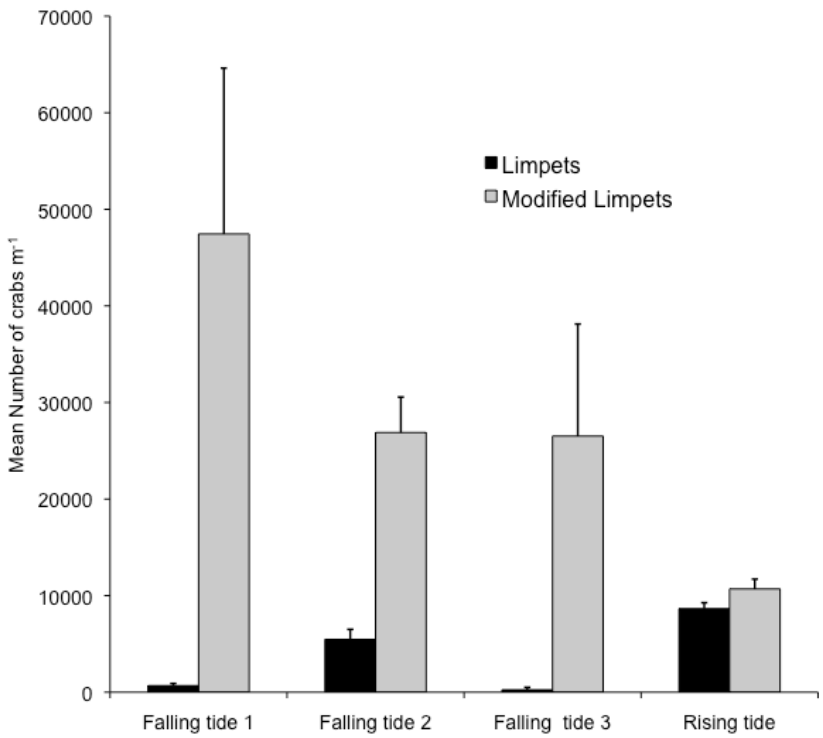

Figure 62 Abundance estimates (number of individuals m^{-1}, + std. errors) for sand crabs using standard LiMPETS and modified LiMPETS sampling protocols on paired transects at Campus Point MPA.

During our surveys, we observed that the standard LiMPETS protocol using a fixed transect location and spacing consistently collected numerous cores above the zonw of the sand crab distribution (Figure 63). This resulted in the standard LiMPETS protocol collecting far greater numbers of cores with zero to few sand crabs in each transect than did the modified protocol (Figure 64). The cores lacking animals were generally located in the upper half to three quarters of the cross shore transects numbering 6-9 cores out of 10 cores. This result is indicative of the problem of a fixed transect and spacing approach failing to capture the highly dynamic distribution of sand crabs in the intertidal zone of sandy beaches. These results (Figure 64) suggest the zone of sampling dictated by the standard LiMPETS protocol consistently missed the majority of the sand crab distribution and that more than half of the core samples were collected above the zone of sand crab occurrence. The only exception occurred on the single date when sampling was conducted during a rising tide and sand crabs moved up into the LiMPETS sampling zone with the rising tide on the last two of the three transects. However, even on a rising tide, the number of cores with 0-1 sand crabs was more than twice that observed on transects sampled with the modified LiMPETS protocol.

In addition, instead of sand crabs, we observed that the standard LiMPETS protocol collected numerous dark red deposit-feeding opheliid worms, *Thoracophelia mucronata*, in the upper cores of the transects. These worms are typically distributed in an intertidal zone located above the sand crab zone (Dugan et al. 2013) (Figure 63) and can occur in very high abundance in the Campus Point MPA. These worms are important to intertidal nutrient cycling and as prey for shorebirds. Because of the LiMPETS benchmark transect placement 5 meters above the swash zone, the standard LiMPETS protocol regularly collected these non-target animals as bycatch, sometimes in high numbers. These worms are sensitive to handling and may be damaged or killed by

Figure 63 Survey of sand crabs at Campus Point MPA using standard LiMPETS protocol in Summer 2013. In this image you can see that the top of the sand crab zone indicated by yellow arrow is located several meters below the sampling grid. The orange flags indicate the location where core samples are to be taken on this transect.

