Baseline Characterization of Sandy Beach Ecosystems in California's North-Central Coast Region

Final Report

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by

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EXECUTIVE SUMMARY

Sandy beaches are among the most intensely used coastal ecosystems for human recreation and are important to coastal economies, foraging shorebirds and surf zone fishes. Sandy beach habitat composes 51% of the 592 km of shoreline in the North-Central Coast (NCC) region but little more than 10% of the available sandy beach habitat in the region was protected in three Marina Protected Areas (MPAs). The goal of this ecological characterization was 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 within and outside of MPAs. We also recommend ecological indicators for targeted, cost-effective assessments and developed two citizen-scientist protocols.

Our baseline monitoring program consisted of five components:

1. A year of monthly surveys of birds, macrophyte wrack (seaweeds, seagrasses and surfgrasses deposited on the beach), human activities and the physical characteristics of 10 focal beaches and their adjacent surf zones (5 MPA, 5 Reference sites);
2. A one-time, comprehensive survey of macroinvertebrate biodiversity of the 10 focal beaches;
3. Surveys of proposed invertebrate indicator species, beach hoppers (talitrid amphipods, *Megalorchestia* spp.) and sand crabs (*Emerita analoga*), at 17 beaches including the 10 focal beaches;
4. Citizen-scientist surveys of proposed fish indicator species, surfperches, at two pairs of MPA and reference beaches conducted seasonally (fall) for two years; and
5. A collaborative comparison of sand crab survey designs at three beaches with the Gulf of the Farallones National Marine Sanctuary's Long-term Monitoring Program and Experiential Training for Students (LiMPETS) program, a citizen-science group monitoring one of our proposed indicator species (sand crabs).

On sandy beaches in the NCC region, drift seaweeds, especially kelps, provide nutritious food for beach hoppers and other invertebrates, which in turn, are an important food source for foraging shorebirds. Other kinds of macrophyte wrack (other seaweeds, seagrasses and surfgrasses) and driftwood provide important habitat for invertebrates and nesting shorebirds, including the federally listed Western Snowy Plover. Sand crabs and other macroinvertebrates also provide food for wading shorebirds and for surfperch and other surf zone fishes, and seabirds, such as Surf Scoters. The physical characteristics of the beach, the surf zone and the sand itself can all have a strong influence on the kinds of animals that dwell there. Heavy human visitation and some beach activities, including running off-leash dogs, can also strongly affect the number and kinds of shorebirds that use different beaches for feeding, nesting and resting.

The study beaches were physically diverse. Of the 17 study beaches, 11 were long beaches and six were pocket beaches, and three of each type were located within MPAs. Four of the 17 and two of the 10 focal beaches were characterized as reflective beaches with coarse sand and narrow surf zones and the rest were intermediate beaches; dissipative beaches did not occur in the NCC region. The physical characteristics of the 17 beaches differed considerably, but there were no consistent differences between MPA and reference beaches, bioregions north and south of Point Reyes (as defined during the MPA planning process), or long and pocket beaches.

The major findings of our baseline characterization are summarized below.

- Not surprisingly, human use of sandy beaches was 10 to 100 times greater on sunny summer weekend days than on weekday mornings during low tides when we conducted our monthly ecological surveys. We observed as many as 390 people and 53 dogs per km of shoreline and as few as none in our surveys. Private access beaches had the lowest rate of visitation. People primarily used beaches, for nature walks, resting/socializing, water sports and beach sports/play (in decreasing order of occurrence). Popular activities in all four categories were most common on long, non-MPA beaches, especially dog walking.

- Macrophyte wrack was most abundant on beaches from June to December but varied greatly in quantity and composition among beaches. Average macrophyte cover ranged from 0.1 to 3 m^2 per meter of shoreline, and peak deposition of fresh kelp plants occurred in November (>2000 plants per km) on pocket beaches. Standardized counts of fresh kelp plants were excellent predictors of the total cover of kelp wrack on the beach. The composition of wrack on beaches depended on the proximity to the source habitats for the macrophytes (rocky reefs, bays and estuaries) and prevailing ocean currents. Wrack abundance, especially kelp wrack, tended to be greater on pocket than long beaches and in the northern than southern bioregion. Wrack abundance and composition did not differ between MPA and reference beaches overall.

- We identified over 67 kinds of macroinvertebrates from the 10 focal beaches. However, only our invertebrate indicator species were observed on all 10 focal beaches, and many macroinvertebrate species were observed on only one beach. The abundance and biomass of beach hoppers and other wrack-associated invertebrates tended to be greater on pocket beaches, whereas the abundance and biomass of sand crabs tended to be greater on long beaches. The total abundance, biomass and richness of macroinvertebrates did not differ between MPA and reference beaches or long and pocket beaches, although invertebrate biomass was generally greater on long beaches.

- Birds were seasonally abundant with over 6,000 birds of 51 species observed on the 10 focal beaches in one year. More species occurred on long compared to pocket beaches. The abundance of birds at MPA and reference beaches did not differ substantially for shorebirds and seabirds overall, although gulls were most abundant on long MPA beaches and pocket reference beaches. Although only a small proportion of birds observed were terrestrial (~ 5%), they were strikingly concentrated on pocket beaches, exceeding the average abundances of shorebirds, sea, birds and gulls on these beaches, only. They were also more abundant on beaches in MPAs, perhaps due to lower human use.

- Citizen-scientist fishers caught six species of surfperches at the two pairs of MPA and reference beaches (all long beaches), but only two species were abundant: Silver (*Hyperprosopon ellipticum*) and Redtail (*Amphistichus rhodoterus*) surfperch. Consistent differences between MPA and reference beaches were not evident for these fishes, but there were large differences in abundance and species composition between beaches located to the north of Bodega Head and those to the south of Point Reyes. No evidence of trophic links between surfperches and the high abundance of macroinvertebrates found in the lee of the Point Reyes headland was found, in contrast to shorebirds and seabirds. Redtail and Silver surfperch may prefer the greater wave exposure, and more complex bottom features present at the beaches to the north of Bodega Head. The close proximity of the paired MPA and non-MPA beaches to each other and the possibility that the beaches may have overlapping populations of mobile surfperches may have reduced any differences due to MPA designation.

- Analyses of the relationships among physical and biological conditions of sandy beaches revealed important ecological links and associations, including new insights into differences between pocket and long beaches and possible impacts of human visitation.
    1. 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 seabirds and fishes that forage in surf zones.
    2. The abundance of shorebirds is tightly correlated with the species richness and biomass of macroinvertebrates as well as with the biomass of sand crabs alone, reflecting trophic links between beaches and wildlife. However, on beaches with high human and dog visitation and those surrounded by high cliffs or bluffs with no safe refuge for foraging shorebirds, these relationships were not apparent.
    3. The abundance and species richness of shorebirds was also correlated with the abundance and composition of macrophyte wrack and macroinvertebrates reflecting the feeding and habitat relationships among these organisms.
    4. Shorebird abundance was correlated with the abundance of beach hoppers on long beaches, but not on pocket beaches.
    5. The abundance of terrestrial birds was also tightly linked to the abundance? and composition of macrophyte wrack and macroinvertebrates indicating a role of beach invertebrates in adjacent terrestrial ecosystems, especially for pocket beaches.
    6. The overall abundance and composition of macroinvertebrates, was also related to physical characteristics of beaches due to the influence of sand grain size on burrowing and energetics.
    7. The diversity and composition of bird assemblages differed between pocket and long beaches, but not between MPA and reference sites or between bioregions; shorebirds and seabirds were most abundant in the lee of the Point Reyes and Bodega Head headlands.
    8. Macrophyte wrack and macroinvertebrate assemblages (all identified organisms) did not differ between MPA and reference beaches, long and pocket beaches or bioregions north and south of Point Reyes, indicating that diversity was similar.

- The sand crab surveys conducted by the LiMPETS citizen-scientist program provides an important pathway for K-12 students to learn about the ecology of sandy beaches, MPAs and the use of scientific evidence to inform management of natural resources. In comparison to our protocol, the LiMPETS protocol:
    1. Yields similar estimates of the *relative* abundances of sand crabs among sites for total and young of year crabs, but *not* for adult crabs;
    2. Underestimates the absolute abundances of sand crabs of all age classes;
    3. Under-samples adult sand crabs in the lower swash zone, especially on steep sloped beaches due to safety considerations for children.
    4. Provides a good estimate of young-of-the-year sand crabs that burrow shoreward of the swash zone.

Recommendations

Beaches in the NCC region were physically and ecologically diverse. Only our proposed invertebrate indicator species were observed on all 10 focal beaches, and a number of macroinvertebrate species were observed on only one beach. Sand grain size, beach slope, wave energy and other physical characteristics varied substantially among beaches, as did the amount and kinds of macrophyte wrack drifting onto the beaches from nearby habitats. Despite this variation, there were no striking or consistent ecological differences between MPA and reference beaches in the region, with the exception of visitation by people and their dogs.

Human visitation was episodically high, and by far, most activities were non-consumptive. MPA beaches were less frequently visited by people and their dogs, making them currently more attractive to shorebirds. However, dog walking and other non-consumptive human activities are not restricted in these MPAs, and therefore, this apparent benefit for shorebirds may not persist.

The most striking ecological differences occurred between long and pocket beaches. Sand crabs and shorebirds were more abundant on long beaches, whereas kelp wrack and wrack-associated invertebrates were more abundant and terrestrial birds were more dominant on pocket beaches. Pocket beaches may thus be areas of enhanced transfer from marine to terrestrial ecosystems. Because the ecology of pocket beaches has not been previously studied, these are new insights into the ecological functioning of different beach types in general and northern California shorelines in particular. The MPA planning process did not consider possible difference among beach types, but these differences should be taken into account when interpreting future ecological changes for adaptive management.

Our work with two citizen scientist initiatives in the region provided excellent opportunities to share knowledge; compare, design and improve survey methods; and collect scientific data to assess the status of different sandy beach species in collaboration with local citizens and students. Together, we were able to estimate differences in the abundance and diversity of surfperch on four NCC beaches. We also identified sound approaches for analyzing historic sand crab data collected by the students in the LiMPETS program and recommended modifications to the protocol.

We recommend using our suite of ecological indicators for continued long-term monitoring of sandy beaches in the NCC. The monitoring can be conducted cost-effectively in collaboration with citizen scientists, provided that technical and administrative oversight and support together with a reliable and enthusiastic group of trained volunteers is available to ensure accuracy and consistency of the data collected. Standardized, monthly to seasonal observations (targeting fall and spring migration seasons) of birds, people, dogs and fresh kelp wrack on beaches could be made by volunteers walking an alongshore transect. Sand crabs and beach hoppers can be relatively quickly sampled, identified and quantified, with minimal training and access to some equipment and a small amount of wet lab space; a single survey in late summer is sufficient for a good population estimate. Standardized fishing for surfperch by recreational anglers seasonally can also be readily implemented. Thus, this suite of indicators would provide a reliable, cost-effective approach to monitor the ecological state of sandy beaches in the region over time.

Introduction

Sandy beaches are among the most intensely used coastal ecosystems for human recreation and are critically important cultural and economic resources to coastal regions. Sandy beaches and adjacent surf zones are also important foraging areas for shorebirds and fishes that feed on intertidal invertebrates. However, despite their ecological and socio-economic importance and strong potential to serve as indicators of coastal ecosystem condition, sandy beach ecosystems are under-represented in the marine ecological literature. Due their highly dynamic nature and heavy recreational use they are inherently less amenable to manipulative field experimentation, and this is especially true at higher, temperate latitudes where wave energy is greater and sands tend to be coarser than at lower latitudes. The recent establishment by California of a new network of marine protected areas (MPAs) along its north-central coast (NCC) provided a unique opportunity to complete the first comprehensive, baseline description of the biodiversity of sandy beaches in the region as part of the North Central Coast MPA Baseline Program. Herein we provide a baseline assessment of sandy beach ecosystems including those within MPAs established in 2010 as well as beaches not included with the boundaries of the NCC network of MPA sites and expand our ecological understanding of their condition and functioning.

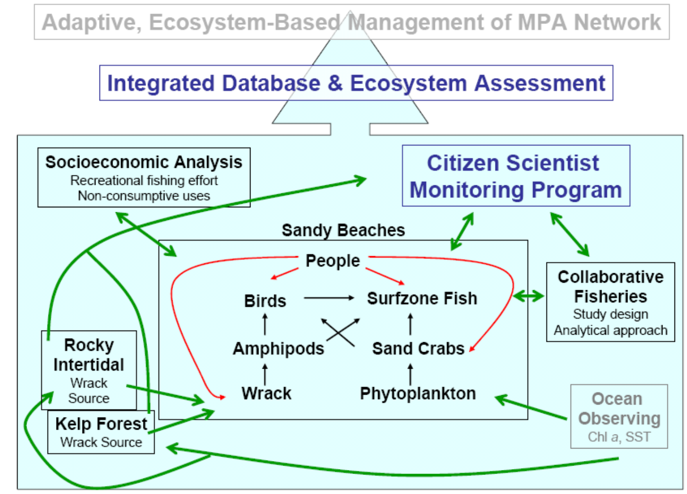


Figure 1. Links among ecosystem features, proposal components, existing datasets and integrated outcomes for sandy beaches. Green arrows show links among proposal components and ecosystem features; black arrows indicate positive effects; red arrows indicate negative effects; black text indicates project module or ecosystem feature; blue text indicates synthetic outcomes; gray text indicates entities or outcomes outside the scope of this proposal (figure copied from the original proposal).

In 2010, 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 while involving citizen scientists (e.g., students, recreational fishers, members of conservation/nature organizations) 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 NCC network of MPAs (Fig. 1). Our monitoring program consisted of five distinct but inter-related components. Three of them were standard ecological surveys or sampling efforts that involved a scientific research team and two were citizen-scientist survey efforts that were designed and led by scientists but engaged volunteers from the community to carry out the field work (and are referred to as ‘citizen scientist surveys’ in the rest of this report).

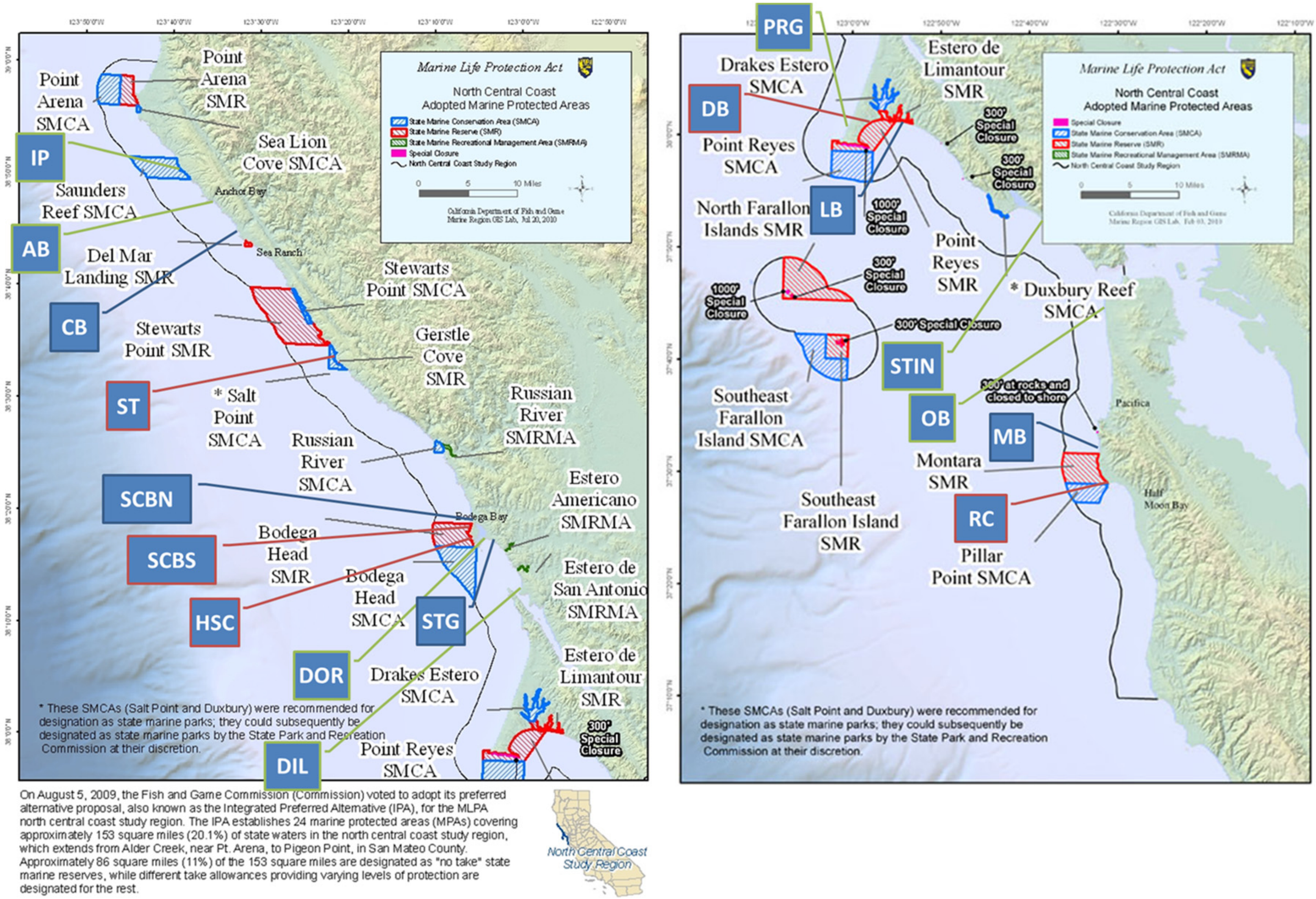
The first standard ecological component was a year of monthly surveys of birds, macrophyte wrack, human activities and the physical characteristics of 10 focal beaches and their adjacent surf zones (Fig. 2). These surveys allowed us to characterize a full seasonal cycle of the dynamics of wrack deposition and the occurrence and diversity of birds and humans uses on regional beaches. The 10 beaches included six long and four pocket beaches, half of each type within MPAs and the other half outside to serve as reference beaches. The second component was a one-time, comprehensive survey of macroinvertebrate biodiversity of the same 10 beaches. The quantitative sampling included core sampling for infauna as well as net sweeps and sticky traps to quantify surface crawling and flying wrack-associated macroinverterbates. The third effort focused on sampling 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*) (Fig. 1). 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. In addition, sand crabs were already the subject of the Gulf of the Farallones (GoF) National Marine Sanctuary (NMS) education and outreach program (Long-term Monitoring Program and Experiential Training for Students or 'LiMPETS' program) that engages local K-12 and community college students in field sampling and we sought to collaborate with and build on this existing monitoring program. We surveyed these target taxa at our 10 focal beaches as well as seven additional beaches in the region (Fig. 2). We used these datasets to explore the hypothesized relationships among beach ecosystem components illustrated in Figure 1.

One of our two citizen-scientist projects focused on engaged regional recreational fishing clubs, several local individuals with extensive expertise in surf zone fishing, as well current and retired staff/biologists from the California Department of Fish and Wildlife in assessing the abundance and diversity of surf zone fishes, with emphasis on surfperch (in the family Embiotocidae). We focused our sampling effort on two pairs of beaches (each with one MPA and a nearby reference beach) within Point Reyes National Seashore along Drake's Bay (DB & LB in Fig. 2, Table 1) and Sonoma Coast State Park just north of Bodega Head (SCBS & SCBN in Fig. 2, Table 1). These two pairs of sampling sites are located on either side of the boundary (approximately located at Point Reyes) that designated the northern and southern bioregions identified in the MPA planning process to ensure representativeness and replication of MPAs within the NCC region (Fig. 2). In addition, the two MPA beaches (SCBS & DB) were the only ones in the region sufficiently long to meet the scientific guidelines for representation of sandy beach habitat within the NCC MPA network (MLPA SAT 2008).

Our final project component, and the second citizen-scientist project, focused on working with the LiMPETS sand crab monitoring program. We collaborated in a replicated, side-by-side sampling effort at three different beaches (SCBN, LB & MB in Fig. 2) that engaged undergraduate marine ecology university students from Sonoma State University and Bodega Marine Laboratory (University of California, Davis), high school students from Lake County participating in the LiMPETS program as well as staff from the LiMPETS program. We compared their sand crab sampling method, initially designed to serve an educational mission but with long-term monitoring in mind, to the method we used in our baseline monitoring program. The aim of this effort was twofold: first, we wanted to cross-calibrate our different methods (if possible) to make the best possible use of existing regional data sets the collected by the LiMPETS program with school kids since 2002 and second, to recommend adjustments to the LiMPETS protocol, if needed, to improve its scientific efficacy as a long-term, citizen science monitoring program for regional sandy beaches (in addition to serving its equally valuable educational mission).

We present our report in four sections:

I. The baseline ecological status of sandy beaches in the NCC
II. A citizen science survey of surf zone fishes along Drake's Bay and the Sonoma Coast
III. Collaborative sand crab monitoring with the Gulf of the Farallones National Marine Sanctuary's LiMPETS education and outreach program
IV. Conclusions and recommendations



* These SMCAs (Salt Point and Duxbury) were recommended for designation as state marine parks; they could subsequently be designated as state marine parks by the State Park and Recreation Commission at their discretion.

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On August 5, 2009, the Fish and Game Commission (Commission) voted to adopt its preferred alternative proposal, also known as the Integrated Preferred Alternative (IPA), for the MLPA north central coast study region. The IPA establishes 24 marine protected areas (MPAs) covering approximately 153 square miles (20.1%) of state waters in the north central coast study region, which extends from Alder Creek, near Pt. Arena, to Pigeon Point, in San Mateo County. Approximately 86 square miles (11%) of the 153 square miles are designated as "no take" state marine reserves, while different take allowances providing varying levels of protection are designated for the rest.

Figure 2. Sandy beach baseline monitoring sites and marine protected areas (MPAs) in NCC region of the network of MPAs. Red outlined callout boxes indicate beaches inside of MPAs and blue outlined ones indicate reference beaches for 10 focal survey beaches, and green outlined ones indicate additional reference beaches surveyed only once for a subset of targeted taxa. See Table 1 for site codes Figure redrawn from MPA maps downloaded from the California Department of Fish and Wildlife's webpage (http://www.dfg.ca.gov/marine/mpa/nccmpas_list.asp; accessed 5/31/2013).

Table 1. Beaches surveyed and sampled for the North Central Coast Baseline Monitoring Program.

Beach	Abbreviation	MPA Name and Management designation(s)	County	Latitude	Longitude
Iverson Point Island Cove Beach	IP	Saunders Reef State Marine Conservation Area; Island Cove Estates Subdivision (private access only)	Mendocino	38.845233	-123.642383
Anchor Bay Beach	AB	Anchor Bay Campground (private access)	Mendocino	38.801867	-123.579767
Cooks Beach	CB		Mendocino	38.789900	-123.560433
Stump Beach	ST	Salt Point State Marine Conservation Area; Salt Point State Park	Sonoma	38.581917	-123.335600
South Salmon Creek Beach (N)	SCBN	Sonoma Coast State Park	Sonoma	38.345217	-123.068383
South Salmon Creek Beach (S)	SCBS	Bodega Head State Marine Reserve; Sonoma Coast State Park	Sonoma	38.329100	-123.071333
Horseshoe Cove Beach	HSC	Bodega Head State Marine Reserve; Bodega Area of Special Biological Significance	Sonoma	38.317000	-123.069400
Doran Beach	DOR	Sonoma Regional County Park	Sonoma	38.313633	-123.042400
Short Tail Gulch Beach	STG	Gulf of the Farallones National Marine Sanctuary	Sonoma	38.303533	-123.013083
Dillon Beach	DIL		Marin	38.249683	-122.968617
Pt. Reyes Great Beach	PRG	Point Reyes National Seashore; Gulf of the Farallones National Marine Sanctuary	Marin	38.078267	-122.975450
Drakes Beach	DB	Point Reyes State Marine Reserve; Point Reyes National Seashore; Gulf of the Farallones National Marine Sanctuary	Marin	38.025950	-122.962683
Limantour Beach	LB	Point Reyes National Seashore; Gulf of the Farallones National Marine Sanctuary	Marin	38.024867	-122.880800
Stinson Beach	STIN	Gulf of the Farallones National Marine Sanctuary	Marin	37.896800	-122.641883
Ocean Beach	OB		San Francisco	37.767883	-122.512033
Montara Beach State Park	MB	Montara Beach State Park; Monterey Bay National Marine Sanctuary	San Mateo	37.550467	-122.514233
Ross Cove Beach	RC	Montara State Marine Reserve / Pillar Point State Marine Conservation Area; Monterey Bay National Marine Sanctuary; James V. Fitzgerald Area of Special Biological Significance	San Mateo	37.500717	-122.498567

I. The baseline ecological status of sandy beaches in the NCC

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 following the implementation of MPS in the region.

BACKGROUND AND MANAGEMENT CONTEXT

Sandy beach habitat makes up 51% of the NCC region's 592 km of shoreline (California Marine Life Protection Act Initiative 2007). A little more than 10% of the available sandy beach habitat in the region was ultimately protected within three MPAs in two of the three 'biogeographical subregions' (bioregions, herafter) of the NCC region (two in the north and one in the south) (California Marine Life Protection Act Science Advisory Team 2008). The three bioregions [Farallon Islands, North and South (from North Beach Road at approximately Point Reyes to Alder Creek and Pigeon Point, respectively)] were recognized as having distinctive oceanographic features, geomorphology and differing species compositions (within state waters) during MPA planning process (California Marine Life Protection Act Science Advisory Team 2008). Broadly speaking, California MPAs restrict extractive activities or consumptive uses within the boundaries of the MPAs, but do not restrict visitation, access or other activities within their boundaries, except for some 'special closures' that prohibits access or restrict boating activities in waters adjacent to sea bird rookeries or marine mammal haul-out sites[1]. This study only included beaches in State Marine Reserves (SMRs) and State Marine Conservation Areas (SMCAs).

In order to capture the two major beach types that were conferred protected status within the region (excluding special closures), we included two types of sandy beaches: long beaches (>1 km of contiguous sandy shoreline) and pocket beaches (< 1 km of contiguous sandy shoreline bounded by rocky shoreline) (Figs. 2) in this baseline assessment. Although about one third of the sandy shoreline included specifically to meet conservation goals for this habitat within NCC MPAs was in the form of pocket beaches, to our knowledge, very few (if any) ecological studies have focused on pocket beaches. Furthermore, although small, pocket beaches are geomorphologicaly and morphodynamicaly distinguished from longer beaches (e.g., Dehouck et al. 2009, Daly et al. 2011), they were assumed to be ecologically equivalent to long beaches in the scientific guidelines used during the MPA proposal evaluation and planning phase (California Marine Life Protection Act Science Advisory Team 2008). Thus we considered increasing our ecological knowledge of pocket beaches an important objective for sandy beach baseline monitoring and opted to include six pocket beaches (two within MPAs) in our monitoring program.

In the MPA planning process an MPA containing at least 1.6 km of sandy shoreline (cumulatively) was considered to sufficient habitat to encompass about 90% of sandy beach species (California Marine Life Protection Act Science Advisory Team 2008) and contribute toward meeting the

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[1] For the detailed, legal definition of the different categories of MPAs in California and their specific regulations please see this webpage: http://www.dfg.ca.gov/marine/mpa/nccmpas_list.asp.

conservation goals specified by the Marine Life Protection Act[2]. However, relatively little sandy beach habitat was actually captured within NCC MPAs especially in comparison to rocky intertidal habitat (*cf.* 10% for sandy beach vs. 30% rocky intertidal habitats; California Marine Life Protection Act Science Advisory Team 2008) and in the entire NCC MPA network there are only two long beaches with >1 km of contiguous sandy shoreline [SCBS and DB in the Bodega Head and Point Reyes State Marine Reserves (SMRs); Fig. 2, Table 1]. These two beaches are included among the total of 11 long beaches we included in our baseline assessment. The third and only other MPA with > 1.6 km of sandy habitat was the Stewarts Point SMR[3], but all in the form of small pocket beaches whose cumulative sum of sandy shoreline reached the benchmark. Most of the pocket beaches within the boundaries of this MPA have limited shore-based access due to steep cliffs or private land ownership, and as a result the two pocket beaches within MPAs included in this study could not be located within the boundaries of the former Stewarts Point SMR (or current Stewarts Point SMCA). Instead we included two accessible pocket beaches within the Salt Point SMCA (ST) and the Bodega Head SMR (HSC) (Fig. 2, Table 1). Thus although the data collected in this effort represent a substantial step forward in our understanding of the ecology of sandy beaches in the region and of smaller pocket beaches in particular, only five of the 17 beaches in total that we surveyed or sampled are within MPAs.

METHODS

We used three different survey and sampling efforts, 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 17 sandy beaches in the NCC region. Six of these beaches were within MPAs, two in SMCAs and four in SMRs (Table 1).

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 10 focal beaches. The 10 focal beaches were surveyed monthly for a year between June 2010 and May 2011 and included five MPA and five reference sites, and seven additional sites were surveyed once in August 2010 (Table 2). An additional one-time survey to estimate the peak usage and activities of people was conducted over a summer weekend day on all 17 beaches in July 2011. Simultaneously with the alongshore surveys, wrack cover was measured using a line-intercept method on each of three shore-normal transects of variable length that extended from the lower edge of

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[2] However, in contrast to many other habitats where the minimum spatial extent was determined by reference to a species area curve for that specific habitat type, this criterion was not data-based for sandy beach habitat and instead relied on expert scientific judgment because of the lack of accessible data (California Marine Life Protection Act Science Advisory Team 2008).

[3] The boundaries of the Stewards Point SMR in effect at the time our baseline monitoring program was subsequently divided into two MPAs (Stewarts Point SMR and SMCA) by emergency action of the California Fish and Game Commission (CFGC 2010). SMCAs allow for some recreational and commercial take while SMRs prohibit all extractive activities. The emergency action was taken after the NCC MPAs were designated in response to a petition by the Kashia Band of Pomo Indians requesting that the CFGC recognize the significance and importance of their historic and contemporary subsistence use of marine resources and that they be allowed to continue.

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.

A standard alongshore transect was established at each of the 10 focal beaches, the size of these transects never exceeded 1 km in length, however shorter segments (120 – 240 m) were required for the pocket beaches (Table 2). Once established, the endpoints of the selected segments were described and their positions determined with GPS.

Table 2. Beaches types, transect lengths and dates surveyed and sampled. Focal beaches are indicated in bold. Abbreviations as in Table1.

Beach Abbreviation	MPA Type	Beach Type	Transect Length (km)	Rapid	Biodiversity	Target 1	Target 2
IP	SMCA	Pocket	0.19				13-Aug-10
AB	Reference	Pocket	0.24				13-Aug-10
CB	Reference	Pocket	0.15	June 2010 - May 2011	18-Jul-11	18-Jun-10	16-Aug-10
ST	SMCA	Pocket	0.12	June 2010 - May 2011	5-Jul-11	18-Jun-10	16-Aug-10
SCBN	Reference	Long	1	June 2010 - May 2011	2-Jul-11	16-Jun-10	9-Aug-10
SCBS	SMR	Long	1	June 2010 - May 2011	3-Jul-11	16-Jun-10	9-Aug-10
HSC	SMR	Pocket	0.17	June 2010 - May 2011	16-Jul-11	15-Jun-10	10-Aug-10
DOR	Reference	Long	1				9-Aug-10
STG	Reference	Pocket	0.12	June 2010 - May 2011	15-Jul-11	1-Jul-10	10-Aug-10
DIL	Reference	Long	1				9-Aug-10
PRG	Reference	Long	1				14-Aug-10
DB	SMR	Long	1	June 2010 - May 2011	17-Jul-11	17-Jun-10	11-Aug-10
LB	Reference	Long	1	June 2010 - May 2011	1-Jul-11	17-Jun-10	11-Aug-10
STIN	Reference	Long	1				12-Aug-10
OB	Reference	Long	1				12-Aug-10
MB	Reference	Long	1	June 2010 - May 2011	6-Jul-11	19-Jun-10	15-Aug-10
RC	SMR/SMCA	Long	1	June 2010 - May 2011	19-Jul-11	19-Jun-10	15-Aug-10

Surveys of the 10 transects were conducted monthly at each of the 10 focal beaches from June 2010 to May 2011 (except July 2010) for a total of 6.56 km of beach and surf zone per month. Using two teams of observers who surveyed two sites per day each, surveys of all 10 beaches were generally conducted within 4-5 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. The single exception to the weekday and low tide conditions for the surveys was during the one-time weekend survey (of all 17 beaches) conducted in July 2011 to estimate peak usage and activities of people (only).

During each month, all shorebirds, gulls, seabirds and other birds, including terrestrial birds, were identified and counted on the selected transects of the 10 focal beaches. Counts were conducted by a single observer (either KJN or SGM) 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 water table outcrop [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 kelp wrack (not dried-up, mostly intact and located below the high tide strand line) of the species *Nereocystis leatkeana*, *Postelsia palmaeformis* and *Macrocystis pyrifera*. To avoid over estimating their abundance due to fragmentation, we identified and enumerated only those individuals with an intact pneumatocyst in the case of *Nereocystis* or holdfast in the case of *Postelsia* or *Macrocystis*. On a couple of occasions when abundances were extraordinarily high in the fall, we made (conservative) order of magnitude estimates in lieu of direct enumeration.

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.

The extent and presence of each type 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 (HTSL) 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®). The number of cars in the parking lot by the access point, any vehicle tracks on the beach 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 HTSL 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, standard deviation (=sorting), skewness, kurtosis for each sample.

Biodiversity sampling

To describe the biodiversity of intertidal invertebrates on the beaches, we quantitatively sampled the intertidal macroinvertebrate community at each of the 10 focal beaches (five MPA and five reference beaches) during daytime spring low tides in July of 2011. These community surveys were temporally constrained to a period of 18 days (over two consecutive spring tide series) to reduce the potential for confounding comparisons due to seasonal variation (Table 2).

The species richness, abundance, biomass and population characteristics of the macroinvertebrate community of the 10 focal beaches was estimated using sampling protocols similar to those used in earlier studies of California beaches (Dugan et al. 2003). Quantitative sampling was conducted on three vertical format (shore-normal) transects as described above for macrophyte wrack surveys and physical measurements (see ***rapid survey*** methods), 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 of the fauna. 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 beach width. 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 (Schlacher et al. 2008). Most species of macrofauna likely to be prey of shorebirds were retained on a 1.5 mm sieve. Sediments were removed from the accumulated core samples from each zone by sieving in the swash zone (at a distance from the sampling transects).

Samples in which large amounts of coarse sediments are retained in the mesh bag were elutriated *in situ* to separate the macroinvertebrates from the sand. Upper cores with retained coarse sediments were hauled back to laboratory and frozen first, and then elutriated. 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 which 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 were placed in labeled plastic bags, chilled and transported to the laboratory for processing and preservation. 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.

In addition, kelp flies were sampled using 50-100 standard sweeps of insect nets along the 3 transects. 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 commercial sticky fly paper (Revenge Fly-catcher®). Two strips of fly paper were deployed in the wrack zone within one meter of each transect line for 15 minutes. 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 all fauna

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.

Target sampling

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 twice (June and August) in 2010 for each of the 10 focal beaches. In August 2010, an additional seven beaches were surveyed. The sampling sites and dates appear in Table 2.

The abundance, biomass and population characteristics of *E. 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 *E. analoga*, we collected a series of 20 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 macrofauna 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 that could be unambiguously sexed (generally >8 mm) were measured with vernier calipers to the nearest mm for future determination of mean adult body size and sex ratios.

For upper beach fauna, including *Megalorchestia* spp., we collected a series of 10 cores from the lower edge of terrestrial vegetation to the lowest stranded wrack or drift line. Cores were pooled and placed in a bag with an aperture of 1.5 mm for sieving and sieved as described immediately above (and ***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 prey species retained on the sieves were identified, enumerated, blotted dry and weighed to the nearest 0.001g.

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 SAS/STAT® Statistical Analysis Software. All bird, human, dog and fresh kelp abundances from the alongshore transects are expressed as the number per km of shoreline (or per 100 m of shoreline in the case of pocket beaches). Macroinvertebrate abundances derived from core samples are 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 use 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.

Statistical analyses

We present our results primarily using descriptive summary statistics, contrasting responses of MPA and reference beaches, as well as pocket and long beaches. Because of the geology of the region, pocket beaches are more common northern than the southern bioregion of the NCC, making it difficult to disentangle biogeography from beach morphology per se, especially given the limited number of beaches surveyed. We explore relationships among hypothesized subsets of response variables representing important or hypothesized ecological links through correlation analyses.

We also used multivariate analyses including non-metric multidimensional scaling (MDS) , hierarchical clustering, PERMANOVA, RELATE and SIMPER available in the statistical software package PRIMER-E (ver. 6.1.13) & PERMANOVA (ver.1.0.3) (Plymouth Marine Laboratory) to investigate the degree of similarity in the taxonomic composition of the macroinvertebrate and bird assemblages and standing crop of macrophyte, their relationships to each other and the physical characteristics of the beach, as well as to address the questions of interest identified, also at the community level. The macroinvertebrate and bird assemblage data were fourth-root transformed prior to analysis and a few of the rarest and taxonomically unresolved species were lumped to a high taxonomic level. The macrophyte data were not transformed, because they were already merged into major functional groups, and were more evenly distributed without an abundance of zeros. Physical data were normalized before analysis. We used Bray-Curtis distances to create the biological resemblance matrices and Euclidean distances for the physical data resemblance matrix. We investigated correlations between the MDS axes and the taxonomic groups used to generate the MDS ordinations as well as their relationship to other key covariates from associated biological and physical data sets. We used the group averaging method in the hierarchical clustering analysis and used a SIMPER analysis to test the null hypothesis that the clusters that emerged were just random groupings of the variable data and had no inherent underlying structure.

RESULTS

Physical Characteristics of the Beaches

The locations, landward boundaries and survey dates of the beaches are given in Figures 2 and Tables 1 & 2.

Intertidal width and zone widths

Mean overall beach widths (landward boundary to low swash level) varied over seven fold, ranging from 24 m to 189 m (Iverson Cove and Ocean Beach, respectively) among the 17 beaches surveyed (Fig. 3). The widest beaches were Stinson Beach and Ocean Beach both > 120 m in overall width. Ten of the 17 beaches surveyed in August 2011 were wider than 75 m. For the 10 focal beaches, the mean widths of the long beaches were generally greater (>75 m) than the pocket beaches with the exception of Ross Cove (34 m) and Salmon Creek Beach North (63 m).

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 3 to 125 m. Salmon Creek Beaches (S & N) and Dillon Beach had the widest average surf zones (106, 119 & 125 m, respectively). Cooks Beach and Stump Beach, both pocket beaches, were the next widest at 80 m each. The remaining pocket beaches had surf zones widths ranging from 63 to 8 m. Ocean Beach and Doran Beach (both long beaches) had surf zones < 6 m. Although the beaches with the widest surf zones were all long beaches, there was no discernible difference in surf zone widths between long (average = 58 m, SD =45) and pocket beaches (average = 49 m, SD =30) overall.

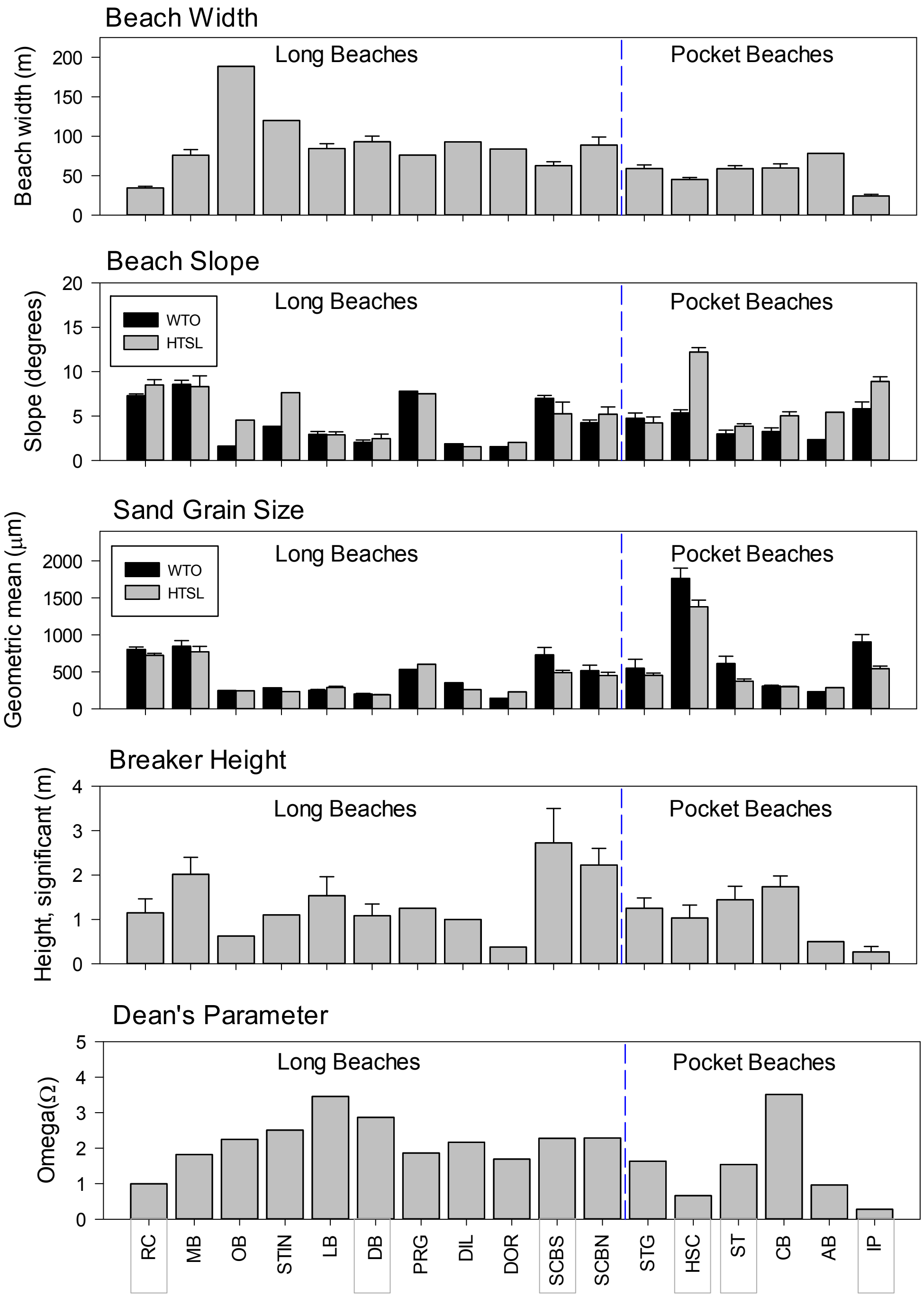


Figure 3. Average physical characteristics of 17 sandy beaches measured monthly between May 2010 and May 2011 (except for OB, STIN, PRG, DIL, DOR, AB & IP that were only visited once in August 2010). Beaches to the left of the dashed line are all long beaches and to the right of the dashed line are all pocket beaches. Within each beach type, beaches are arranged from southernmost on the left to northernmost on the right. All data are averages (+ SE).

Beach Slope

Mean values of beach slope did not vary consistently with intertidal level, (high tide strand vs water table outcrop), at the beaches, although the steepest slope was generally observed at the high tide strand line. Beach slope at the WTO and the HTS varied more than five-fold among beaches (Fig. 3). Mean slopes at the water table outcrop varied from 2.1° to 8.6° among the 10 focal beaches and 1.6° to 8.6° for the survey of 17 beaches (Fig. 3). Slopes generally were steeper at the HTSL where mean slopes varied from 2.5 to 12.2° among the 10 focal beaches and 1.6° to 12.2° for the survey of 17 beaches (Fig. 3). For the 10 focal beaches, the lowest mean WTO slopes (< 3°) occurred on the wide flat beaches of Limantour and Drakes beaches during the baseline study. During the survey of 17 beaches, WTO slopes of < 2 were observed at Dillon Beach, Doran Beach and Ocean Beach (Fig. 3). Anchor Bay also had a WTO slope of < 3° during that survey. For the 10 focal beaches, the pocket beaches of Stump Beach and Cooks Bay had flat beach profiles (3.0°o and 3.3° at the WTO, respectively). Steepest mean slopes (>7°) were observed at the long beaches of Ross Cove, Montara Beach and Salmon Creek Beach South. Moderately steep mean slopes (>4.25° at the WTO) also occurred at Salmon Creek Beach North, Shorttail Gulch and Horseshoe Cove. Beach slopes at the HTSL and WTO were significantly correlated ($r = 0.648$, $p< 0.05$) for the 10 primary study sites and for the 17-beach survey ($r = 0.691$, $p< 0.005$).

Sediment grain size

The mean grain size of sediments from the water table outcrop varied more than eight-fold among the 10 focal beaches, ranging from fine sand, 200 microns, at Drakes Beach to very coarse sand, 1764 microns for the pocket beach at Horseshoe Cove (Fig. 3). The mean grain size at the WTO ranged from 143 microns to 1764 microns in the 17 beach survey. The mean grain size at the WTO was finer, < 260 microns, at the beaches located south of Bodega Head and north of Half Moon Bay in both the focal beaches and the 17 beach survey with the exception of Anchor Bay which had fine sand. Mean grain size at the WTO was generally coarse, exceeding 500 microns, for the beaches north of Bodega Head and those beaches south of Half Moon Bay. Patterns were similar for mean grain size at the high tide strand level (Fig. 3). Mean grain size at the HTSL was highly correlated with mean grain size at the WTO ($r = 0.978$, $p <0.001$ and ($r = 0.958$, $p <0.001$) in both sets of surveys. For the 10 focal beaches, mean grain size was positively correlated with beach slope at the HTSL ($r = 0.966$, $p <0.001$) but not at the WTO ($r = 0.520$, $p >0.05$). For the survey of 17 beaches, mean grain size at the WTO and the HTSL were both positively correlated with the beach slope at the WTO ($r = 0.602$, $p <0.02$ and $r = 0.650$, $p <0.005$, respectively).