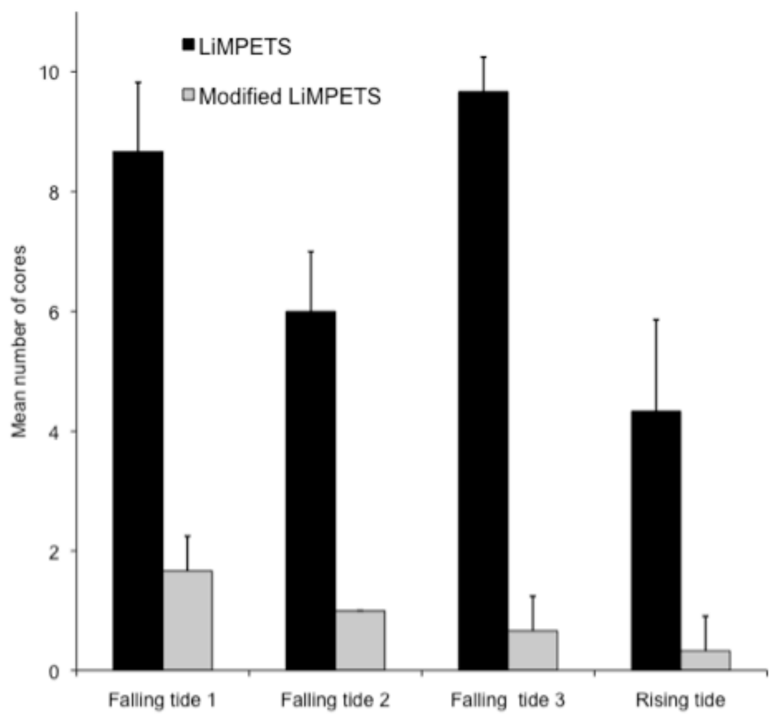

Figure 64 The mean values (+ 1 std. dev) of numbers of cores containing 0-1 sand crabs for samples collected using standard LiMPETS and the modified LiMPETS sampling protocols in surveys of paired transects in the Campus Point MPA during summer 2013.

the sampling process. The bycatch and potential harming of non-target animals, such as that observed using the standard LiMPETS sampling grid in the Campus Point MPA, should be avoided in any monitoring effort. This is particularly important in monitoring of MPAs where non-destructive sampling methods should be used whenever possible.

The increased number of crabs collected using the modified LiMPETS protocol we tested means that those samples can provide a far more accurate estimate of the population size structure of sand crabs. However, with the resulting larger numbers of sand crabs collected in core samples using the modified protocol, a more rapid approach to measuring size of sand crabs is required. Measuring each crab individually with vernier calipers is not practical and the calipers can be confusing and time consuming to use without sufficient training and practice. Our calibration of carapace length and total length for sand crabs allowed us to pilot a more efficient and rapid approach to measuring of size structure. In addition it reduced handling time and associated trauma and damage to the sand crabs. We tested the use of a simple sheet with a scale of total lengths than can be copied onto waterproof paper and used on a clipboard to rapidly measure sand crab lengths in each sample (Figure 65). This method provides a rapid way to measure large numbers of sand crabs.

Figure 65 Sand crab (adult female crab) on the scale we developed and tested for rapidly measuring total length of sand crabs in the field.

Teacher Workshop and Symposium

Based on our evaluation of the currently used LiMPETS sand crab sampling protocols during both the NCC and SC MPA baseline monitoring programs we have clearly determined that the current LiMPETS sand crab protocol does not yield accurate results on sand crab populations and therefore is not suitable for use in a long term monitoring program. The standard LiMPETS sampling protocol consistently underestimated population size, and in some cases entirely failed to find any sand crabs on beaches where abundant populations were present. However, a modified or adapted sampling protocol for sand crab populations could be used to enhance opportunities to engage citizens and students in collecting data that has the potential to be sufficiently accurate for long term monitoring. To evaluate this possibility, we tested the feasibility of the modified LiMPETS sand crab sampling protocol with K-12 teachers participating in a Teacher Professional Development Workshop at UCSB in June 2014. Our objective was two-fold: 1) to design a tractable and safe protocol that citizen scientists (primarily students) could carry out consistently to yield improved estimates of sand crab population size, and 2) to create a protocol that would enhance opportunities for scientific thinking and learning, and align with Next Generation Science Standards.