Significant breaker height and period

Significant breaker heights varied more than nine fold among the beaches, with means ranging from 0.3 m to 2.7 m in the 17 beach survey and 1.0 m to 2.7 m at the 10 focal beaches (Fig. 3). Mean breaker heights > 2.0 m were observed on three of the long beaches, Montara, Salmon Creek Beach South and Salmon Creek Beach North. No regional variation in wave heights was evident in either survey (Fig. 3). Seasonal variation in wave height may contribute to the lack of regional pattern in these results.

Beach morphodynamics - Dean's parameter

The modal morphodynamic state of the beaches as estimated by Dean's parameter ranged from reflective (Dean's < 1.0) to intermediate (Dean's >1 to <5) in both surveys (Fig. 3). For the 17-beach survey, four of the beaches were reflective with values of Dean's parameter ranging from 0.3 to 1.0. The rest of the beaches (13 sites) were intermediate with Dean's ranging from 1.5 to 3.5. Two of the 10 focal beaches were reflective with mean values of Dean's parameter <1 (Ross Cove and Horseshoe Cove). The remaining eight focal beaches were intermediate in morphodynamic type with mean values of Dean's parameter between >1 and <5. Dean's parameter alone is not considered the best estimator of the morphodynamic state for embayed pocket beaches due to the topographic constraints of headlands on wave climate and beach morphology.

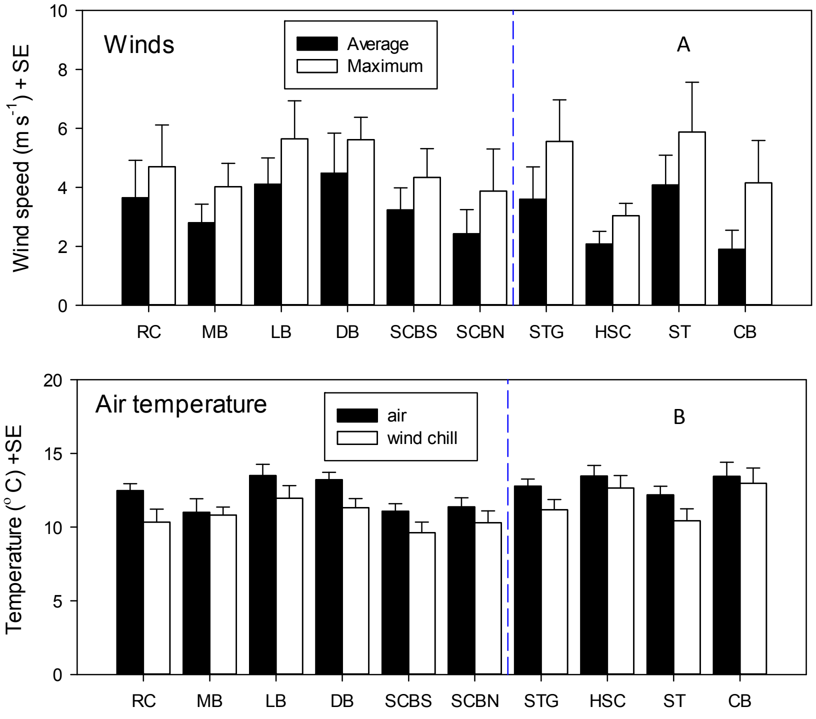


Figure 4. Wind speeds and air temperatures at the 10 focal beaches. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE).

Wind speed and air temperature

Mean values for average wind speeds during surveys varied nearly two fold among the beaches, ranging from 1.9 m s^{-1} to 4.5 m s^{-1} (Fig. 4). Peak wind speeds observed ranged from 4.0 m s^{-1} to 5.6 m s^{-1}. The lowest average wind speeds were observed on two of the pocket beaches, however peak wind speeds were similar among long and pocket beaches. Seasonally averaged wind speed varied more than five-fold among months with strongest overall average (6.7 m s^{-1}) and peak winds (>11 m s^{-1}) observed in

June (followed by May), when upwelling favorable winds are strong, and the lightest winds (1.1 m s^{-1}) were observed in October (Fig. 5) as is typical for the region in fall.

Spatial variation in mean values for air temperature among the beaches was low (11.0 to 13.5 °C) (Fig. 4). Seasonal variation in overall mean air temperatures ranged from 9.9 °C in February to 16.7 °C in September during the baseline study (Fig. 5).

Birds: Abundance

During the baseline study, 110 monthly surveys were conducted on the 10 focal beaches between June 2010 and May 2011. No surveys were conducted in July 2010. We counted birds on 6.56 km of beach and surf zone each month. A total of 6243 birds occurred in the 110 surveys (Table 3). We observed 1317 individuals of 14 species of shorebirds, 3173 individuals of six species of gulls and 1428 individuals of 10 species of seabirds in the monthly surveys (Table 3). We also recorded 325 terrestrial and aquatic birds of 17 species in our monthly surveys (Table 3). On average we observed 86.5 birds km^{-1} in the monthly surveys with averages of 18.3 birds km^{-1} for shorebirds, 44 birds km^{-1} for gulls and 19.3 birds km^{-1} for seabirds (Table 3).

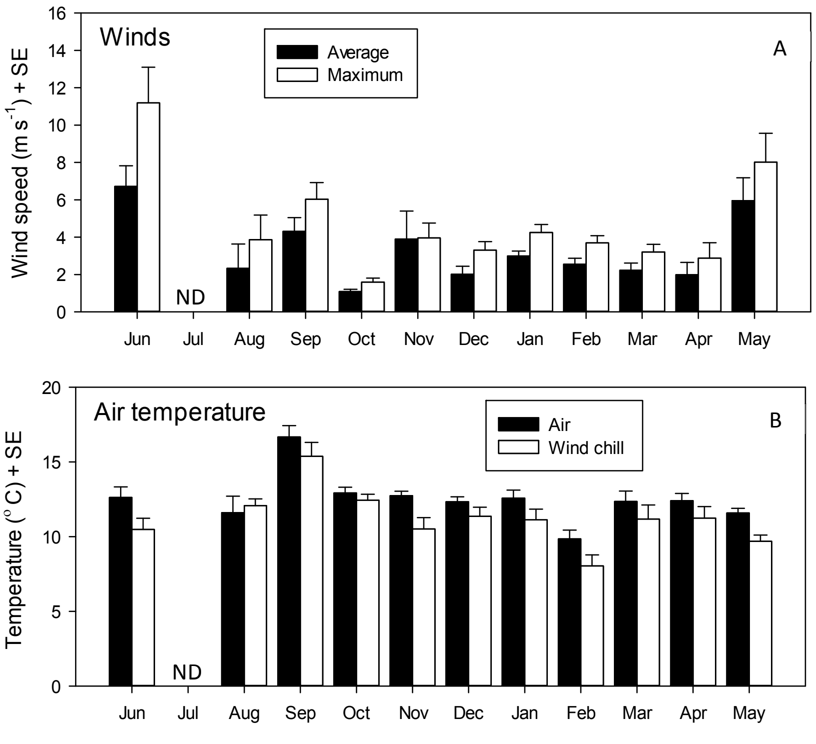


Figure 5. Seasonal variation in wind speeds and air temperatures at NCC beaches. All data are averages (+ SE). No data (ND) for July.

Birds: Temporal patterns

Shorebirds

Shorebird abundance exhibited a strong seasonal pattern (Fig. 6). With the exception of three key breeding species, Black Oystercatcher, Western Snowy Plover, and Killdeer most shorebirds observed in the study were migratory species that nest in other regions during the summer. The total number of shorebirds observed on the 10 beaches (6.56 km of beach shoreline) varied more than an order of magnitude among survey months, ranging from 12 shorebirds in June 2010 to 236 shorebirds in May 2011 and averaging 1.8 to 36.0 birds km^{-1}. The greatest numbers of shorebirds were observed on the beaches in the fall (October, November) and spring (March - May), coinciding with migration periods (Fig. 6). The low number of shorebirds observed at the beaches in June 2010, corresponded to the breeding season for many shorebird species. Exceptions to those temporal patterns were observed for the Black Oystercatcher, Western Snowy Plover, and Killdeer all of which nest on a subset of the beaches.

Gulls

Gulls were the most abundant type of bird observed in our surveys of the beaches. The abundance of gulls also varied seasonally with lowest abundance in the summer (Fig. 6). The total number of gulls observed on the 10 focal beaches ranged from 94 gulls in June 2010 to 894 gulls in January 2011. Average monthly abundance ranged from 14 to 136 birds km^{-1} for gulls.

Seabirds

The abundance of seabirds observed on the beaches and in the nearshore waters of the beaches varied seasonally with a distinct peak in the fall surveys (October, November) and low numbers in the spring and summer (Fig. 6). The total number of seabirds observed on the 10 focal beaches ranged from 41 seabirds in April 2011 to 468 seabirds in October 2010. Monthly average abundance for seabirds ranged from 6 to 71 birds km^{-1}.

Birds: Spatial patterns

Regional patterns in overall bird abundance were not easily discerned in our study due to the distribution of the two types of beaches we surveyed. The beaches at and south of Bodega Bay were long beaches (1 km or greater) that generally contained some back beach or dune habitat. This included the MPA sites of Salmon Creek Beach South, Drakes Beach and Ross Cove and the reference sites of Salmon Creek Beach North, Limantour Beach and Montara Beach. At Bodega Bay and to the north, the beaches were pocket beaches that were less than 200 m in length and embedded in rocky habitats. These beaches included the MPA sites of Horseshoe Cove, Stump Beach and the reference sites of Shorttail Gulch and Cooks Beach, all < 200 m in total shoreline length.

Shorebirds

Spatial variation in shorebird abundance and distribution was evident within the two types of beaches. Mean abundance of shorebirds varied over an order of magnitude among the six long beaches, ranging from 4 to 39 shorebirds km^{-1} (Fig. 7). On the four pocket beaches, the abundance of shorebirds ranged from 0.24 to 2 birds 100 m^{-1} (Fig. 7).

The highest mean number of shorebirds per month 39 birds km^{-1} was observed at Limantour Beach (Ref) during the study (Fig. 7). The highest numbers of shorebirds on a single transect were recorded in five of the 11 monthly surveys at this beach. Mean numbers of shorebirds per month also exceeded 20 birds km^{-1} at Drakes Beach (MPA). Low mean numbers of shorebirds (<10 birds km^{-1}) were observed at Ross Cove (MPA) and Montara Beach (Reference) located at the southern end of the study region. The four pocket beaches in our study supported very low numbers of shorebirds with peak numbers observed at Shorttail Gulch (2 birds 100 m^{-1}) (Fig. 7). For the six long beaches, the greatest peak abundance of shorebirds observed in single surveys were 153 birds km^{-1} at Drakes Beach (MPA) and 125 birds km^{-1} at Limantour Beach (Reference). The site with the lowest peak abundance of shorebirds, 11 birds km^{-1} in a survey was Ross Cove (MPA). For the pocket beaches, the highest peak abundance of shorebirds, 16.7 birds 100 m^{-1}, was observed at Shorttail Gulch and the lowest peak abundance, 1.3 birds 100 m^{-1}, was observed at Cook's Bay (Reference) (Fig. 8).

No consistent differences in the abundance of shorebirds were evident between MPA and Reference beaches, for both long and pocket beaches, during the baseline study (Fig. 9).

Gulls

Spatial variation was also evident in gulls among the beaches. Mean abundance of gulls varied five fold among the six long beaches ranging from 17.4 to 89.5 birds km^{-1} (Fig. 7). On the four pocket beaches, the abundance of gulls ranged from 1.1 to 4.8 birds 100 m^{-1}. Mean abundance of gulls per month exceeded 70 birds km^{-1} at two of the long beaches, Drakes Beach (MPA) and Salmon Creek Beach North (Reference) and (Fig. 7). The highest peak abundance of gulls observed in a single survey was 607 birds km^{-1} at Salmon Creek Beach North (Reference) in month year (Fig. 8). Peak abundance of gulls in single surveys exceeded 240 birds km^{-1} at Drakes Beach (MPA) and Salmon Creek Beach South (MPA) (Fig. 8). On the four pocket beaches, the highest peak abundance of gulls, 18.3 birds 100 m^{-1}, was observed at Shorttail Gulch and the lowest peak abundance, 2.5 birds 100 m^{-1}, was recorded at Stump Beach (MPA) (Fig. 8).

During the baseline study, gulls were more abundant at MPA than reference beaches on long beaches. However on the pocket beaches, gulls were more abundant on reference than MPA beaches (Fig. 9).

Table 3. Abundance (as total counts across all surveys and per km per month), peak abundance (as maximum count) and occurrence (number of times observed) of shorebirds, gulls, seabirds and other birds on MPA (n= 5) and reference (n= 5) beaches from paired monthly surveys between June 2010 and May 2011 (except for July). Five beaches were within MPAs and five were reference beaches. Counts were made along a standard 1 km transect except at four pocket beaches (two MPA and two reference) where transect lengths ranged from 0.12 to 0.17 km (total length of shoreline surveyed each month = 6.56 km).

Common Name	**Species**	**Abundance**				**Maximum**			**Occurrence**		
		MPA Sites	**Ref Sites**	**All Sites**	**All sites km^{-1}mo^{-1}**	**MPA Sites**	**Ref Sites**	**All Sites**	**MPA Sites**	**Ref Sites**	**All Sites**
SHOREBIRDS											
Sanderling	*Calidris alba*	209	538	747	11.4	45	125	125	9	13	22
Marbled godwit	*Limosa fedoa*	188	24	212	3.2	110	17	110	5	3	8
Willet	*Tringa semipalmata*	69	33	102	1.6	50	10	50	8	7	15
Killdeer	*Charadrius vociferus*	52	0	52	0.8	43	0	43	3	0	3
Black oyster catcher	*Haematopus bachmani*	22	10	32	0.5	5	4	5	11	3	14
Black turnstone	*Arenaria melanocephala*	19	2	21	0.3	9	2	9	4	1	5
Western snowy plover	*Charadrius nivosus nivosus*	12	54	66	1.0	6	41	41	4	5	9
Semipalmated plover	*Charadrius semipalmatus*	11	2	13	0.2	8	1	8	4	2	6
Whimbrel	*Numenius phaeopus*	10	32	42	0.6	3	16	16	7	5	12
Black bellied plover	*Pluvialis squatarola*	7	3	10	0.2	4	3	4	3	1	4
Turnstone (unid'd)	*Arenaria* spp.	3	0	3	0.0	3	0	3	1	0	1
Ruddy turnstone	*Arenaria interpres*	2	0	2	0.0	2	0	2	1	0	1
Western sandpiper	*Calidris mauri*	1	4	5	0.1	1	2	2	1	2	3
Sandpiper (unid'd)	*Calidris* sp.	1	0	1	0.0	1	0	1	1	0	1
Spotted sandpiper	*Actitism macularius*	0	1	1	0.0	0	1	1	0	1	1
Surfbird	*Aphriza virgata*	0	8	8	0.1	0	8	8	0	1	1
All shorebirds		***606***	***711***	***1317***	***20.1***						

Table 3 (con’t).

Common Name	**Species**	**Abundance**				**Maximum**			**Occurrence**		
		MPA Sites	**Ref Sites**	**All Sites**	**All sites km^{-1}mo^{-1}**	**MPA Sites**	**Ref Sites**	**All Sites**	**MPA Sites**	**Ref Sites**	**All Sites**
GULLS											
Western gull	*Larus occidentalis*	786	73	859	13.1	148	12	148	35	26	61
California gull	*Larus californicus*	176	4	180	2.7	70	1	70	8	4	12
Heermann's gull	*Larus heermanni*	144	118	262	4.0	94	50	94	8	14	22
Herring gull	*Larus argentatus*	95	49	144	2.2	51	17	51	7	6	13
Mew gull	*Larus canus*	40	0	40	0.6	25	0	25	2	0	2
Glaucous wing gull	*Larus glaucescens*	1	0	1	0.0	1	0	1	1	0	1
Gull (unid’d)	*Larus* spp.	616	1071	1687	25.7	277	600	600	33	37	70
All gulls		***1858***	***1315***	***3173***	***48.4***						
SEABIRDS											
Surf scoter	*Melanitta perspicillata*	415	528	943	14.4	150	300	300	17	25	42
Pigeon guillemot	*Cepphus columba*	68	0	68	1.0	61	0	61	3	0	3
Double crested cormorant	*Phalacrocorax auritus*	57	34	91	1.4	33	14	33	11	9	20
Western grebe	*Aechmophorus occidentalis*	46	5	51	0.8	29	5	29	5	1	6
Brown pelican	*Pelecanus occidentalis*	40	72	112	1.7	22	23	23	5	11	16
Horned grebe	*Podiceps auritus*	37	0	37	0.6	37	0	37	1	0	1
Pelagic cormorant	*Phalacrocorax pelagicus*	30	12	42	0.6	12	11	12	10	2	12
Clark's grebe	*Aechmophorus clarkii*	2	0	2	0.0	2	0	2	1	0	1
Loon (unid’d)	*Gavia* sp.	1	1	2	0.0	1	1	1	1	1	2
Tern (unid’d)	*Thalasseus*	1	3	4	0.1	1	2	2	1	2	3
Common loon	*Gavia immer*	0	4	4	0.1	0	4	4	0	1	1
White pelican	*Pelecanus erythrorhynchos*	0	7	7	0.1	0	7	7	0	1	1
Cormorant (unid’d)	*Phalacrocorax* spp.	20	45	65	1.0	8	44	44	5	2	7
All seabirds		***717***	***711***	***1428***	***21.8***						

Table 3 (con't).

Common Name	**Species**	**Abundance**				**Maximum**			**Occurrence**		
		MPA Sites	**Ref Sites**	**All Sites**	**All sites km^{-1}mo^{-1}**	**MPA Sites**	**Ref Sites**	**All Sites**	**MPA Sites**	**Ref Sites**	**All Sites**
TERRESTRIAL BIRDS											
Brewer's blackbird	*Euphagus cyanocephalus*	62	5	67	1.0	42	5	42	3	1	4
Turkey vulture	*Cathartes aura*	51	28	79	1.2	13	8	13	16	10	26
Raven	*Corvus corax*	47	21	68	1.0	22	5	22	13	11	24
American crow	*Corvus brachyrhynchos*	12	28	40	0.6	4	13	13	6	9	15
Bufflehead	*Bucephala albeola*	11	0	11	0.2	11	0	11	1	0	1
Great blue heron	*Ardea herodias*	8	0	8	0.1	2	0	2	7	0	7
Black phoebe	*Sayornis nigricans*	6	3	9	0.1	2	2	2	4	2	6
Snowy egret	*Egretta thula*	4	0	4	0.1	2	0	2	3	0	3
Osprey	*Pandion haliaetus*	4	4	8	0.1	3	2	3	2	3	5
Barn swallow	*Hirundo rustica*	4	10	14	0.2	3	5	5	2	3	5
Rock dove	*Columba livia*	3	0	3	0.0	3	0	3	1	0	1
Mallard	*Anas platyrhynchos*	2	0	2	0.0	2	0	2	1	0	1
Canadian goose	*Branta canadensis*	2	0	2	0.0	2	0	2	1	0	1
Northern harrier	*Circus cyaneus*	2	2	4	0.1	1	1	1	2	2	4
Cliff swallow	*Hirundo pyrrhonota*	2	0	2	0.0	2	0	2	1	0	1
Swallow (unid'd)		2	0	2	0.0	2	0	2	1	0	1
Sharpshinned hawk	*Accipiter striatus*	1	0	1	0.0	1	0	1	1	0	1
Song sparrow	*Melospiza melodia*	1	0	1	0.0	1	0	1	1	0	1
All terrestrial birds		***224***	***101***	***325***	***5.0***						
TOTAL BIRDS		**3405**	**2838**	**6243**	**95.2**						

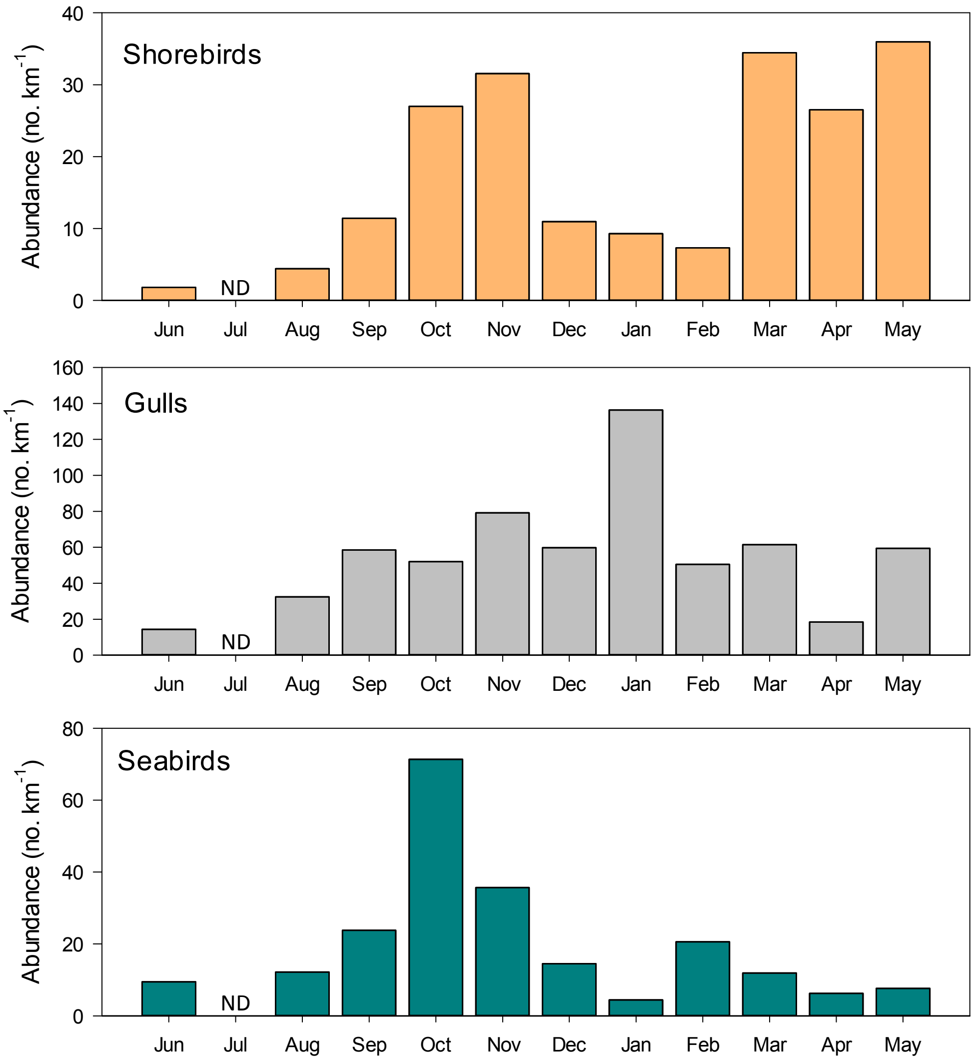


Figure 6. Seasonal abundance of shorebirds, gulls and seabirds observed along NCC) sandy beaches. Surveys were conducted once a month from June 2010 to May 2011 (except in July = ND). Five beaches were within MPAs and five were reference beaches. All observations were made along a standard 1 km transect except at four pocket beaches (two MPA and two reference) where transect lengths ranged from 0.12 to 0.17 km. The data are expressed as total number of birds observed across all 10 sites, within each taxonomic group, divided by the total length of shoreline surveyed each month (6.56 km).