We co-hosted a teacher training workshop and symposium in June 2014 at the University of California at Santa Barbara, entitled, 'Teaching Environmental Science in a Changing Climate' to provide teachers with helpful tools and resources focused on environmental and climate science education in the context of the Common Core and Next Generation Science Standards. Our partners in the teacher workshop included the UCSB Marine Science Institute's REEF Education Program, Channel Islands National Marine Sanctuary, Channel Islands National Park, the SBC LTER, the LTER and NSF sponsored Math and Science Partnership, and NatureBridge. The 5-day workshop was attended by 24 teachers, and included sessions focused on both sandy beach and rocky intertidal LiMPETS training and sampling. About 20% of the participating teachers had prior experience with the LiMPETS program. An overview of the LiMPETS sandy beach program was followed with field and laboratory activities. The activities were designed to introduce the teachers to the modified LiMPETS protocols for sand crabs and solicit their feedback.

Teachers were introduced to the sandy beach ecosystem and its highly mobile inhabitants and were given a short homework exercise that we created to introduce the concept of measuring density (m^2) vs. abundance (m^{-1}) in a highly mobile animal living in a dynamic habitat, such as sand crabs on sandy beaches (Appendix B). The following morning we led a field sampling exercise with the teachers using the modified LiMPETS protocols and newly designed datasheets (Appendix B). We conducted this exercise on the sandy beach at Campus Point used in our 2013 comparison of sampling protocols. The teachers were divided into 5 groups of 4-5 teachers, each with a leader who was familiar with use of the modified protocols. Each group of teachers was assigned to one of five cross-shore transects delineated with a meter tape extending from the bluff toe to the high swash level.

- Prompted by the datasheet, the teachers first made natural history observations of the distribution and locations of beach features, such as the high tide line and water table outcrop, and of beach animals, such as beach hoppers and sand crabs on their assigned transect (Appendix B).
- Second, the teachers determined the zone of occurrence of sand crabs on each transect by investigating the distribution across the beach and marking the locations of the upper and lower bounds of the sand crab distribution and the width of the sand crab zone.
- Based on the width of the sand crab zone, teachers determined the uniform core spacing needed to span the zone for each transect.
- Teachers quickly collected 10 uniformly spaced cores to 10 cm depth across the sand crab zone and placed the cores in individual mesh bags.
- The sand from each core was sieved through these bags in the shallow swash zone, at a distance of at least 5 m from any of the transect, retaining the animals from the core.
- Crabs from each core were placed in a plastic cup in a numbered grid drawn on damp sand located above the reach of the waves and above the sand crab zone for each transect.

- The total body length of all crabs in each core's cup was measured using the calibration sheet (Figure 65) and recorded.
- All sand crabs were released after measurement.

Hundreds of sand crabs were collected, measured and released in the survey (Table 9). Following the field survey of sand crabs, we led the teachers in calculations of sand crab abundance from their samples (Appendix B) and a discussion of the results. The estimated total abundance of sand crabs averaged > 39,287 crabs m^{-1} across the five transects. However estimated abundance varied considerably among transects, ranging from 1179 crabs m^{-1} to 107,038 crabs m^{-1} (Table 9). The teachers who were sampling sand crabs in Transects 4 and 5 noted that they had walked and stood around on the transects in the sand crab zone before taking any of the core samples. This disturbance of the sampling zone appears to have moved the crabs off the transects resulting in very low catch of sand crabs (Table 9). Using their own observations based on the natural history we had previously introduced and shown them in the field, the teachers were able to observe that the sand crabs in their sampling area had moved to the west. Although variability was high (standard deviation exceeded the mean), this survey yielded an overall abundance estimate of nearly 4 million sand crabs in 100 m of shoreline. Our results with the teachers aptly illustrate the significant challenges of accurately sampling the abundance of a highly mobile and easily disturbed animal in the intertidal swash zone of sandy beaches.

Transect	**1**	**2**	**3**	**4**	**5**	**Mean**	**Std dev**
zone width m	6	10	11	20.7	27		
core spacing m	0.66	1.1	1.2	2.3	3		
Core #							
1	293	0	0	0	0		
2	195	20	123	0	0		
3	150	1	62	0	0		
4	141	98	126	1	0		
5	87	35	41	0	0		
6	121	5	10	1	0		
7	112	17	4	0	0		
8	33	7	2	0	1		
9	62	12	7	0	1		
10	71	4	1	2	4		
Total	1265	199	376	4	6		
Crabs per m	107038	28064	57846	1179	2308	**39287**	44386

Table 9. Results of sand crab survey by teachers using modified protocols at Campus Point MPA in June 2014

During the workshop we engaged 24 teachers [half of whom teach students in middle school (grades 5-8) and half in high school (grades 9-12)] to test out the new adaptive grid protocol and provide us with feedback on feasibility and ways we might improve, clarify or streamline the protocol for use with their students and in their science classes. We asked teachers who had participated in the new protocol and analysis to provide structured feedback in the form of a survey (Appendix C). The survey included questions with ranked answers on a standard 5-point Likert scale as well as opportunities for qualitative feedback. We also took notes on the comments and discussion points generated during the activity with the teachers. We were interested in determining, from the teachers' perspective, whether or not the modified protocol was logistically feasible and if they thought it provided enhanced student learning of scientific concepts.

Teachers who participated evaluated their prior knowledge of sandy beach ecosystems as 'medium to low' overall (on a scale ranging from none to very high) with 8 out of 22 teachers (36%) having participated in some type of intertidal educational or sampling activity in the past, primarily through the LiMPETS program (Figure 66). After completing the workshop and the field experience where they engaged in the modified LiMPETS sand crab sampling protocol they ranked their own knowledge level of sandy beach ecosystems as 'high,' increasing by one step in the median response on the scale. When asked if they felt that had sufficient knowledge to use sandy beach ecosystems as an educational tool in their classrooms after completing the activity, 21 out of 22 teachers replied affirmatively. However, many indicated a desire for additional background information and reference materials to prepare lesson plans, such as those provided in the introductory presentation.

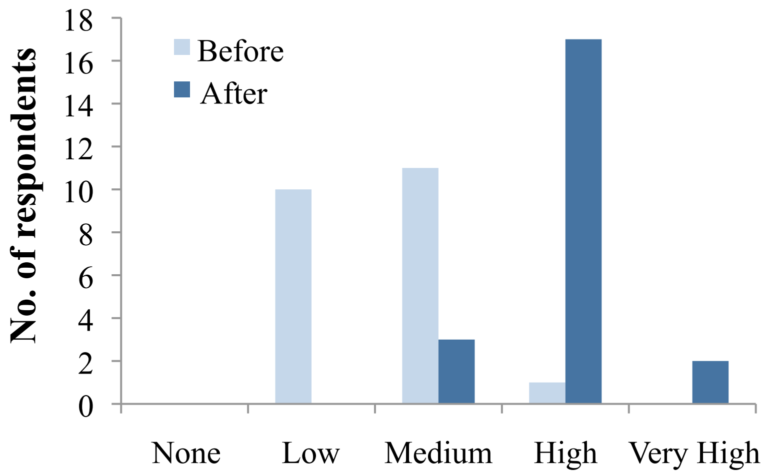

Figure 66 Workshop teachers self-ranking of their knowledge of sandy beach ecosystems before and after participating in the workshop activity on sandy beaches in June 2014.

We were especially interested in how teachers perceived the feasibility of the adaptive grid protocol since it required making qualitative natural history observations on the beach at the time of sampling to determine how to set up the sampling grid (Figure 67). We asked them to rank seven specific aspects (question 7, Appendix C) and the overall feasibility of using the 'adaptive grid' protocol with their students (question 5, Appendix C). The specific aspects we asked them about were: 1) sampling efficiency and time needed to conduct field work; 2) collecting observations and measurements that provide context on beach habitat; 3) describing the distribution of crabs before grid layout and sampling; 4) calculating core spacing based on observations; 5) minimizing disturbances of sand crabs prior to sampling; 6) calculating the estimates of crab abundance per meter of shoreline; and 7) entering the data collected into an online form. The median response to the first six questions was ‘feasible with minor modifications’ and ‘completely feasible with no modifications’ required for the last question. There was no indication from this group of teachers that these specific elements of the protocol were too challenging or complex to be feasible. Responses to the question of the overall feasibility of using the ‘adaptive grid’ protocol with their students varied from ‘very high’ to ‘low’ but the median response (9 out of 22 respondents) was ‘high.’ Reasons given for low rankings included logistics and costs associated with getting students to and from field sites and acquiring equipment. Suggestions for improving the activity included: having students practice techniques and protocol prior to executing the population survey; creating/providing a video showing the technique; having an expert such as a graduate student come to make a presentation in the classroom or join the class in the field; reviewing math and equations required to make and interpret population size estimates, and providing pre and post activities and informational handouts such as pictures of animals.