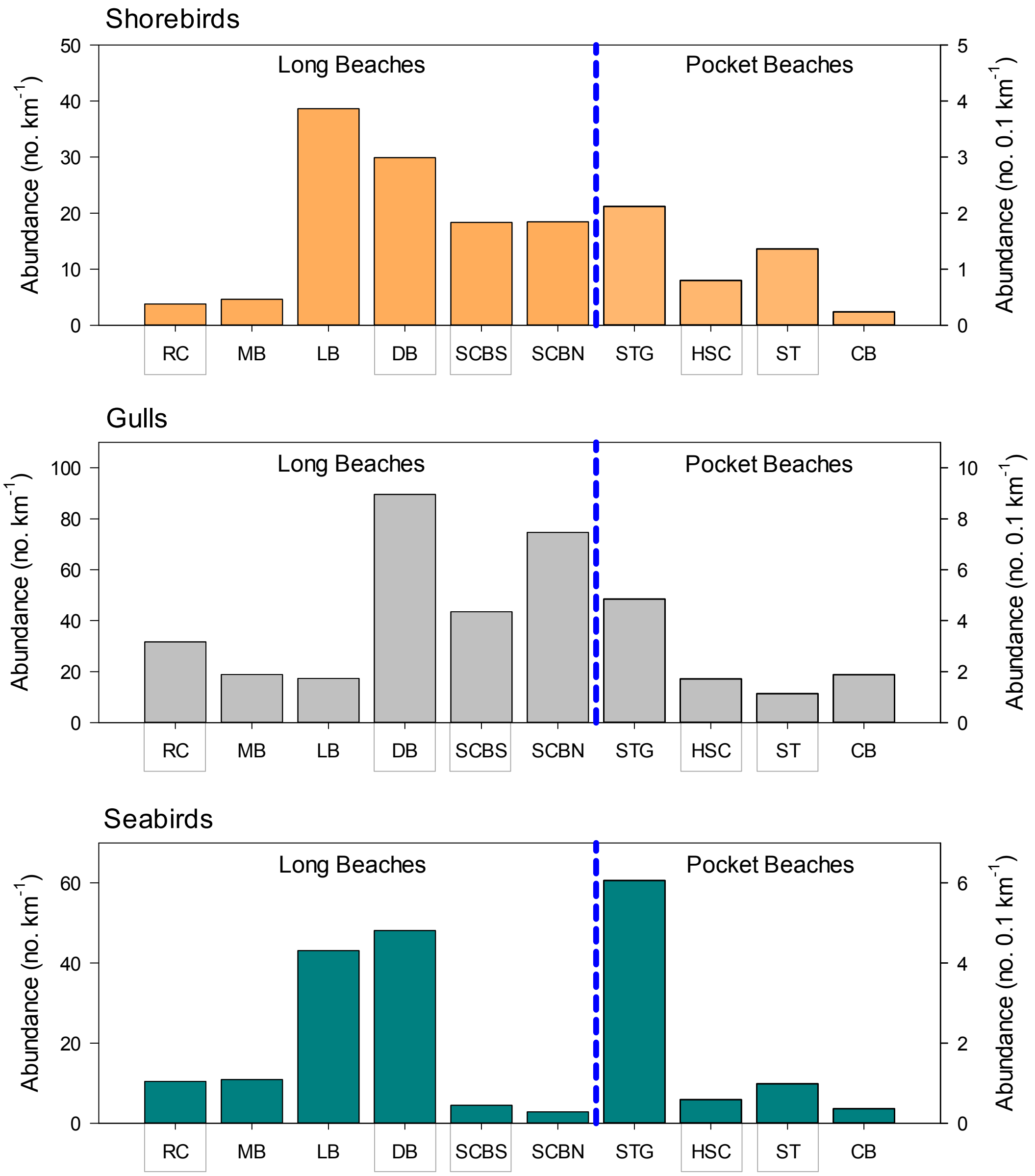


Figure 7. Average abundance of shorebirds, gulls and seabirds observed at 10 beaches from 11 monthly surveys between June 2010 and May 2011 (no survey done in July 2010). All observations were made along a standard 1 km transect except on pocket beaches where transect lengths were truncated to the length of the shoreline present (STG = 0.12 km, HSC = 0.17 km, ST = 0.12 km & CB = 0.15 km). Abundances were normalized to 0.1 km for all pocket beaches. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches; note difference in axis scaling). Five of 10 the beaches surveyed were within MPAs (indicated by gray boxes). Site codes: RC = Ross Cove Beach, MB = Montara Beach State Park, LB = Limantour Beach, DB = Drake's Beach, STG = Shorttail Gulch Beach, HSC = Horseshoe Cove Beach, SCBS = Salmon Creek Beach (South), SCBN = Salmon Creek Beach (North), ST = Stump Beach and CB = Cook's Beach.

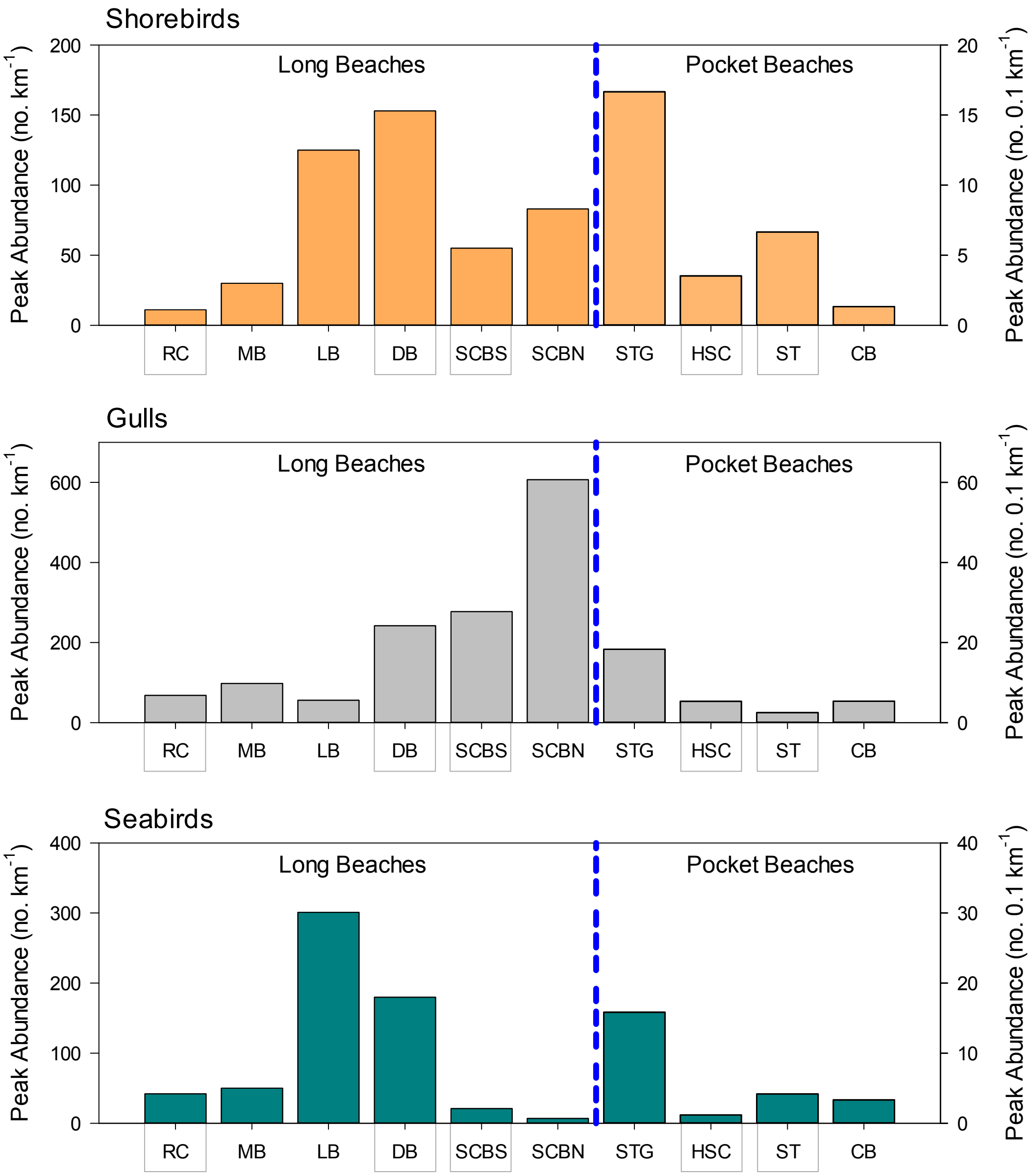


Figure 8. Peak abundance of shorebirds, gulls and seabirds observed at 10 beaches from 11 monthly surveys between June 2010 and May 2011). All other information as in Fig. 7.

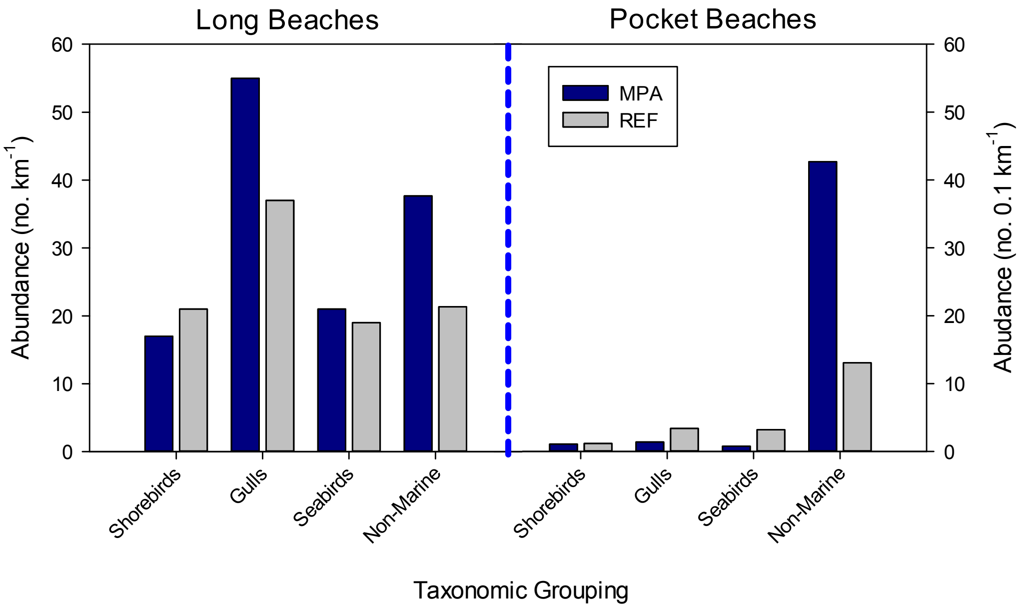


Figure 9. Average abundance of shorebirds, gulls, seabirds and non-marine (or terrestrial) birds observed in MPA and reference beaches by beach type. Data are from 11 monthly surveys at 10 sites between June 2010 and May 2011. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). Note the differences in vertical scale for long and pocket beaches; the left scale *only* applies to the long beaches and the right hand scale *only* applies to the pocket beaches.

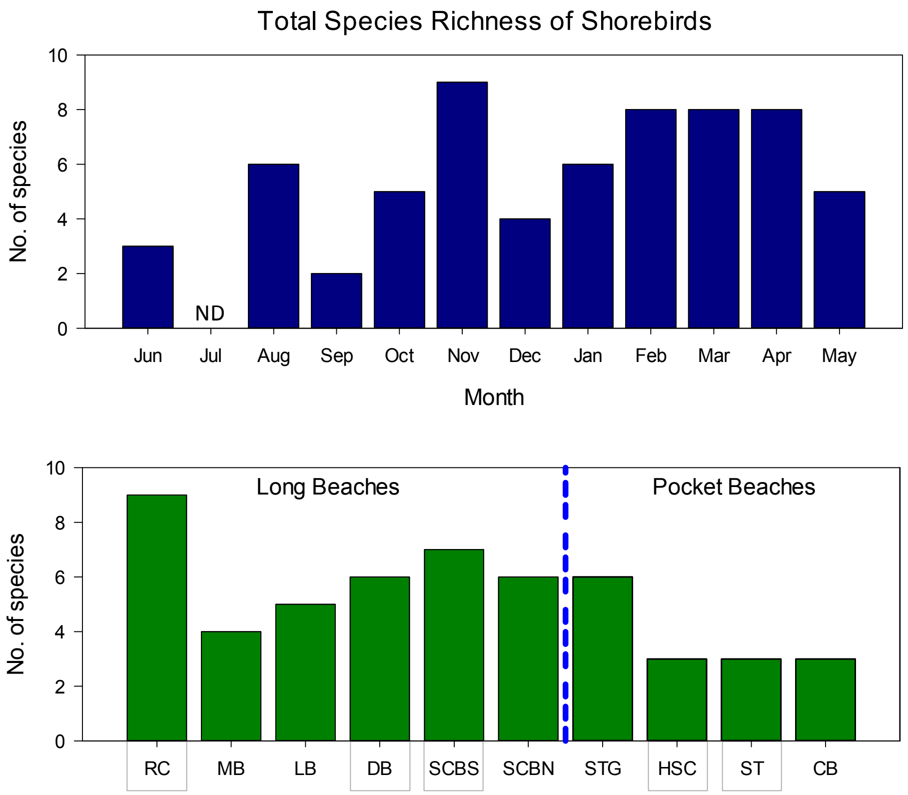


Figure 10. Total species richness (gamma diversity) of shorebirds by month and site. All observations were made along a standard 1 km transect except at four pocket beaches where transect lengths were truncated to the length of the shoreline present (STG = 0.12 km, HSC = 0.17 km, ST = 0.12 km & CB = 0.15 km). See captions of Figs. 6 & 7 for additional information.

Seabirds

The mean abundance of seabirds also varied strikingly among the beaches (Fig. 7). On the long beaches mean seabird abundance per month varied over an order of magnitude ranging from 2.8 birds km-^{1} to 48.1 birds km^{-1} (Fig. 6). Mean abundance of seabirds per month exceeded 40 birds km^{-1} at two beaches, Limantour Beach and Drakes Beach, but was less than 11 birds km^{-1} at the other four long beaches. Seabird abundance on the pocket beaches showed a similar pattern with an average of 6 birds 100 m^{-1} at Shorttail Gulch and averages of $\leq$ 1 birds 100 m^{-1} at the other three pocket beaches (Fig. 7). The peak abundance of seabirds observed in a single survey was 301 birds km^{-1} at Limantour Beach in month/year (Fig. 8). A peak abundance of 180 birds km^{-1} was recorded at Drakes Beach. Peak abundances were 50 birds km^{-1} or fewer at the other four long beaches. For the pocket beaches, the peak abundance of seabirds in a single survey was 16 birds 100 m^{-1} at Shorttail Gulch (Fig. 8).

For both long and pocket beaches, we found no consistent differences in the abundance of seabirds between MPA and Reference beaches in the baseline study (Fig. 9).

Terrestrial Birds

There were strikingly more terrestrial (non-marine) birds than marine birds on pocket beaches, and their overall abundance was also almost an order of magnitude greater on pocket beaches (Fig. 9). Terrestrial birds were also more abundant on MPA beaches than reference beaches regardless of beach type (Fig. 9).

Birds: Species Richness of Shorebirds

Fourteen species of shorebirds were observed in the 110 surveys of the beaches (Table 3). Peak species richness occurred during migration in the fall and spring (Fig. 10). Total species richness also varied among months ranging from two to nine species observed each month on the 10 focal beaches (Fig. 10). The average total number of shorebird species observed was 5.7 species per month.

The total number of species observed during the study varied more than two fold among the beaches, ranging from three to nine species and averaging five species per study beach (Fig. 10). Note that these values are not corrected for transect length or the number of individuals observed. The highest number of shorebird species (eight) was observed at Ross Cove, a site where Black Oystercatchers occurred. Other beaches with high total species richness (> 6 species) included Drake's Beach, Salmon Creek Beach North and Salmon Creek Beach South and the pocket beach of Shorttail Gulch. The maximum number of species of shorebirds observed on a single 1 km survey was five species during the study.

Beaches where greater numbers of shorebird species were observed generally had high habitat heterogeneity, containing some rocky outcrops (Ross Cove, Shorttail Gulch) or occurring near estuaries (Salmon Creek N and S and Limantour Beach). Relatively low total species richness (three species) occurred on the pocket beaches at Horseshoe Cove, Cooks Bay and Stump Beach (Fig. 10). The latter two beaches have creek mouths and rocky habitat but are very short embayed beaches with tall trees and cliffs overlooking the beach habitat. These landscape features can provide perches for raptors that prey on shorebirds and affect bird distributions.

The total species richness of shorebirds was not significantly correlated with the total abundance of shorebirds or with transect length.

Birds: Species Accounts

Shorebirds

Overall, abundance varied greatly among individual species of shorebirds, ranging over two orders of magnitude from 0.01 birds km^{-1} to 11.4 birds km^{-1} for total monthly observations (Table 3). The average abundance of three species of shorebirds exceeded 1 individual km^{-1} during the baseline study. Based on average abundance observed over the study, the most abundant shorebird species were Sanderling (11.4 birds km^{-1}), Marbled Godwit (3.2 birds km^{-1}) and Willet (1.6 birds km^{-1}), all of which breed outside the study region. Other important species included Whimbrel (0.6 birds km^{-1}) and three species that nest in the study region, Western Snowy Plover (1.0 birds km^{-1}), Killdeer (0.8 birds km^{-1}), and Black Oystercatchers (0.5 birds km^{-1}). Sanderlings comprised 57%, Marbled Godwits comprised 16%, Willets comprised 8% and Western Snowy Plovers comprised 5%, of the total shorebirds observed in the study. Nine species of shorebirds were observed in five or more of the monthly surveys (Table 3). Sanderlings, Willets and Whimbrels which use NCC beaches as migration and wintering habitat were observed in 22, 15 and 12 of the surveys, respectively. Black Oystercatchers, which are resident and nest in the study area, were observed in 14 surveys. Western Snowy Plovers, which also nest on the beaches were observed in nine of the surveys. Killdeer also nest on beaches in the NCC region, including one of the focal beaches during the baseline study.

Sanderling

Sanderlings were the most abundant shorebird observed in the baseline study and accounted for 57% of the shorebirds observed. A total of 747 Sanderlings were observed in 110 surveys of the 10 beaches (Table 3). The average total abundance of Sanderlings was 11.4 birds km^{-1}. Sanderlings were observed in 10 months of the baseline surveys and total numbers observed on the 10 focal beaches ranged from 0 to 209 birds month^{-1}. The total abundance of Sanderlings showed strong seasonal patterns corresponding to fall and spring migration with total abundance exceeding 100 birds km^{-1} in November, March and May on the beaches.

Although they were the most abundant shorebirds observed and occurred in the greatest number of our surveys (22 surveys or 20%), Sanderlings only occurred at five of the six long beaches and were never recorded on the four pocket beaches during our baseline study (Fig. 11). In addition, the average abundance of Sanderlings varied nearly an order of magnitude among the long beaches, ranging from 0 to 31 birds km^{-1} (Fig. 11). The study beach with the highest average numbers of Sanderlings (31 birds km^{-1}) was Limantour Beach. Other study sites where average abundance of Sanderlings was >10 birds km^{-1} included Salmon Creek Beach North and Salmon Creek Beach South. Sanderlings were never observed on the transect at Ross Cove.