We queried the teachers about the potential for this protocol to help their students develop observational and quantitative reasoning skills (Figure 68). The protocol involves students in making and interpreting natural history observations to determine where sand crabs are present on the beach. It also requires the use of quantitative reasoning to determine the spacing of cores within the sand crab zone, the locations of the transects on the beach, and to convert the data collected on sand crab abundances in the cores into a population size estimate for the beach along with its associated precision or uncertainty. Of the 21 teachers who responded to questions about the modified protocol’s potential to help students develop observational and quantitative reasoning skills 17 and 18, respectively, scored the protocol high or very high (the median response was ‘high’ for both).

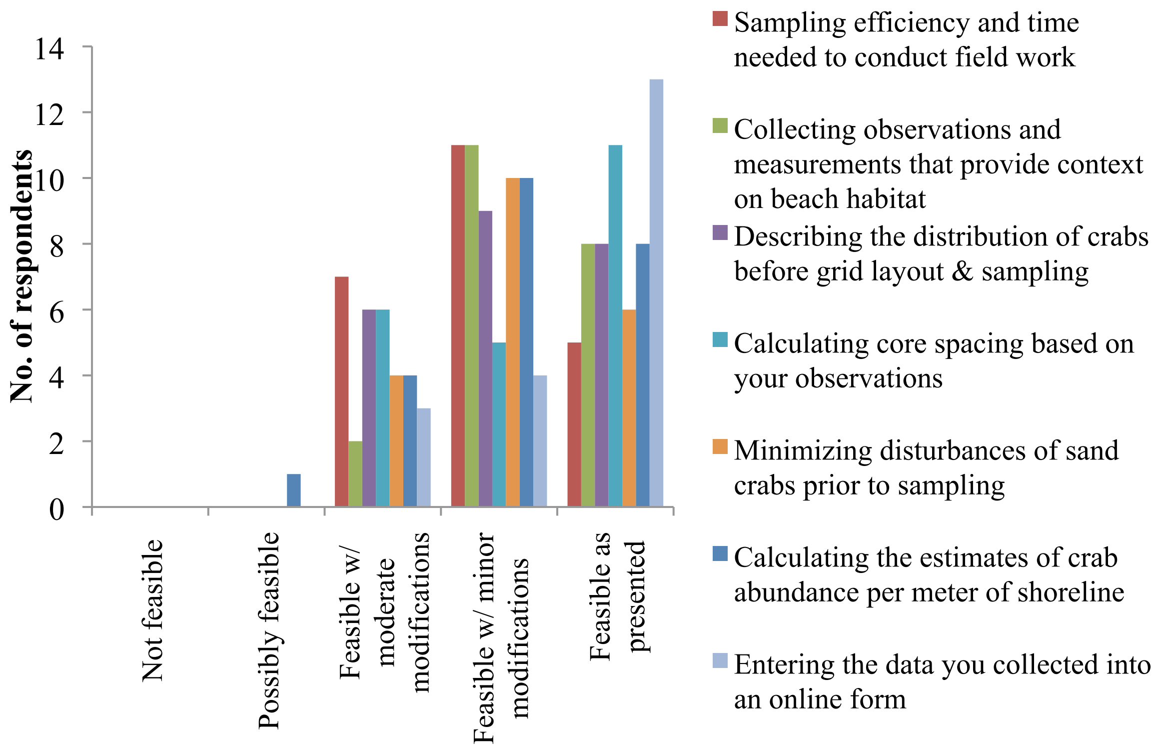

Figure 67 Teacher workshop participants evaluation of the feasibility of seven specific aspects of the adaptive grid sand crab monitoring protocol.