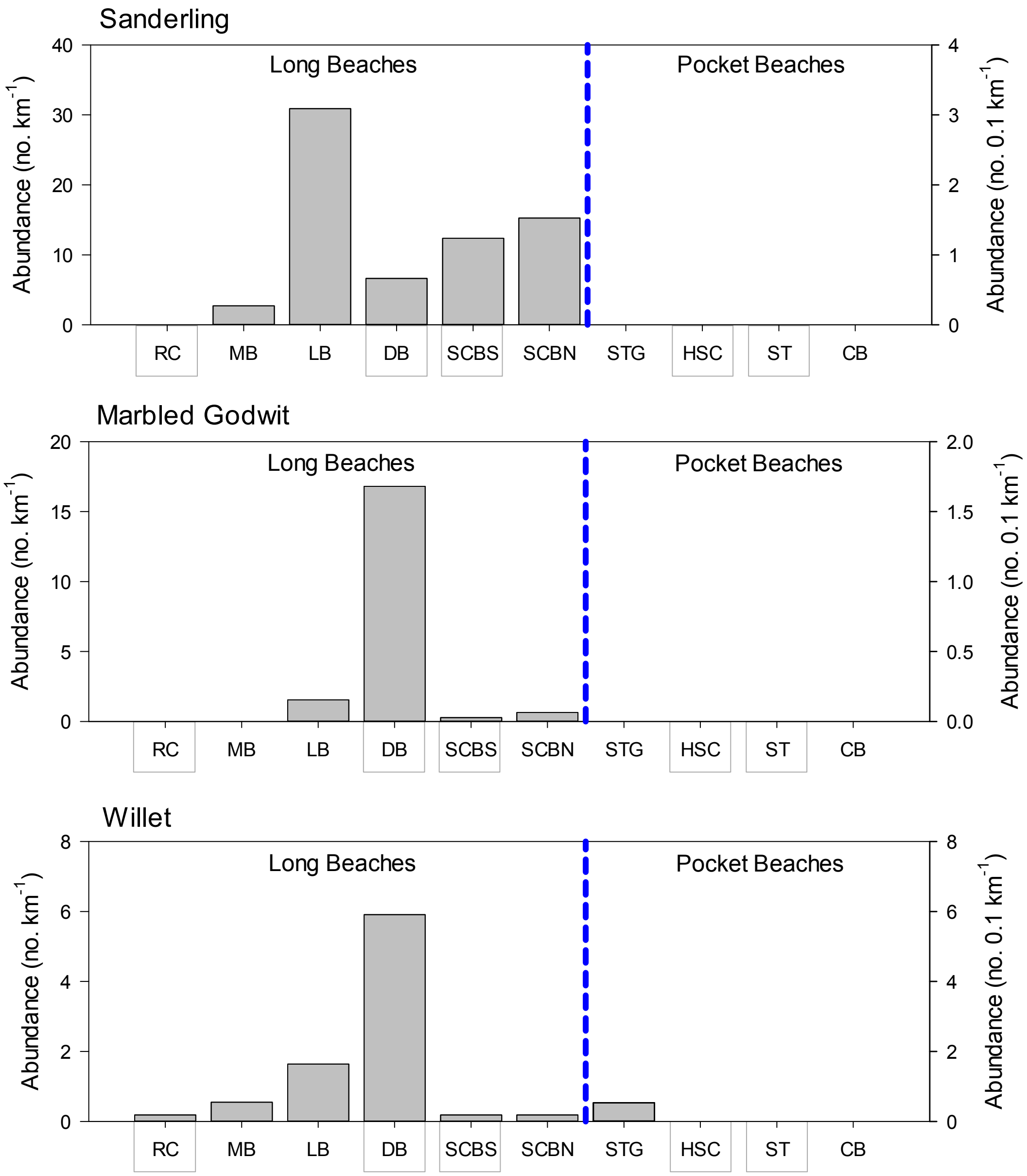
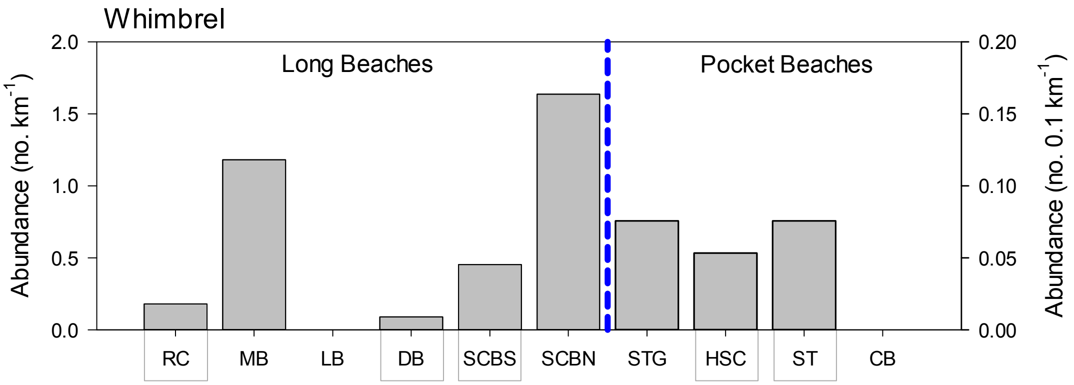
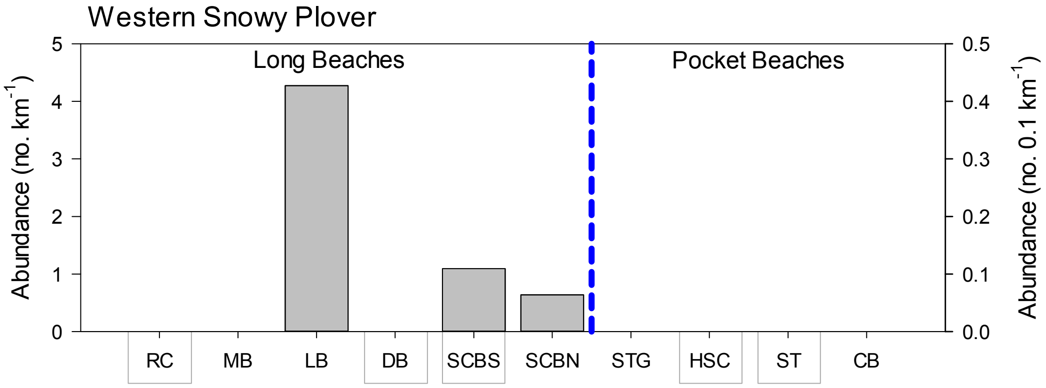


Figure 11. Average abundance of the seven most abundant shorebird species (non-breeding: Sanderling, Marbled Godwit, Willet and Whimbrel; breeding: Black Oystercatcher, Killdeer and Western Snowy Plover) and the terrestrial Raven across the 10 beaches surveyed in the NCC region between June 2010 and May 2011. All other information as in Fig. 7.





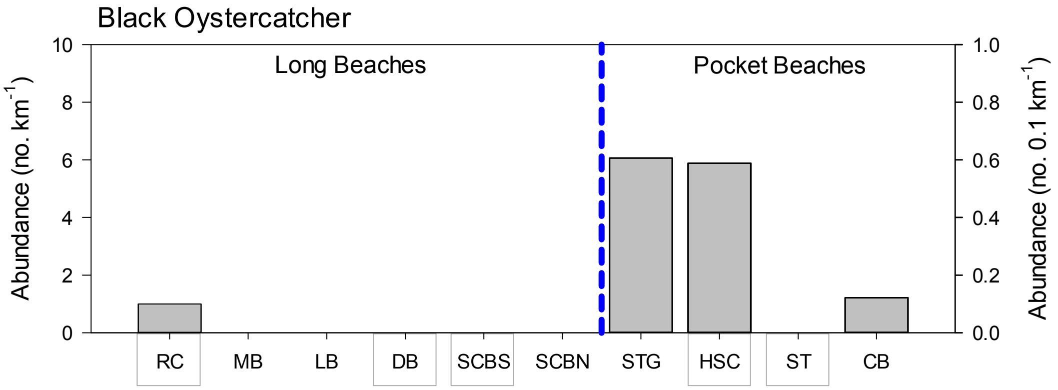
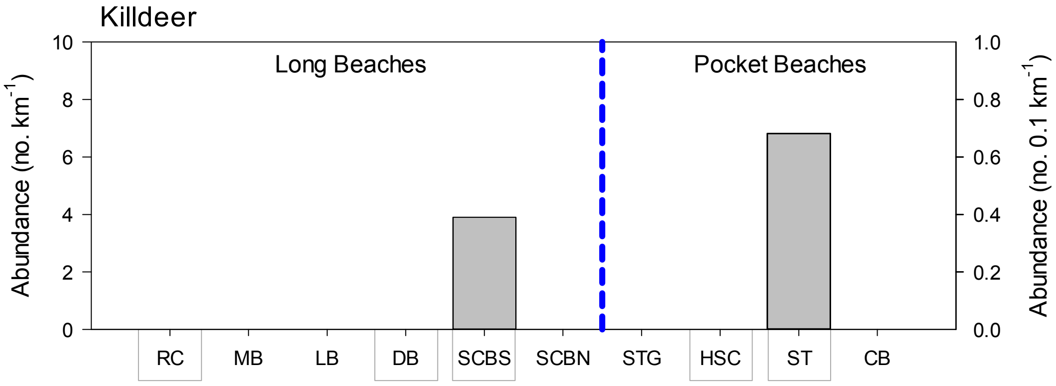


Figure 11. (Con't).



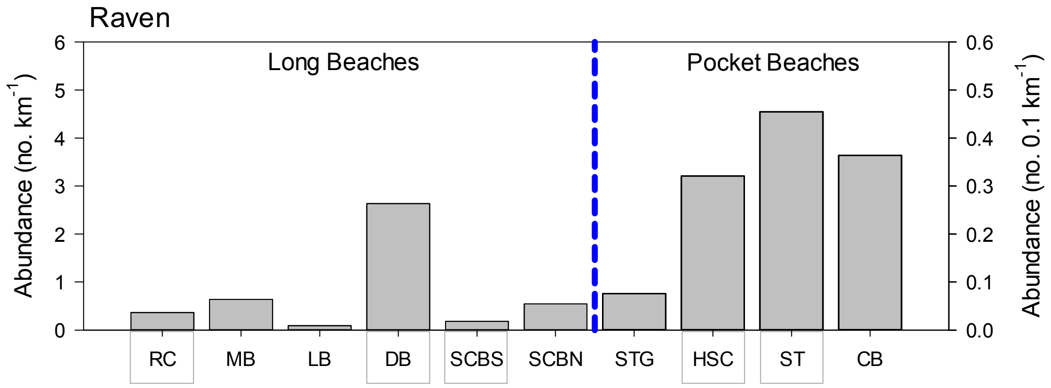


Figure 11. (Con't).

Marbled Godwit

A total of 212 Marbled Godwits occurred in the study (Table 3). Marbled Godwits accounted for 16% of the total shorebirds and were observed in eight surveys. The overall average abundance of Marbled Godwits was 3.2 birds km^{-1} (Table 3).

Marbled Godwits were observed in six months of the baseline surveys and total abundance varied among months, ranging from 0 to 110 birds month^{-1}. Peaks in the total abundance of this species (17 to 110 birds) occurred during fall migration (October and November). However, very few individuals (<10) were observed in spring migration on the beaches. Although they were the second most abundant shorebirds we observed, Marbled Godwits only occurred at four of the six long beaches and were never recorded on the four pocket beaches during our baseline study (Fig. 11). Average abundance of Marbled Godwits varied nearly an order of magnitude among the long beaches, ranging from 0 to 17 birds km^{-1} (Fig. 11). The study beach with the highest average numbers of Marbled Godwits (17 birds km^{-1}) was Drakes Beach.

Willet

A total of 102 Willets were observed in the baseline study. Willets accounted for 8% of the total shorebird abundance and were observed in 15 surveys (Table 3). The overall average abundance for Willets was 1.4 birds km^{-1} during the study.

Willets were observed in eight months of the baseline surveys and the total number observed on the 10 focal beaches varied among months, ranging from 0 to 55 birds $month^{-1}$. The peak in the total abundance of Willets occurred in April 2011 during spring migration (Table 3). Total abundance of Willets exceeded 10 birds in only two other months December and February. At total of five or fewer willets were recorded in the 10 focal beaches in all other months.

Willets were more widely distributed than Sanderlings and Marbled Godwits occurring on all of the long beaches and one of the pocket beaches. The average abundance of Willets varied five-fold among the long beaches, ranging from 0.2 to 6 birds km^{-1} (Fig. 11). The highest average number of Willets occurred at Drake Beach, which averaged 6 birds $survey^{-1}$.

Whimbrel

A total of 42 Whimbrels were recorded in the baseline study (Table 3). Whimbrels accounted for 3.8% of the total shorebirds and were observed in 12 surveys. The overall average abundance of Whimbrels was 0.6 birds km^{-1}.

Whimbrels were observed in six months of the baseline surveys and total abundance varied among months, ranging from 0 to 19 birds $month^{-1}$. Peak abundance of this species was observed during spring migration (April and May) while a total of < 3 individuals occurred on the beaches during fall migration (August, October, November).

Whimbrels were the most widely distributed shorebird, occurring on eight of the 10 focal beaches including five of the long beaches and three pocket beaches. The average abundance of Whimbrels varied more than four fold among sites, ranging from 0.0 to 1.6 birds km^{-1} on the long beaches and 0 to 0.08 birds km^{-1} (Fig. 11). The highest average abundance of Whimbrels (1.6 birds km^{-1}) occurred at Salmon Creek Beach North.

Western Snowy Plover

Western Snowy Plovers are listed as a threatened species. These shorebirds nest on beach, river bar, salt flat and estuarine habitats in the study region. On beaches, they depend on macroalgal wrack associated prey resources making them important species to consider as potential indicators of ecosystem condition and connectivity in MPA baseline evaluation. A total of 66 Western Snowy Plovers were observed in the baseline study (Table 3). Western Snowy Plovers accounted for 5% of the total shorebirds and were observed in nine surveys. The overall average abundance for Western Snowy Plovers was 1.0 birds km^{-1} (Table 3).

Western Snowy Plovers were recorded in seven months of the baseline surveys and peak abundance of this species occurred between the months of August and February at wintering/staging sites. The peak number of Snowy Plovers observed in a single survey, 41 birds, was in March 2011 at Limantour Beach, where a roost site may occur during pre-breeding dispersal. The highest abundance of this species was observed in winter and early spring. Our observations of low numbers of this species present in June 2010, and April and May 2011 suggests that one or more pairs nested at Salmon Creek Beaches during the study period. This was corroborated by direct observation of brooding by at least one pair made by a Bodega Marine Reserve manager at Salmon Creek Beach South (Jackie Sones, pers. comm.) and our research team along the survey transect during the same field season. However, raptors were also present at the site; we observed a Sharp-shinned Hawk hunting over the area while the breeding pair was nesting on the beach. Ultimately, the breeding attempt was not successful. This was the first recorded observation of a breeding attempt by Western Snowy Plovers at this site (Jackie Sones, pers. comm.).

Western Snowy Plovers had a restricted spatial distribution, occurring at only three of the beaches during the baseline surveys (Fig. 11). Snowy Plovers were not observed at three of the long beaches or any of the pocket beaches during the study.

Black Oystercatcher

Black Oystercatchers are not a listed species but are a shorebird of high conservation concern. These shorebirds nest in the study area and on the beaches, making them important species to consider as potential indicators of ecosystem condition and connectivity in MPA baseline evaluation. A total of 32 Black Oystercatchers occurred in the baseline study (Table 3). This species accounted for 2.4% of the total shorebirds and were observed in 14 surveys. The overall average abundance of Black Oystercatchers was 0.5 birds km^{-1} (Table 3).

Black Oystercatchers were observed in eight months of the baseline study, and total abundance varied among months, ranging from 0 to 7 birds month^{-1}. Peak monthly abundance of this species was observed in September, and in February and March.

The distribution of Black Oystercatchers was restricted (Fig. 11) and they were observed on only four beaches during the baseline study, Ross Cove, Shorttail Gulch, Horseshoe Cove and Cooks Beach, all beaches with either rocky outcrops along the transect (Ross Cove) or bounded by rocky cliffs and outcrops in the case of the three pocket beaches (Shorttail Gulch, Horseshoe Cove and Cooks Beach). The average abundance of Black Oystercatchers ranged from 1 bird km^{-1} at the long beach, Ross Cove and from 0.1 to 0.6 birds 100 m^{-1} on the three pocket beaches.

Killdeer

Killdeer also nest in the study area and on the beaches making this plover species a potential indicator of ecosystem conditions. A total of 52 Killdeer were observed in the baseline study with an average abundance of 0.8 birds km^{-1} (Table 3).

Killdeer were observed in three months of the study with abundance ranging from 4 to 43 birds month^{-1}. The largest numbers of Killdeer on the focal beaches were recorded outside the nesting season (October, December and January), including a large wintering flock in January 2011.

Killdeer were observed on only two of the focal beaches (Fig. 11), one long beach (Salmon Creek Beach South) and one pocket beach (Stump Beach). A pair of Killdeer was present during the breeding season at Stump Beach indicating that nesting likely occurred at that site during the baseline study.

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 3). The average abundance of four species of gulls and of unidentified gulls exceeded 1 individual km^{-1} during our study. 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 3). 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 3).

Seabirds

Overall, abundance varied greatly among individual species of seabirds, ranging over two orders of magnitude from 0.03 birds km^{-1} to 14.1 birds km^{-1} for total monthly observations (Table 3). The average abundance of three 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 Surf Scoter (14.1 birds km^{-1}), Brown Pelican (1.7 birds km^{-1}), and Double Crested Cormorant (1.4 birds km^{-1}) (Table 3). Surf Scoters comprised 66%, Brown Pelicans comprised 7.8 %, and Double Crested Cormorants comprised 6.4% of the total seabirds observed in the study. Seabirds were regularly observed with three species of seabirds and unidentified cormorants observed in 10 or more of the individual surveys (Table 3).

Terrestrial Birds

Scavenging and carrion feeding birds were regularly recorded and were among the most abundant terrestrial birds on both the MPA and reference beaches during the baseline study (Table 3). The corvids, Ravens and American Crows, were important components, together making up 33% of the total terrestrial birds observed and recorded (Table 3). Turkey vultures were also important making up 24% of the terrestrial birds observed and recorded in 26 of the 110 surveys (Table 3). Brewers' blackbird was the most abundant passerine species observed (67 individuals, 0.9 birds km^{-1}) but were only recorded in four individual surveys in the baseline study (Table 3).

Ravens

Ravens are known to prey upon nesting shorebirds such as Western Snowy Plovers and Black Oystercatchers and can cause decreased reproductive success in Western Snowy Plover, a beach nesting species listed as threatened. A total of 68 Ravens were observed in the baseline study (Table 3). This species is a resident breeding species that accounted for 21% of the terrestrial birds and were observed in 24 of the 110 surveys. The overall average abundance of Ravens was 0.9 birds km^{-1} (Table 3).

Ravens were observed in all 11 months of surveys with monthly total abundance ranging from one to 22 birds. Total abundance was generally < 10 individuals per month. Peak abundance of ravens on the beaches was observed in October 2010.

Ravens were widespread and observed on every beach during the baseline study (Fig. 9). On the long beaches the abundance of ravens ranged from 0.1 to 2.6 birds km^{-1} (Fig. 11). On the pocket beaches, abundance of ravens varied from 0.1 to 0.5 birds 100 m^{-1} (Fig. 11).

Human use & activities

Visitors used beaches in a wide variety of ways that are categorized into four broad groups in decreasing order: nature walks, resting or socializing, water sports and beach sports or play (Table 4). Popular activities in all four categories were more common at reference than MPA sites and long than pocket beaches.

In the nature walk category, most people were walking on the beach, occurring 74 times by 594 people. People were accompanied by dogs 15 times with 86 dogs, most of which were off leash. Dogs occurred only once in a MPA and 10 of 15 times on long beaches.

In the resting/socializing category, most people were resting on the beach, including sitting, lying or standing, and resting was observed 46 times for 273 people. Other common activities were sunbathing, picnicking and barbequing. These activities were more common at reference (65 times, 448 people) than MPA (23 times, 246 people) sites and long (75 times, 608 people) than pocket (23 times, 86 people) beaches

Surfing and surfcasting were the most common water sports. Surfing occurred 13 times by 75 people, and it occurred only twice in MPAs by 10 people. Surfcasting occurred eight times by 21 people, and it occurred only once in a MPA – by a pair of fishermen on a pocket beach. Only one abalone diver was observed at a reference pocket beach.

Jogging, frisbee, catch, kite flying, digging and building sand castles were popular beach sport/play, occurring 21 times by 59 people. These activities were more common at reference (21 times, 47 people) than MPA (five times, nine people) sites and long (22 times, 48 people) than pocket (four times, eight people) beaches.

People were most abundant on long beaches, especially Montara Beach, Limantour Beach and Drakes Beach (Fig. 12). The most popular pocket beaches were Stumps Beach and Cooks Beach. Public access is restricted from the pocket beach at Horseshoe Cove, which is a research site that is part of the University of California Reserve System. Dogs were most abundant on three of the five most popular beaches: Montara Beach, Limantour Beach and Cooks Beach.

Table 4. Frequency of occurrence and number of people engaging in human activitiesduring paired monthly surveys of five beaches in MPAs and five neighboring reference beaches in the North Central Coast Region from June 2010 to May 2011, except July. Five beaches were in MPAs and five were neighboring reference beaches. Six of the sites were long beaches and four of them were pocket beaches (2 MPA and 2 reference). Counts were made along a standard 1 km transect except at the pocket beaches where transect lengths ranged from 0.12 to 0.17 km (total length of shoreline surveyed each month = 6.56 km).

Activity	**Frequency**					**Number**				
	MPA	**Reference**	**Long**	**Pocket**	**Total**	**MPA**	**Reference**	**Long**	**Pocket**	**Total**
Nature walk										
Strolling	28	43	54	17	71	235	188	366	57	423
Milling around	0	3	2	1	3	0	171	167	4	171
Dog walking unleased	0	8	5	3	8	1	51	36	16	52
Dog walking leashed	0	3	2	1	3	0	21	17	4	21
Dogwalking unspecified	1	3	3	1	4	3	10	11	2	13
Bird watching	1	3	4	0	4	2	5	7	0	7
Tidepooling	1	0	1	0	2	3	0	0	3	3
Photography	1	2	3	0	3	1	2	3	0	3
Beach combing	1	0	1	0	2	1	0	1	0	1
Total	***33***	***65***	***75***	***23***	***100***	***246***	***448***	***608***	***86***	***694***
Resting/socializing										
Resting	3	11	11	3	14	38	98	129	7	136
Sunbathing	5	11	15	1	16	12	57	62	7	69
Picnicking	3	7	9	1	10	19	31	48	2	50
Barbequeing	1	0	1	0	2	13	0	13	0	13
Bonfire/campfire	1	0	1	0	2	3	0	3	0	3
Musical instruments	0	2	2	0	2	0	2	2	0	2
Total	***13***	***31***	***39***	***5***	***46***	***85***	***188***	***257***	***16***	***273***
Water sports										
Surfing	2	11	13	0	13	10	65	75	0	75
Surfcasting	1	7	7	1	8	2	15	15	2	21
Boogie boarding	0	2	2	0	2	0	9	9	0	9
Jetskiing	0	1	1	0	1	0	2	2	0	2
Parasailing	0	1	1	0	1	0	1	1	0	1
Paddle boarding	1	0	1	0	2	1	0	1	0	1
Abalone diving	0	1	0	1	1	0	1	0	1	1
Total	***4***	***23***	***25***	***2***	***28***	***13***	***93***	***103***	***3***	***110***
Beach sports/play										
Jogging	1	8	9	0	9	1	14	15	0	15
Frisbee	1	2	2	1	3	3	5	5	3	13
Catch	0	3	1	2	3	0	12	8	4	12
Kite flying	1	3	4	0	4	1	9	10	0	10
Digging/sand castles	2	3	5	0	5	4	5	9	0	9
Horseback riding	0	1	0	1	1	0	1	0	1	1
Hulahoop	0	1	1	0	1	0	1	1	0	1
Total	***5***	***21***	***22***	***4***	***26***	***9***	***47***	***48***	***8***	***61***

People and dogs were about twice as abundant at reference sites than MPA sites on long beaches, but this was not the case on less popular pocket beaches (Fig. 13). At pocket beaches, people visited reference and MPA sites in similar numbers, and dogs were more abundant at reference sites due to the high use of Cooks Beach.

Visitors to beaches varied considerably based on one region-wide survey of all 17 beaches (Fig. 14). Visitation was low in the morning on weekdays at all beaches surveyed during one week in August. In contrast, visitation tended to be one to two orders of magnitude greater from 10 am to 2 pm on one sunny Saturday in late July. This also was the case for dog walkers at four of the long beaches: Ocean Beach, Stinson Beach, Dillon Beach and Doran Beach, but it was not the case at the other 13 beaches.

Beach Wrack

The cover of macrophyte (macroalgae, surfgrasses [*Phyllospadix* spp.] and eelgrasses [*Zostera* spp.]) wrack was used to estimate the standing crop of drift macrophytes at each study beach during the rapid monthly surveys as well as during biodiversity and target species sampling. The macrophyte wrack observed on the 10 focal beaches consisted primarily of subtidal and intertidal kelps (mostly *Nereocystis leutkeana, Postesia palmeformis and Egregia menziesii),* other brown algae (mostly *Cystoseira osmundacea, Desmerestia* spp.and fragments of various kelps that could not be unambiguously identified), a diversity of red algae and surfgrasses (*Phyllospadix* spp.). Other subtidal and intertidal kelps including the giant kelp, *Macrocystis pyrifera, Pterygophora californica, Laminaria spp. and Lessoniopsis litoralis* were observed regularly, but were not abundant. Eelgrass was common only at sites near estuaries, esteros or bays.