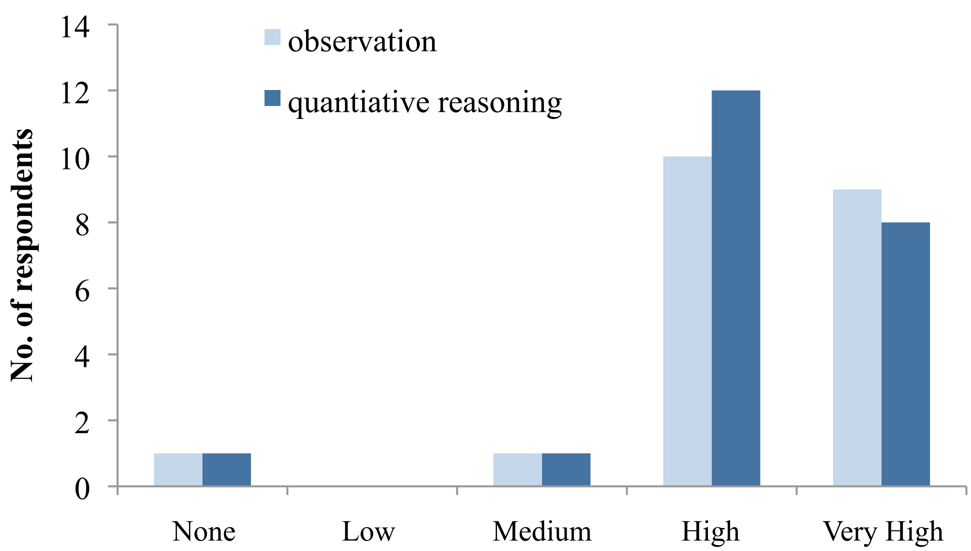

Figure 68 Teacher perception of the adaptive grid sand crab sampling protocol to support development of scientific observation and quantitative reasoning skills in their students.

One possible tool that may be considered for long-term monitoring of sandy beach ecosystems in California could involve sand crab sampling by citizen scientists, such as LiMPETS. The modified protocol we developed and tested during the SC baseline study and in the teacher workshop is intended to provide a way to increase the potential reliability and utility of data on sand crabs that may be collected by citizen scientists. The modified protocol was developed in response to significant concerns by scientists about the accuracy of the LiMPETS data sets and their interpretation. The original LiMPETS protocol was developed to support an educational program, and was not intended to provide reliable long-term monitoring data on sand crabs. The evidence collected in 2013 as part of this project and prior evidence from the NCC MPA baseline project report (Nielsen et al. 2013) confirms that these concerns are valid.

There may be concerns that the modified protocol with the adaptive grid for sand crabs surveys would be too challenging for teachers and students to implement. The results of this workshop trial, as supported by the survey results reported above, suggest this is not likely to be the case. The teachers thought that with some minor additional ‘scaffolding’ around the exercise their students would be able to conduct the sampling effectively. Additionally, the teachers were very enthusiastic about how the modified protocol provided opportunities to engage in scientific thinking and quantitative reasoning that aligned well with Next Generation Scientific Standards.

We also asked teachers in the workshop if they thought the data collected by their students, acting as citizen scientists through classroom activities like this one, would be useful for monitoring the health or population status of marine resources for the state of California. Overall the teachers thought the data could be ‘useful’ especially with respect to students gaining hands-on experiential learning about scientific monitoring, and developing an understanding of sandy beach ecosystems, organisms and general environmental stewardship. However this was strongly tempered in written comments provided by 12 out of 19 teachers expressing concerns over the reliability and accuracy of the data based on their own experience in the workshop, especially in the absence of time for students to hone their skills through repeated practice.

Overall the results of the survey indicate that the modified protocol with the adaptive grid approach for sand crab surveys is feasible and represents a more accurate protocol for possible monitoring of sandy beach ecosystems via citizen science than the existing LiMPETS protocol. Nonetheless the challenges of accurately estimating population size in highly mobile intertidal invertebrates are formidable. Our results suggest a tiered approach to training citizen scientists (Table 10) is needed to improve the potential quality of any data collected, while also providing higher quality science educational experiences and encouraging ecosystem stewardship.

Recommendations

Based on our evaluations and the results of the teacher workshop, we have developed a number of recommendations for modified protocols for surveys of sand crab populations on the California coast.

1. Use an adaptive sampling approach that is suitable for mobile beach invertebrates

- Modify Sampling grid to match the dynamic distribution of sand crabs on each sampling date and site. Alter location of highest and lowest cores, spacing of cores and width of zone surveyed with cores.