The average cover of macrophyte wrack varied over an order of magnitude among the beaches, ranging from 0.11 to 3.37 m^2 m^{-1} (Fig. 15). A pocket beach (Stump Beach) had the greatest average cover of wrack, double the amount seen at all other beaches except Ross Cove. Low average wrack cover, < 0.7 m^2 m^{-1}, occurred at all of the long beaches, except Ross Cove (where there are several rocky outcrops along the beach that probably serve as a nearby source), and at only one of the pocket beaches, Shorttail Gulch (Fig. 15). Three of the four pocket beaches had an average macrophyte wrack cover exceeding 1 m^2 m^{-1} (Fig. 15).

Macrophyte wrack composition varied sharply among beaches. Kelp and other brown macroalgae made up 50 to 97 % and kelp alone 34 to 77 % of the macrophyte wrack at five of the beaches (Salmon Creek Beaches [N & S], Montara, Stump and Cooks Beaches) (Fig. 15). The wrack at Limantour Beach, Drakes Beach and Shorttail Gulch was between 40 and 72 % eelgrass (Fig. 15). While red macroalgae made up 69 to 79 % of the macrophyte wrack at Ross Cove and Horseshoe Cove (Fig. 15). All major categories of macophyte wrack were observed at all 10 focal beaches in at least trace amounts, but Cooks Beach and Ross Cove had almost no eelgrass, on average, and green algae was uncommon across all the study sites except Ross Cove.

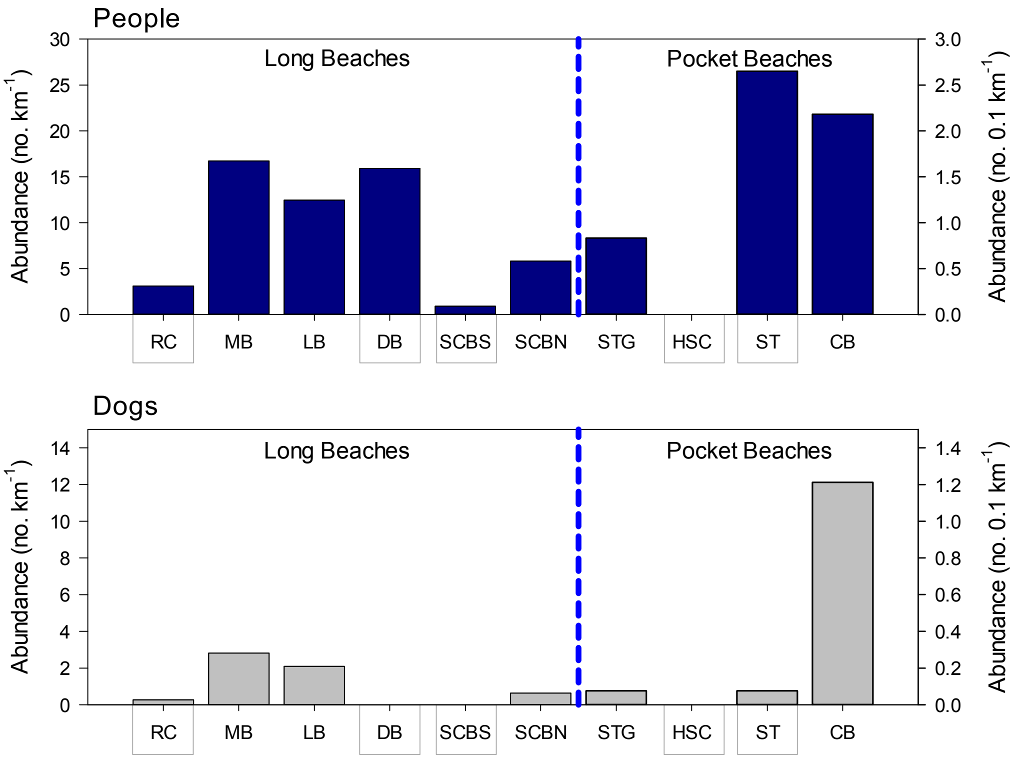


Figure 12. Average abundance of people and dogs across the 10 beaches surveyed in the NCC region between June 2010 and May 2011. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). Additional information as in Fig. 7.

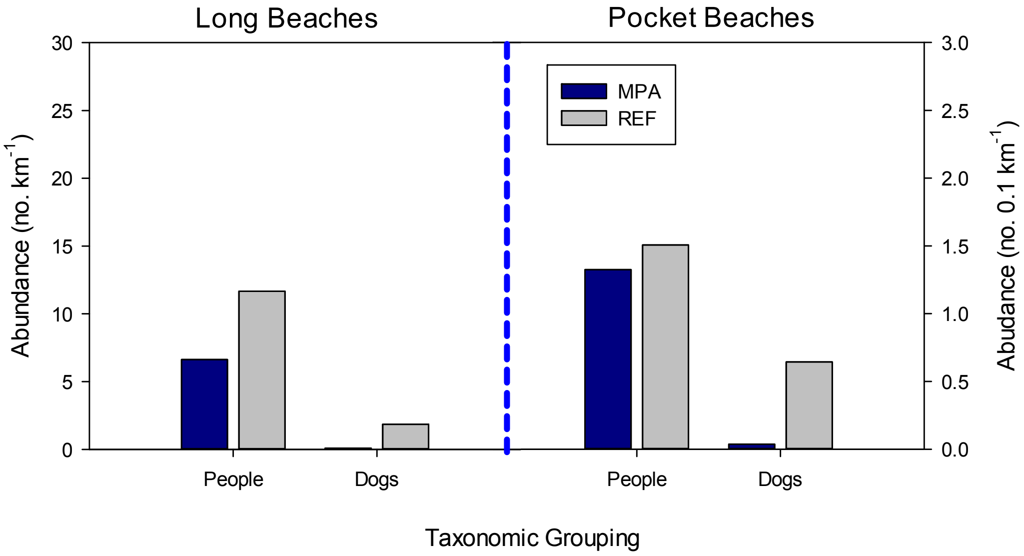


Figure 13. Average abundance of people and dogs observed in MPA and reference beaches by beach type. Data are from 11 monthly surveys at 10 sites between June 2010 and May 2011.

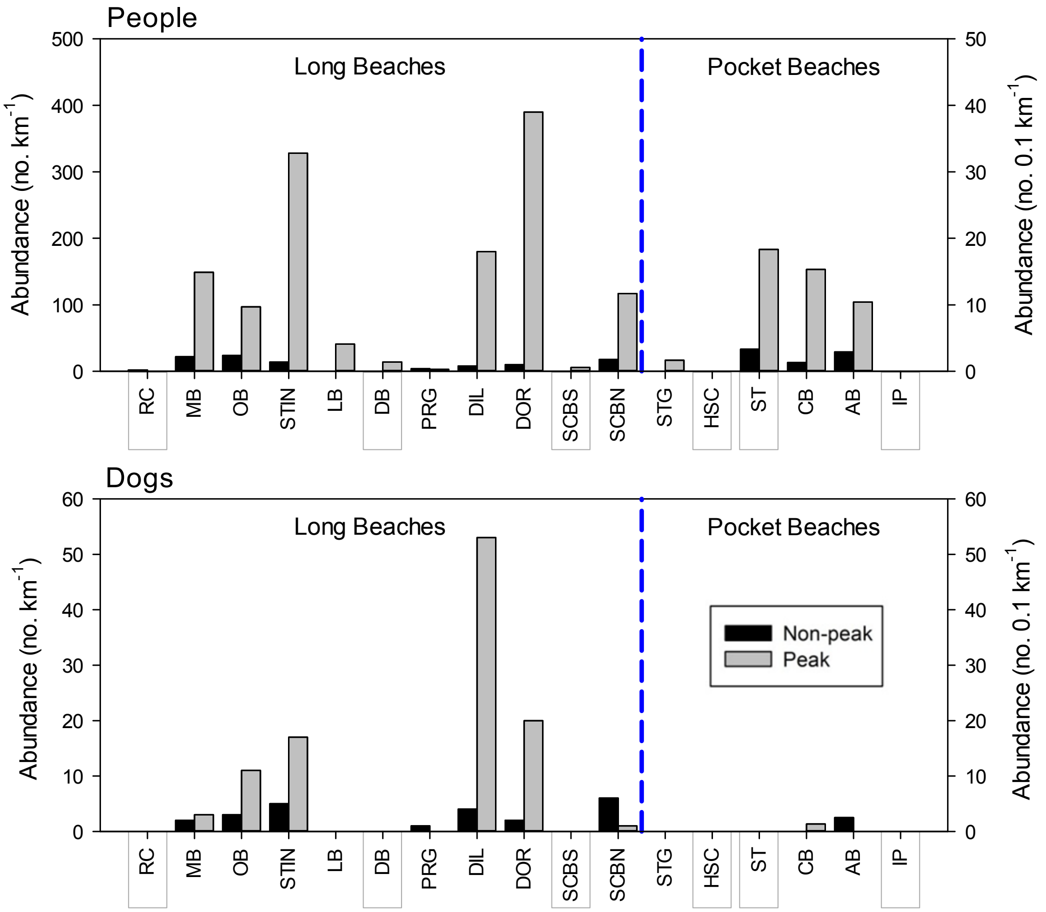


Figure 14. Abundance of people and dogs on 17 beaches in the NCC region during summer. Surveys were conducted along standard 1 km transects on long beach or the length of the shoreline for pocket beaches as for the bird surveys, but only once for each site during June, July or August. Peak denotes surveys conducted on a sunny summer weekend day between 10 am and 2 pm all on a single Saturday in late July. Non-peak denotes surveys conducted on early morning weekdays between 6 am and 10 am within a single week in early August. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches).

The average total abundance of fresh beach-cast kelp thalli (*Nereocystis leatkeana*, *Postelsia palmaeformis* and *Macrocystis pyrifera*) quantified in the alongshore surveys varied over three orders of magnitude (from 70 to 2,693 thalli km^{-1}) among sites (Fig. 15). Stump Beach and Cooks Beach both had > 1000 thalli km^{-1}. *Nereocystis* made up more than 75% of the abundance of fresh kelp thalli at half of beaches (Ross Cove, Montara Beach, Salmon Creek Beach (N), Shorttail Gulch, Stump Beach and Cooks Beach). The two beaches with the lowest abundance of fresh kelp thalli overall (Limantour Beach and Drakes Beach) were where we observed the most *Macrocystis pyrifera* composing over 75% of the fresh kelp. *Postelsia palmaeformis* was observed at all sites except Limantour Beach and made up over 18 % of the fresh kelp thalli at five of the focal beaches (Montara Beach, Salmon Creek Beach (N & S), Horseshoe Cove, Stump Beach and Cooks Beach) (Fig. 15). The average abundances of *Postelsia* and *Nereocystis* were very strongly correlated (r = 0.98, p < 0.0001), but the average abundance of

Macrocystis and *Nereocystis* were not at all ($r = -0.17$, $p = 0.6456$). Not surprisingly, the average cover of kelp wrack across the entire width of the beach is also very highly correlated with total abundance of fresh kelp thalli ($r = -0.92$, $p < 0.0001$), suggesting that fresh kelp surveys might be a sufficient proxy for estimating standing crop of kelp wrack on a beach. The average abundance of fresh kelp thalli tended to be greater on pocket beaches than long beaches, but there was substantial variation among sites (Fig. 16). There was no evident difference in the abundance of fresh kelp thalli between MPA and reference sites (Fig. 16).

The large spatial differences observed in macrophyte wrack accumulation and composition at the beaches are most likely related to the proximity of rocky reefs and prevailing current and wind patterns. The abundance of primary consumers of macrophytes, such as talitrid amphipods, likely influences the turnover rates and the standing crop of macrophyte wrack observed among beaches as well.

Other, non-macrophyte components of beach wrack (marine animal detritus, driftwood and trash) displayed very different spatial patterns (Fig. 15). Driftwood cover was highest at Salmon Creek Beach (S) (1.03 $m^2\ m^{-1}$), followed by Drakes Beach (0.5 $m^2\ m^{-1}$) and Salmon Creek Beach (N) (0.3 $m^2\ m^{-1}$); but was much lower at the rest of the beaches (ranging from 0.11 to 0.02 $m^2\ m^{-1}$) (Fig. 19). The average cover of animal wrack (consisting of hydroids, bird feathers, shells, jellies, etc.) was very low and less spatially variable overall ranging from 0.002 to 0.034 $m^2\ m^{-1}$, except at Horseshoe Cove where it was 0.062 $m^2\ m^{-1}$ (Fig. 15). Trash on the beach was also low overall ranging from 0.011 to < 0.001 $m^2\ m^{-1}$. Trash was greatest at Drakes Beach at 0.040 $m^2\ m^{-1}$ (Fig. 15), where a restaurant and large parking lot were immediately adjacent to the beach access point.

There was strong seasonal variation in the abundance of beach wrack in the region during the baseline study (Fig. 17). Macrophyte wrack was most abundant on the beaches between June and December with overall mean cover ranging from 0.9 to 2.7 $m^2\ m^{-1}$; August, October and November were the months with the highest cover (Fig. 17), but note no data were collected in July. Very low macrophyte wrack abundance was evident on the beaches from December to May (< 0.19 $m^2\ m^{-1}$ or 6% of the average cover between June and December) (Fig. 17). The abundance of fresh kelp plants (*Nereocystis* and *Postelsia*) in the monthly alongshore counts peaked strongly in November (>2000 plants km^{-1}) coinciding with the peak cover of kelps on the cross shore transects. Very low counts of fresh kelp plants were observed on the beaches from December through May (Fig. 17). There was a strong correlation between average kelp wrack cover and average abundance of fresh kelp thalli over time on the focal beaches ($r = 0.87$, $p = 0.0003$).

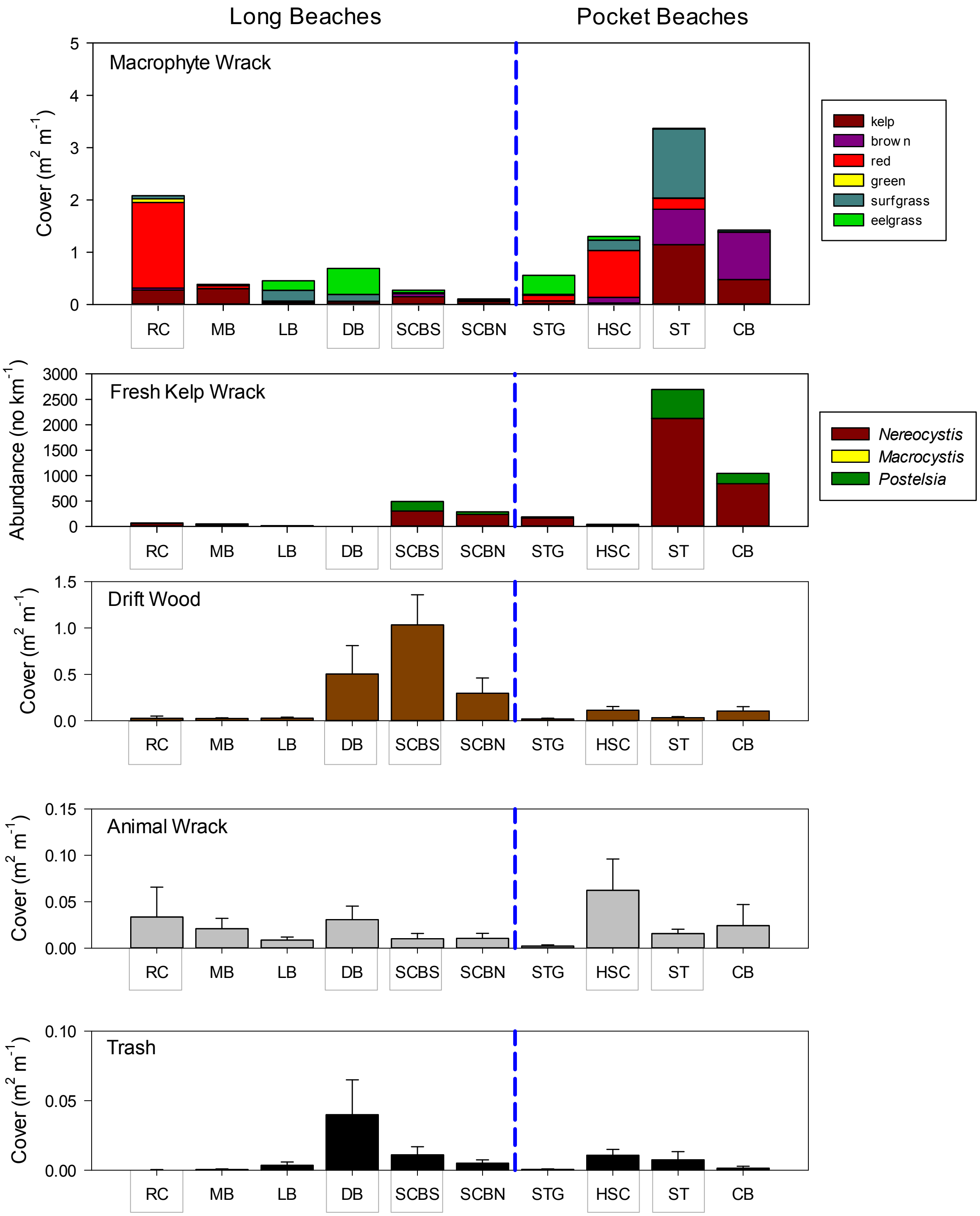


Figure 15. Average abundance of macrophyte wrack, fresh kelp plants, driftwood, animal wrack and trash on the 10 focal beaches. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE).

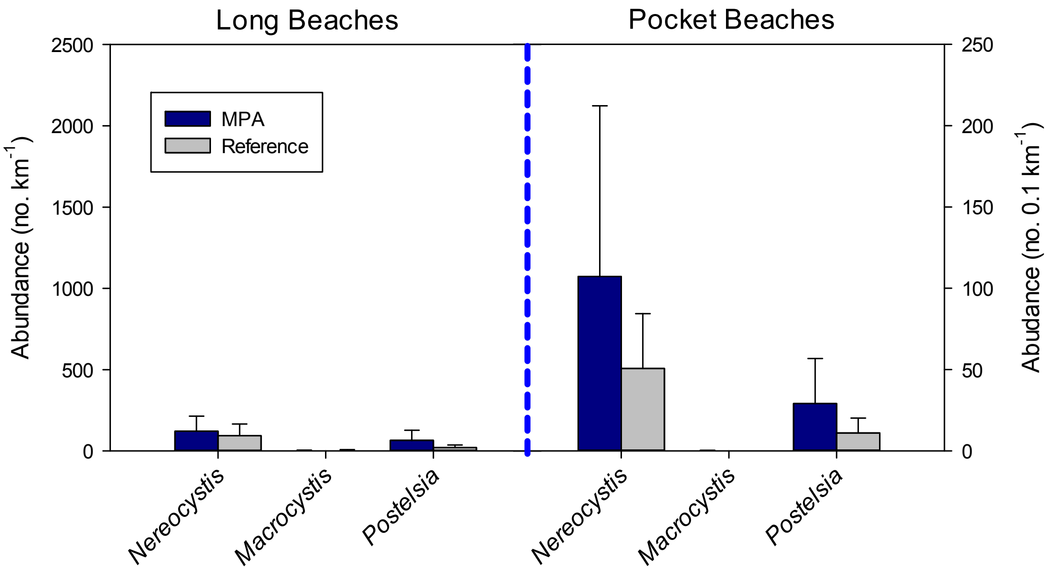


Figure 16. Average abundance of fresh kelp thalli of three species on transects at MPA and reference beaches during the baseline study, by beach type. Data are from 11 monthly surveys at 10 sites between June 2010 and May 2011. All data are averages (+ SE).

Postelsia and young *Nereocystis* plants (operationally defined as up to ~2 m from haptera to pneumatocyst) made up the greatest percentage of fresh kelp thalli in May (76%) and June (97%), presumably as fast growing and weakly attached plants are pruned off by waves during the months with the strongest winds associated with upwelling (Figs. 5 & 17). In April, when *Nereocystis* made up the smallest percentage of the fresh kelp thalli on the beaches, the percentage of *Macrocystis* was greatest. However, *Macrocystis* plants were most abundant on the beaches in December (16 km^{-1}).

The seasonal cover of driftwood and kelp wrack on the beaches were negatively correlated (r=-0.69, p= 0.0138) (Fig. 17). Animal wrack cover on the beaches was most abundant in August (Fig. 17), and the most trash was observed, surprisingly, in February and March rather than summer (Fig. 17).

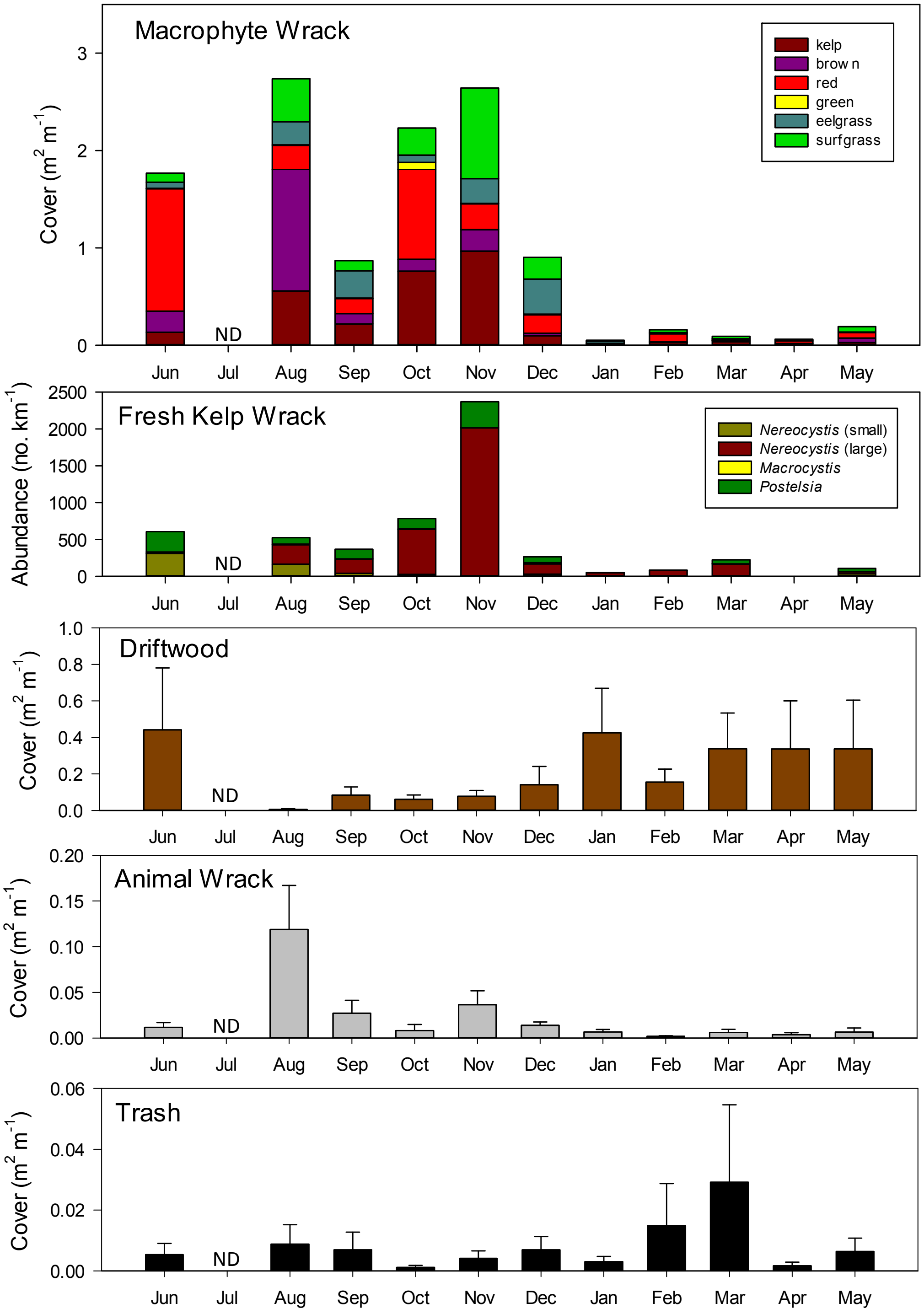


Figure 17. Seasonal abundance of macrophyte wrack, fresh kelp plants, driftwood, animal wrack and trash on the 10 focal beaches. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE). No data (ND) for July.