2. Develop decision tree for locating and setting up sampling grid and determining core spacing

3. Reduce disturbance of highly mobile reactive intertidal animals
   - Modify transect sampling, core collection and sieving process to reduce trampling and time spent in swash zone

4. Improve efficiency of population size structure measurement.
   - Eliminate use of calipers and adopt new method to measure carapace lengths with calibration to total length

5. Adopt a tiered sampling model based on observer training and skill

Tiered sampling model details

One potential approach to the inherent limitations posed by the wide range of observers with highly variable experience, knowledge and goals involved in the LiMPETS program is to develop a strictly tiered approach to surveys of sand crabs. The simplest tier, Tier 1, would focus on discovery and exploration of beach ecosystems and an introduction to sand crabs, Tier 2 would introduce quantitative sampling approaches and adaptive protocols for sand crabs. Tier 3 would be open to only the most experienced and trained volunteers. We anticipate that the majority of sampling events would be in Tiers 1 and 2. The tiered approach (similar to experience levels for data collection in other citizen science groups such as REEF Check) would provide experiences for data collection for samplers at all levels. Moving from one tier to the next would require a demonstration of knowledge sufficient to collect meaningful information at the next level. The lowest tier could include most general science education for students and the public. The next level could include more experienced teachers/participants, who could potentially develop a time series for internal (classroom) use. The highest level would be limited to a fully trained group of samplers that collect certain types of data that could be entered into the LiMPETS network database. The benefits of this approach would be to provide the LiMPETS program with a way to meet educational and scientific goals, without compromising data quality. The database could be set up to allow for entry into these separate tiers, thus enabling students to work with data that have been collected in similar ways by other groups or through time. Modifications to data sheets would be required. The goals, required actions and intended results for each of the proposed tiers are described in Table 10.

Table 10. A summary of goals, actions and intended results based on the incorporation of a tiered sampling model approach to LiMPETS surveys of sand crabs.

TIER	GOAL	ACTION	RESULT
1	Introductory Ocean Experience, Increase Ocean Literacy, Promote ocean stewardship	Search for sand crabs and explore zone and behavior	Highlight exploration during field trip (rather than data collection), Emphasis on basic science education
2	Introduction to Data Collection and Basic monitoring techniques	Observe and measure beach profile and features, Determine sand crab occurrence and zone, Use adaptive monitoring protocols, Introduce basic QA/QC	Collect and build upon time series for teaching purposes, Emphasis on how to be a scientist, rationale for monitoring, the scientific method, quantitative reasoning, and beach ecology Increased accuracy and precision,
3	Collect scientifically -sound monitoring data that meshes with monitoring by experienced scientists	Use fully adaptive monitoring protocols Rigorous training, Use of experienced field samplers, Reduced disturbance of animals, Implement QA/QC,	Emphasis on scientific goals, Higher accuracy and precision,

Beach Metrics

An important and promising citizen science and educational activity conducted during our baseline study investigated the feasibility and requirements for developing a successful and sustainable citizen science program that could contribute to monitoring the ecological condition of sandy beaches in the SC region. This component is based on collaboration with a working group made up of scientific experts, environmental educators, and other stakeholders and is ongoing. The goal of this effort is to develop a set of indicators suitable for ecological monitoring of sandy beach ecosystems by citizen scientists, including key physical and biotic components. The data collection and potential monitoring program will rely on accurately recording the presence or absence of indicator taxa and features on beaches over repeated visits that will allow the surveys to capture the inherent variability in these dynamic ecosystems.

Progress toward this goal is excellent. With the assistance of Surfrider and one of their summer interns, we collaborated on a pilot version of a beach indicator-based citizen-scientist volunteer monitoring program at eight SC beaches, all located in Orange County, during Year one (2012) of the baseline study. The beaches surveyed in this initial pilot study included 4 located in MPAs (Crystal Cove SMCA, Laguna Beach SMR and Dana Point SMR) and 4 reference beaches. All beaches were surveyed once using a draft survey protocol and form. The results of this survey were used to refine the protocol and data collected. In collaboration with the beach metrics working group, we used those preliminary results to inform the further development of indicators and survey protocols. This year we have begun to develop a training program including data forms and materials, that will be used in a more extensive pilot study conducted by the working group at a subset of our 12 study beaches in Winter 2014-2015. The results of this 2nd study will be analyzed and used to evaluate and refine the protocols for use by volunteers. Over the next year, we will recruit committed adult volunteers from communities adjacent to MPAs. We will coordinate with established programs, such as the Audubon Society and Surfrider, to build on these local resources in order to develop a reliable trained group of volunteers that can help us further test the use of the beach checklist for citizen scientists in a broader pilot study. Another component of this work is a new website on sandy beach ecosystems developed in collaboration with California Sea Grant (http://ca-sgep.ucsd.edu/focus-areas/healthy-coastal-marine-ecosystems/explore-beach-ecosystems). This website provides accessible information and insights on sandy beaches as ecosystems. We are also developing an iPhone/iPad application for field identification of typical plants and animals of sandy beach ecosystems in the South Coast Region. We anticipate that this project will lay the essential groundwork for the effective development of a long term monitoring program for sandy beach ecosystems in the South Coast region.