Macroinvertebrates

Macroinvertebrate abundance and biomass varied sharply among the 10 focal beaches we sampled quantitatively (Figs. 18 & 19) and were not correlated with each other. Total abundance varied over an order of magnitude from 2,072 individuals m^{-1} at Stump Beach to 83,616 individuals m^{-1} at Drakes Beach. Total biomass of macroinvertebrates varied over two orders of magnitude ranging from as little as 64 g m^{-1} also at Stump Beach to as high as 6,833 g m^{-1} at Limantour Beach. Values of macroinvertebrate abundance >10,000 animals m^{-1} are considered high for open coast beaches and have been reported primarily on high intermediate and dissipative beaches outside of California (McLachlan *et al.*, 1996).

Species occurrences and composition among sites was extremely heterogeneous (Table 5, Figs. 18 & 19). Total species richness (equivalent to total species density as we sampled the same total area/volume of sand at each beach) ranged from 10 to 26 species, but over 67 macroinvertebrate taxa were observed across all 10 beaches sampled in the NCC (Table 5). More than 15 species of macrofauna occurred in our samples at six of the 10 focal beaches. Limantour and Drakes beaches really stand out with respect to their total species richness (26 and 25 species, respectively, followed by Cooks Beach (20), one of the pocket beaches. Montara Beach had the lowest total species richness (10) of the 10 focal beaches.

Wrack-associated invertebrate species, (talitrid amphipods, isopods, insects and arachnids) (Table 5), which depend on subsidies of drift macroalgae from nearshore kelp forests and reefs, comprised an important component of the diversity of the intertidal community at all of the beaches. The proportion of wrack associated species, ranged from 30% to 73% (three to 11 species) among beaches and made up an average of 54% of the total number of invertebrate species found on the focal beaches.

The only two invertebrates observed across all 10 sites were our target species, *M. benedicti,* and *E. analoga* (Table 5). The taxon, *Megalorchestia* spp., was remarkably diverse in the study area, with five species represented, including: *M. benedicti*, *M. californiana*, *M. columbiana, M. corniculata* and *M. pugettensis*. Two additional taxa of macrofauna occurred in samples from seven of the study beaches: the kelp fly, *Fucellia* spp., and the cirolanid isopod, *Excirolana linguifrons*. Two macroinvertebrate species occurred at six of the focal beaches, the isopod *Alloniscus perconvexus* and the mysid *Archaeomysis grebnitzki*. Species that occurred at five of the sites included the polychaetes, *Nephtys californiensis* and *Saccocirrus sonomacus,* and the beetle, *Cercyon fimbriatus.*

Sand crabs and wrack-associated invertebrates

Although the two ecologically important taxa we are evaluating as potential indicators of the ecological state of sandy beaches (*E. analoga* and talitrid amphipods in the genus *Megalorchestia*) were present on all 10 of the focal beaches they varied substantially among beaches in both their numerical abundance and biomass. *Megalorchestia* spp. dominated the abundance of all wrack-associated macroinvertebrates (that also includes Coeloptera, Diptera and other insects representing a diversity of trophic levels and ecological roles) both numerically and by weight. Talitrids made up between 54 and 98 % (average [SD] = 81 [15] %) of the numerical abundance and between 56 and 98 % of the biomass (average [SD] = 89 [14] %) of all wrack-associated macroinvertebrates sampled (Figs. 18 & 19).

The average abundance of *E. analoga* and wrack-associated invertebrates across all 10 beaches was surprisingly similar (average [SD] = 4,402 [7,651] no. m^{-1} and average = 3,759 [4,161] no. m^{-1}, respectively), but the range of abundances varied over as much as three orders of magnitude (34 to 25516 no. m^{-1} and 379 to 14,275 no. m^{-1} for *E. analoga* and wrack-associated invertebrates, respectively) (Fig. 18). However, as expected, the average total biomass across all beaches sites varied substantially between these two groups of organisms (average [SD] = 2,110 [1,792] g m^{-1} and average = 89 [108] g m^{-1}, for *E. analoga* and wrack-associated invertebrates, respectively), as well as among sites ranging from 11 to 4,835 g m^{-1} for *E. analoga* and 6 to 366 g m^{-1} for wrack-associated invertebrates (Fig. 19).

Emerita analoga made up between 31 and 47 % of the numerical abundance of macroinvertebrates at Montara Beach, Drakes Beach, Salmon Creek Beach (S) and Shorttail Gulch but between 69 and 99 % of the biomass at all the long beaches except Drakes Beach (where it was only 58%) and at one pocket beach, Shorttail Gulch. Wrack-associated invertebrates made up over 73% of the numerical abundance of macroinverterbates at two pocket beaches (Stump and Cooks beaches) as well as at Ross Cove where it made up the highest percentage at 90%. Wrack-associated invertebrates generally made up only a small fraction of the total macroinvertebrate biomass at most sites, < 0.1 % to 2 % except at Ross Cove (27 %), Stump Beach (13 %), Cooks Beach (18 %) and Horseshoe Cove where this group peaked at 82 %.

Talitrid amphipods and dipteran flies

To quantify the abundance of dipteran flies and other flying insects not easily sampled with the infaunal cores, we used sticky traps placed adjacent to piles of fresh kelp wrack for standard time periods on our cross-shore transects during the biodiversity surveys, and during target species sampling (see methods above). The sticky traps also captured talitrid amphipods that are active on the sand surface and other crawling and hopping arthropods, such as beetles. Several species of flies were collected on the sticky traps, including *Fucellia spp.* (Anthomyiidae) and *Coelopa vanduezii* (Coelopidae) Dolichopodidae, Empididae and Sphaeroceridae families, along with talitrid amphipods and Coleoptera (primarily Staphylinidae and Hydrophilidae).

The abundance of dipteran flies and talitrids measured with this method are presented in Fig. 20. The average number of dipteran flies per trap was greatest at Stump Beach, the site with the highest abundance of brown macroalgal wrack, averaged over all three sampling dates. , However when target sampling was done across all 17 sites in August 2010, abundances at Ross Cove and Montara Beach were also somewhat elevated (Fig. 20). In general, sites with the highest abundance of dipteran flies tended to have few talitrid amphipods and the opposite was also true (Fig. 20). When examined at the scale of individual sticky traps, the pattern was even more striking (lower 2 panels in Fig. 20, (for lower right panel, $r = 0.638$, $p < 0.001$, $n = 114$) suggesting strong interactions between these two taxa that feed on brown macroalgae wrack.

Polychaete worms

The abundance, biomass, diversity, occurrence and species composition of polychaete worms varied tremendously among beaches and between long and pocket beaches (Figs. 18 & 10, Table 5). Limantour and Drakes beaches stand out with respect to the number of different species observed (20) as well as the overall abundance and biomass of polychaetes on these beaches (Figs. 18 & 10, Table 5). The deposit-feeding ophelid polychaetes, *Euzonus* spp. and the predatory glycerid polychaetes only occurred on these two long beaches. Lumbrineirid and saccocirrid worms however were notably absent from these two long beaches. Lumbrineirid worms were exclusively found on beaches north of Bodega Head starting at Salmon Creek Beach (N) and present on all the pocket beaches except Horseshoe Cove where the sand is exceptionally coarse (Figs. 3, 18 & 10, Table 5). The worm *Saccocirrus sonomacus* was notably abundant on the beaches with coarser sands (Ross Cove, Montara Beach, Salmon Creek Beach (S), Horseshoe Cove and Stump Beach) (Figs. 3, 18 & 10, Table 5). This species is considered an interstitial invertebrate, which lives in the spaces between sand grains rather than burrowing. Such taxa are generally too far small to be retained on the sieves we sampled with and are not considered part of the macroinvertebrate community. However, this species is unusually big and was retained on our sieves in large numbers (> 6000 individuals m^{-1}) at Horseshoe Cove and Montara Beach, both of which are characterized by extremely coarse sand and correspondingly large interstitial spaces.

Other macroinvertebrates

Many of the intertidal isopods, amphipods and other small crustaceans, including swash zone mysids and haustoriid amphipods, were most abundant and had the highest biomass on the long beaches, except at the southern sites of Ross Cove and Montara beaches. These taxa were also abundant on Cooks Beach, a pocket beach (Figs. 3, 18 & 10, Table 5). The haustoriid amphipod, *Eohaustorius washingtonianus,* was the most abundant single species observed at any site with 36,516 individuals m^{-1} recorded at Drakes Beach.

Beach Wrack

The cover of beach wrack when the biodiversity samples were collected in July 2011 is presented in Fig. 21. Patterns were broadly similar to those reported for the rapid monthly surveys in the prior year across these same sites, except that the cover of eelgrass on Drakes Beach was very high on this sampling date (Fig. 21).

Contrasts between beach types and MPA status

There were some interesting differences in the distribution of the potential indicator taxa between long and pocket beaches and between MPA and reference sites as well. The abundance of wrack associated invertebrates was four fold higher on pocket beaches than long beaches (average [SD] on pocket beaches: 6,840 [5,480] no. m^{-1} vs. long beaches: 1,705 [699] no. m^{-1}). Wrack-associated invertebrates made up 29% of the total invertebrate biomass on pocket beaches vs. only 5% on long beaches. While there was no apparent difference in numerical abundance between MPA and reference sites (average [SD] on MPA beaches: 3,099 [2,426] no. m^{-1} vs. reference beaches: 4,419 [5,655] no. m^{-1}), wrack-associated invertebrates made up 25% of the total biomass on MPA beaches compared to only 5% on the reference beaches. In contrast, *E. analoga* was almost five times more abundant, on average on long beaches compared to pocket (average [SD] on pocket beaches: 6,426 [9,478] no. m^{-1} vs. long beaches: 1,365 [2,328] no. m^{-1}), although the range of values among beaches was highly variable. The total biomass of this crab on long beaches was double the total biomass found on pocket beaches (average [SD] on long beaches: 2,727 [1,769] g m^{-1} vs. pocket beaches: 1,769 [1,588] g m^{-1}), making up 81 % vs. 48 % of the total invertebrate biomass, respectively. Additionally, total *E. analoga* biomass was almost three times greater on reference beaches compared to MPA beaches (average [SD] on reference beaches: 3,229 [1,588] g m^{-1} vs. MPA beaches: 991 [1,256] g m^{-1}), making up 84 % vs. 52 % of the total macroinvertebrate biomass.

Macroinvertebrates and shorebirds

The total species richness and biomass of macroinvertebrates at a site were both strongly correlated with average shorebird abundance (r = 0.75 and r = 0.66, respectively; Fig. 22). The correlations were even stronger when two beaches that appear to be outliers (Montara and Cooks beaches) are removed from the analyses (Fig. 22). Both of these beaches experience high human and dog visitation (Figs. 12 & 14) and are surrounded by high cliffs or bluffs, making these beaches less hospitable to shorebirds. The Montara Beach transect is embedded in the shortest shoreline extent of our long beaches. *Emertia analoga* biomass is highly correlated with total macroinvertebrate biomass on a beach (r = 0.95; Fig. 23), and thus is also a very strong correlate of shorebird abundance once the extreme outlier, Montara Beach, is excluded from the analysis (r = 0.84; Fig. 23). Talitrid amphipods appeared to have a much different association with shorebird abundance that varied strongly with beach type and was a function of their numerical abundance rather than their total biomass (Fig. 24). On long beaches they were positively correlated (r = 0.78) while on pocket beaches the relationship appeared strongly reversed (r = -0.83), but the data were very sparse (n = 4) and the evidence was thin (p-value = 0.0815; Fig. 24).

Targeted sampling of potential indicator species

The two surveys of potential macroinvertebrate indicator taxa in June and August of 2010 yielded comparable estimates of abundance and biomass of these taxa at the 10 primary study beaches. The two major macroinvertebrate indicator taxa, which are important food sources for higher trophic levels, were sampled: swash zone prey focusing on *E. analoga* and wrack-associated prey focusing on *Megalorchestia* spp. We also collected aerial taxa focusing on dipterans of several species. We extended this sampling effort in the NCC region to an additional seven beaches beyond the 10 focal beaches in August 2010 only.

Overall patterns in the abundance and biomass of the two macroinvertebrate indicator taxa were generally similar to those observed in biodiversity samples of summer 2011. However, large differences between spring and late summer abundance of the indicator taxa were evident in our surveys for many beaches.

For the indicator taxa surveys in 2010, the overall mean abundance of talitrid amphipods varied by almost an order of magnitude among study beaches and was lower in June than in August. Mean abundance ranged from 243 to 1,101 individuals m^{-1} in the June surveys and 254 to 8,329 individuals m^{-1} in August surveys. Overall mean abundance of this taxa generally increased between the June and August surveys (9 of 10 beaches), averaging a 200% increase. The overall mean values of abundance for June and August surveys were positively but not significantly correlated suggesting an increase in abundance over the summer. For the biodiversity surveys in July 2011, the abundance of talitrid amphipods varied over two orders of magnitude among the sites, ranging from 212 to 13, 081 individuals m^{-1}.

In the indicator taxa surveys, the overall mean biomass of *Meglaorchestia* spp. varied by an order of magnitude among beaches, ranging from 3.6 to 53.7 g m^{-1} in the June surveys (data not shown) and 3.8 to 133.4 g m^{-1} in August (Fig. 25). Overall mean biomass of this taxon generally increased between the June and August surveys (six of 10 beaches), averaging a 55% increase. In addition, mean values for biomass of *Megalorchestia* spp. for June and August surveys were positively but not significantly correlated, suggesting an increase in biomass over the summer. For the biodiversity surveys in July 2011, the biomass of talitrid amphipods varied over an order of magnitude among the study sites, ranging from 4.7 to 359 g m^{-1}.

The talitrid amphipods were most abundant on the northernmost beaches, but especially on three of the six pocket beaches, Cooks, Anchor Bay and Iverson Point beaches (Fig. 25). Pocket beaches supported the highest abundance and biomass of *Megalorchestia* spp. observed in our study in all our surveys. Three of the six pocket beaches surveyed in August 2010 supported more than 4000 individuals m^{-1} and >90 g m^{-1} of biomass (Fig. 25). Overall abundances of this taxon, exceeding 2,000 individuals m^{-1}, only occurred at five beaches (four pocket beaches and one long beach) in August 2010 (Fig. 25). Abundances exceeding 2000 individuals m^{-1} were not observed in the June 2010 surveys. Low abundance of *Megalorchestia* (< 1000 individuals m^{-1}) occurred at eight of the 10 sites surveyed in June and occurred at seven of the 17 sites surveyed in August 2010. In July 2011, abundance of talitrids was greater and exceeded 1000 individuals m^{-1} at eight of the 10 beaches, Cooks Beach, a pocket beach. Low biomass (<10 g m^{-1}) of *Megalorchestia* occurred at six of the 10 sites in June 2010, seven of the 17 sites in August 2010 but only two of the 10 sites in July 2011.

Macrophyte wrack composition and cover varied strongly among sites also. Red and brown algae were most abundant on northern pocket beaches, while eelgrass wrack was abundant on the beaches of Point Reyes and to the north of Tomales Bay but south of Bodega Head (Fig. 25). Doran Beach had the greatest cover of macrophyte wrack (mostly eelgrass and green algae), but the lowest abundance of talitrid amphipods (Fig. 25). However, Eelgrass is not very palatable to amphipods due to its zosteric acid content.

In contrast to the distribution of talitrids, sand crabs were most abundant on long beaches in the southern portion of the study region. Both Montara and Drakes beaches stood out in terms of the high numerical abundances and biomass of *E. analoga* on their shores (Fig. 26). Total biomass was somewhat more evenly distributed among sites than numerical abundance, indicating some of the sites with low abundances had populations skewed toward larger and older individuals (Cooks Beach and Anchor Bay Beach, for example) (Fig. 26).

The average abundance of *E. analoga* varied over two orders of magnitude among the 17 beaches surveyed in August 2010, ranging from 0 to 28,245 individuals m^{-1} (Fig. 26). For the 10 focal beaches, the mean abundance of *E. analoga* in the macroinvertebrate indicator taxa surveys also varied over two orders of magnitude among sites, ranging from 43 to 2,037 individuals m^{-1} in the June surveys and 0 to 28,245 individuals m^{-1} in the August surveys (Fig. 26). Peak numbers were observed and average abundance was generally higher in August than June. The abundance of *E. analoga* in the August surveys was not correlated with that of the preceding June surveys, suggesting recruitment may occur after June in the study region. The highest mean abundances for *E. analoga* (>20,000 individuals m^{-1}) were observed on long beaches, specifically Montara Beach and Drakes Beach, where both survival and recruitment appeared to be high. Pocket beaches had lower abundance of sand crabs (Fig. 26) The exception was Shorttail Gulch, a pocket beach with high connectivity to adjacent beaches where sand crab abundance exceeded >4,000 individuals m^{-1} at in the July 2011 biodiversity survey. Relatively low abundance of this species (<1,000 individuals m^{-1}) was observed at the majority of sites, specifically at 6 of the 10 beaches surveyed in June 2010 and 10 of the 17 beaches surveyed in August 2010. For the biodiversity surveys in July 2011, the abundance of sand crabs varied over two orders of magnitude among the study sites, ranging from 34 to 25,516 individuals m^{-1}.

The mean biomass of *E. analoga* measured in the indicator taxa surveys varied over three orders of magnitude among the beaches in the large scale regional survey in August 2010, ranging from 0 g m^{-1} to 7,501 g m^{-1} among the 17 beaches (Fig. 26). For the 10 primary study beaches, the mean biomass of *E. analoga* in the macroinvertebrate indicator taxa surveys varied over four orders of magnitude among sites, ranging from 0.1 g m^{-1} to 3,088 g m^{-1} in June surveys and 0 to 7,501 g m^{-1} in August (Figure 12). Mean biomass was higher in the August surveys than in the June surveys at eight of the 10 beaches, reflecting the rapid growth and increasing size of crabs over the summer months (Figure 12). The biomass of *E. analoga* in the August surveys was weakly correlated with that of the preceding June surveys. For the biodiversity surveys in July 2011, the biomass of sand crabs varied over two orders of magnitude among the study sites, ranging from 11 to 4,835 g m^{-1}.

The greatest mean biomass values for *E. analoga* (>4,000 g m^{-1}) observed in the baseline surveys were on the long beaches at Limantour Beach, Drakes Beach and Montara Beach. In the biodiversity study, biomass also exceeded >3,000 g m^{-1} at Shorttail Gulch, a pocket beach with high connectivity to adjacent beaches. Low biomass (< 100 g m^{-1}) of this species was observed at three of the four pocket beaches in June 2010 (Fig. 12).

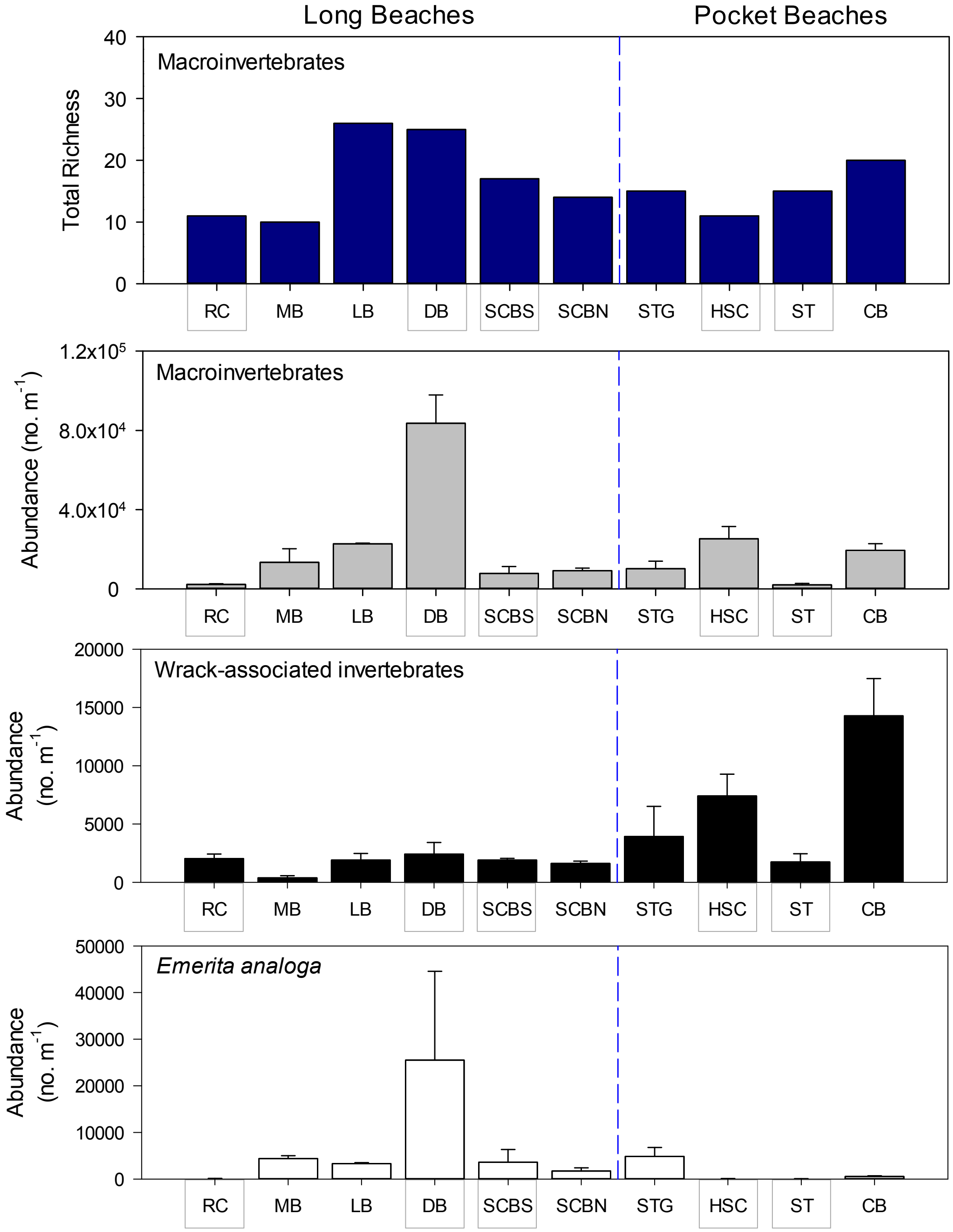


Figure. 18 Abundance and total richness of macroinvertebrates, wrack-associated invertebrates, hippid crabs, talitrid amphipods, phytoplankton, detritus feeding and sand-licking invertebrates, *Excirolana* spp., mysids, *Olivella biplicata* and glycerid, lumbrineirid, nephytid, saccoccird, ophelid and other polychaete worms. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE).