IV. Monitoring Recommendations

Beaches in the SC region were physically and ecologically diverse. Only our proposed macroinvertebrate indicator taxa, sand crabs and talitrid amphipods, were observed on all 12 focal beaches, and a number of macroinvertebrate species were observed on only a few beaches. Sand grain size, beach slope, wave energy and other physical characteristics varied substantially among beaches, as did the amount of macrophyte wrack deposited onto the beaches from kelp forests and reefs. Despite this variation, there were no striking or consistent ecological differences between MPA and reference beaches in the region in the baseline study. Our work with two citizen scientist initiatives in the region provided excellent opportunities to share knowledge; compare, design and improve survey methods.

Physical and ecological characteristics of sandy beach ecosystems are extremely dynamic on temporal scales ranging from hourly to decadal. Ecological monitoring of sandy beach ecosystems is currently extremely limited in the state of California. This has resulted in a significant lack of knowledge that severely hinders conservation and management of these dynamic ecosystems and the ecological functions and wildlife they support. We recommend using the suite of ecological indicators and metrics identified and evaluated in this study (Table 1) for use in much needed long-term monitoring of sandy beaches in the SC region. These indicators include shorebirds, macrophyte wrack and selected macroinvertebrates that represent the two main branches of the subsidized beach food web. Standardized, monthly observations of birds, fresh kelp plants, people and dogs on beaches along standardized alongshore transects should be a component of long term monitoring. Our two primary macroinvertebrate indicator taxa, sand crabs and talitrid amphipods, can be relatively quickly sampled, identified and quantified by trained observers. Surveys of these taxa should be conducted at least once a year however conducting spring and fall surveys would yield much needed insights on the dynamics of recruitment, production and survival of these key taxa. The recommended suite of indicators could provide a cost-effective and scientifically valid approach to monitor the ecological state of sandy beaches in the SC region over time. With appropriate modifications, tiered structure, additional testing and validation, combined with considerable scientific oversight to ensure accuracy and consistency of the data collected, some of aspects of monitoring SC beaches may potentially be conducted in collaboration with trained and committed citizen scientists.

Our surveys revealed that a great number of endemic and rare intertidal invertebrates with restricted distributions inhabit SC beaches, including MPAs. For this reason, we recommend that the biodiversity of beaches should be evaluated with comprehensive surveys that are conducted every few years.

V. Integration

Here we provide a very brief summary of the areas in which results from our South Coast Sandy Beach Baseline Project are being used to explore integrative issues, beyond the sandy beach ecosystem, and involving integrative analyses of data collected by other South Coast MPA Baseline Projects.

- Biogeographic patterns of communities across multiple marine ecosystems in southern California". Jeremy Claisse, Carol Blanchette, Jennifer E. Caselle, Jonathan P. Williams, Daniel J. Pondella, Laurel A. Zahn, Chelsea M. Williams, Jenifer Dugan, James Lindholm, Ashley Knight, Dan Robinette, Meredith Elliott, Rani Gaddam, Katie Davis and others TBD
- Distribution of birds as high trophic level indicators". Jenifer Dugan, David Hubbard, Dan Robinette and Carol Blanchette
- "Citizen science monitoring of marine protected areas: case studies and recommendations for integration for among monitoring programs". Jan Friewald, Jennifer Caselle, Karina Nielsen, Steven Morgan, Ryan Meyer, Doug Neilson, Kevin Hovel, Jenny Dugan, Dina Liebowitz, and Julie Bursek.

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