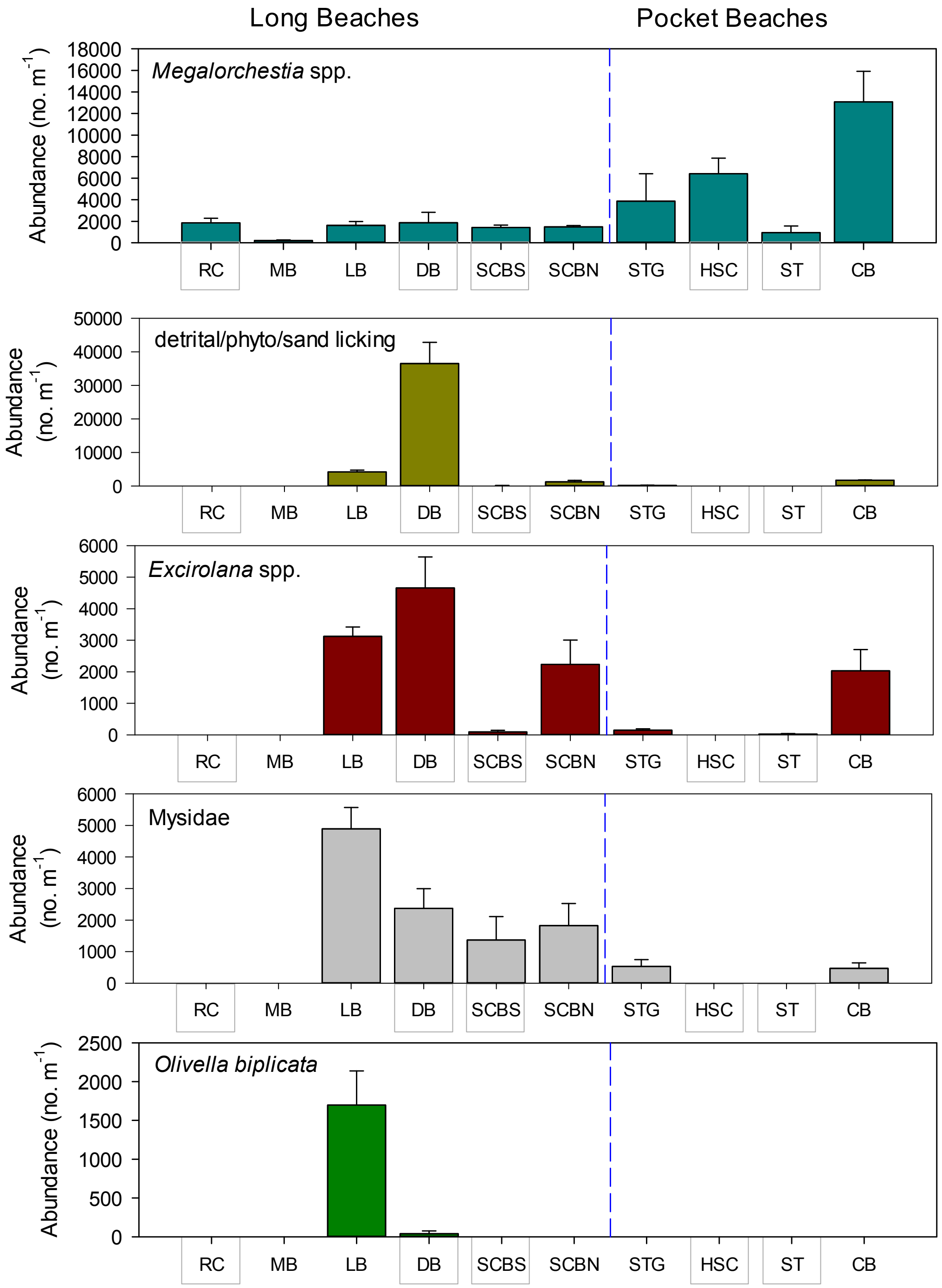


Figure 18. (Con’t.)

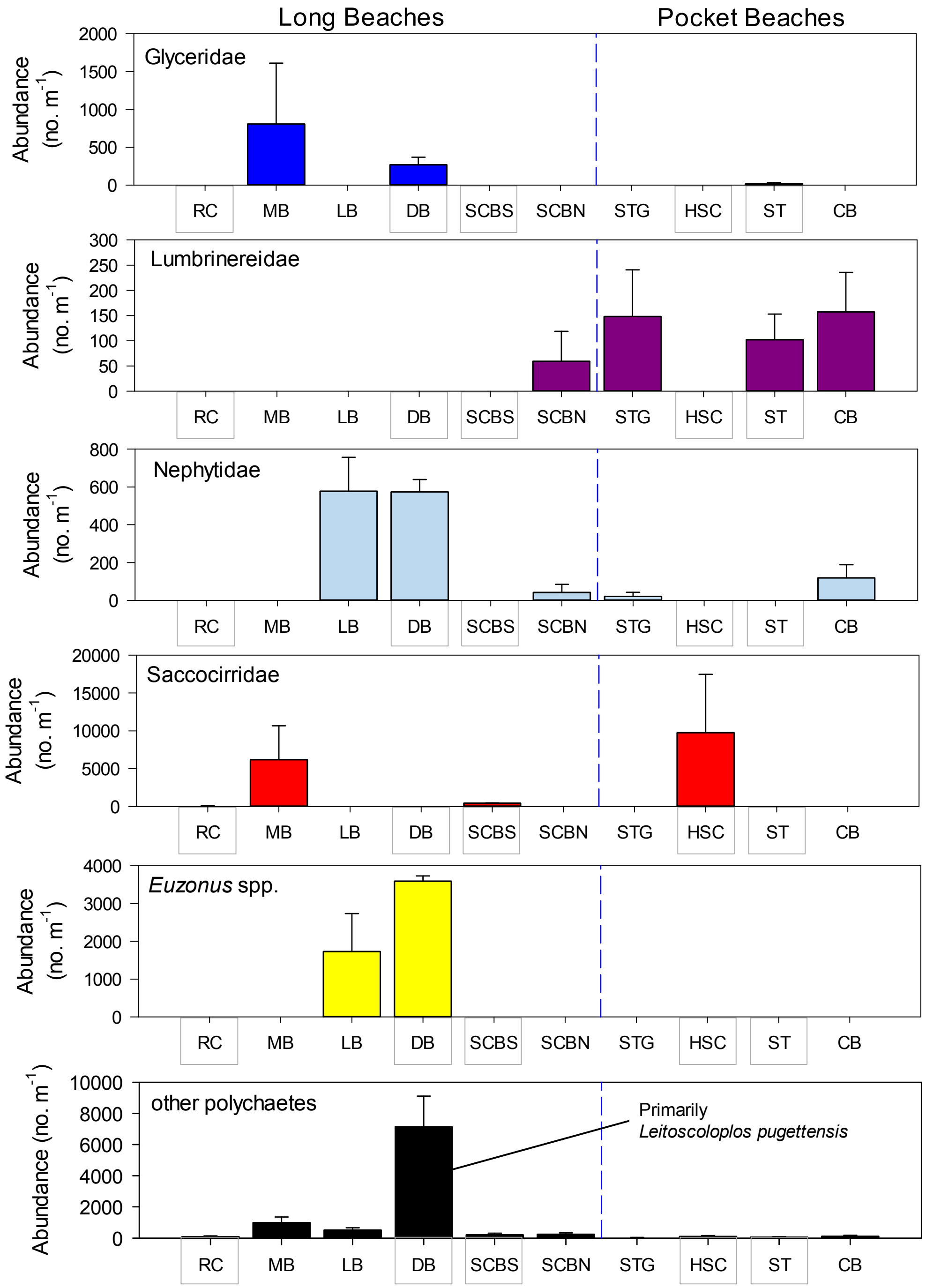


Figure 18. (Con't.)

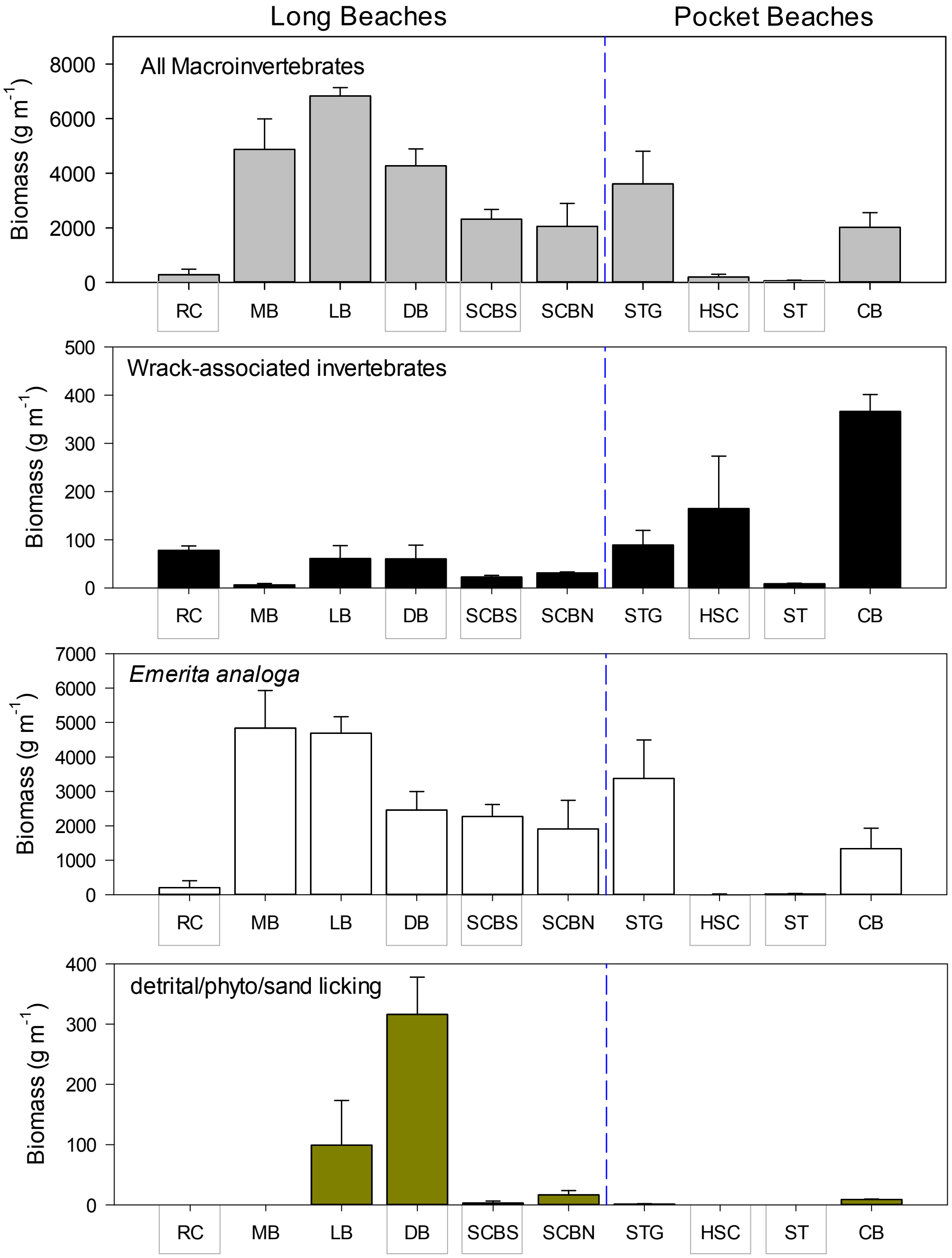


Figure 19. Biomass of macroinvertebrates, wrack-associated invertebrates, hippid crabs, talitrid amphipods, phytoplankton, detritus feeding and sand-licking invertebrates, *Excirolana* spp., mysids, *Olivella biplicata* and glycerid, lumbrineirid, nephytid, saccoccird, ophelid and other polychaete worms. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE).

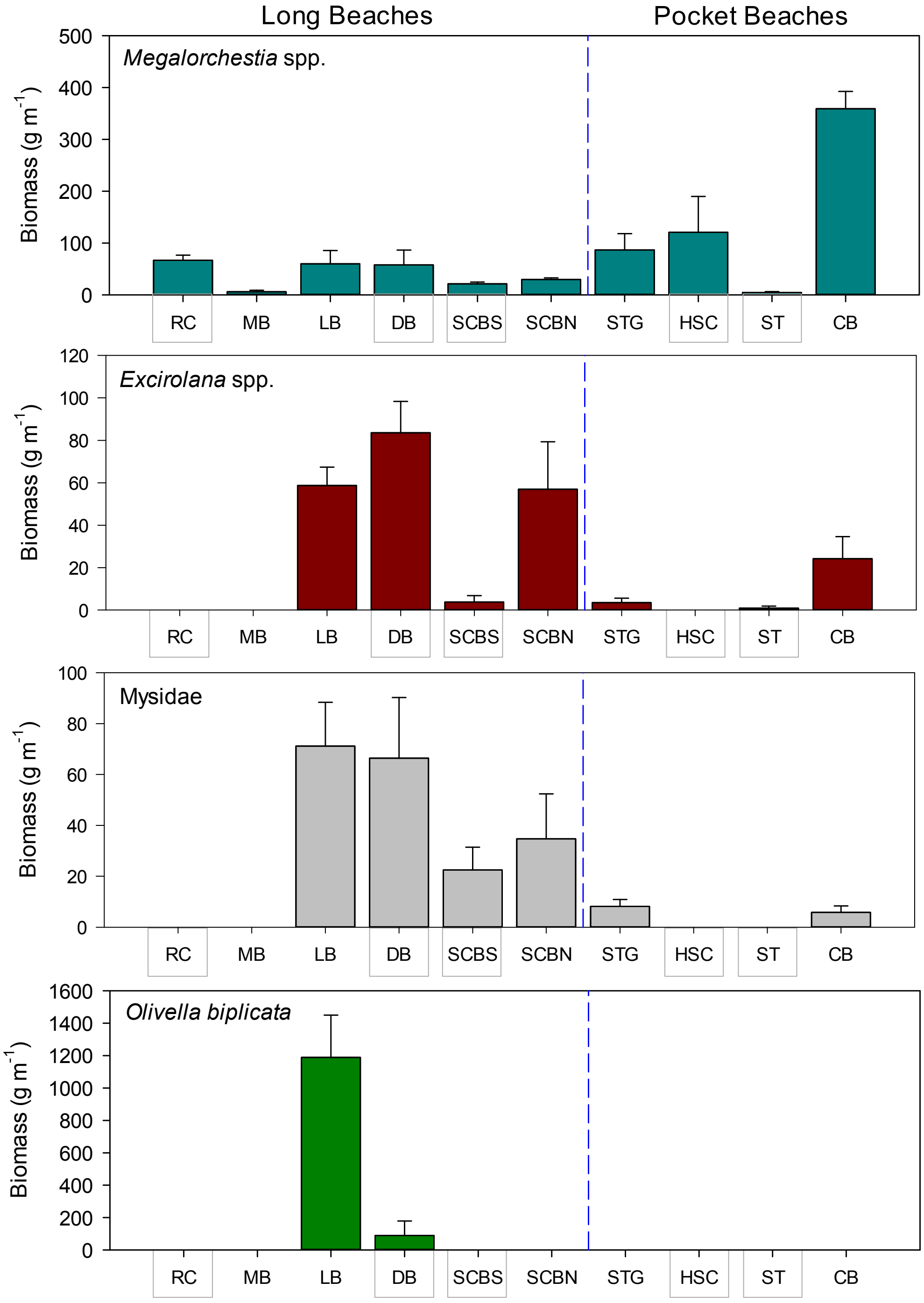


Figure 19. (Con't.)

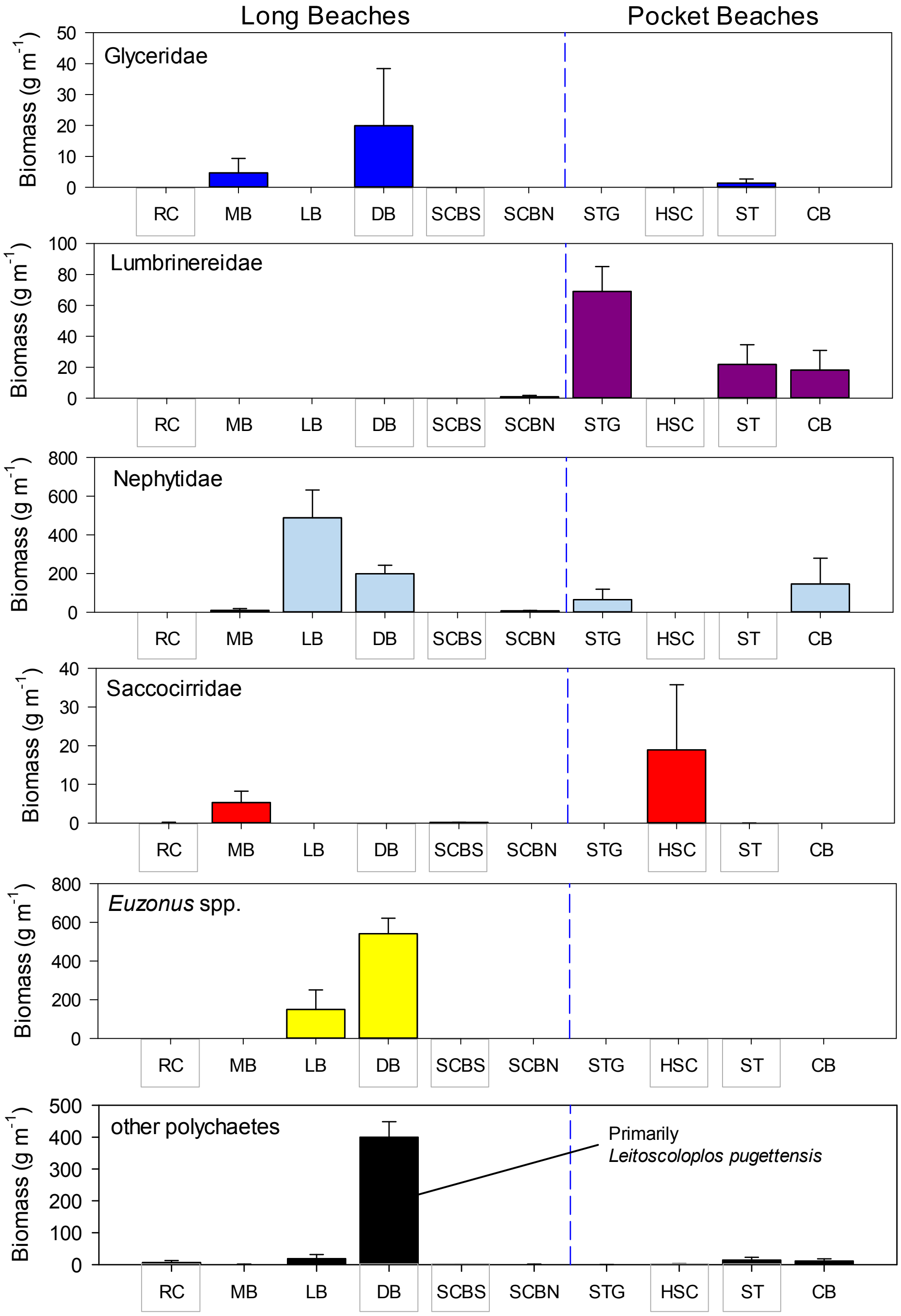


Figure 19. (Con't.)

Table 5. Macroinvertebrate species occurrence and total species richness at 10 focal beaches. Species occurrence is denoted by an X in a gray box, if its abundance was > 2,000 individuals m-1 shoreline it is bold-faced as is the border. Species observed at the site from other ancillary sampling efforts (sticky traps and net sweeps) are denoted by 'p' also in a gray box. Juvenile *Megalorchestia* spp. that could not be identified to the species level are included because they were numerical very abundant, but are denoted by an X in a light gray box.

Species, by taxonomic group	**Long Beaches**						**Pocket Beaches**			
	MPA			**MPA**	**MPA**			**MPA**	**MPA**	
	RC	**MB**	**LB**	**DB**	**SCBS**	**SCBN**	**STG**	**HSC**	**ST**	**CB**
Annelida (Clitellata)										
Enchytraedae (f)		X								
Annelida (Polychaeta)										
Glycera dibranchiate				X						
Hemipodia simplex		X		X					X	
Lumbrineris zonata										X
Lumbrineris							X		X	
Lumbrinereidae (f)						X				
Nephtys californiensis			X	X		X	X			X
Nephtys		p								
Nephtyidae (f)										X
Arabella sp.									X	p
Pisione hermansi	X	X			X		X			
Pionosyllis sp.								X		
Saccocirrus sonomacus	X	**X**			X			**X**	p	
Pygospio californica			X	X						
Scolelepis squamata				X						
Dispio uncinata			X	X						X
Capitellidae (f)		X			X					
Euzonus dillonensis			X	X						
Euzonus mucronata			X	**X**						
Euzonus williamsi			X							
Leitoscoloplos pugettensis			X	**X**						
Arthropoda (Arachnida)										
Paraonidae (f)						X				
Garypus californicus							X		X	
Neomolgus littoralis			X							
Arthropoda (Chilopoda)										
Chilopoda (c)								X		

Table 5. (Con't.)

Arthropoda (Insecta, Coleoptera)										
Coelopa vanduzeei				p		p				
Coelopa										p
Emphyastes fucicola			X	X			X			
Euspilotus scissus									X	
Histeridae (f)	X									
Cercyon fimbriatus					X	p	p		X	X
Cercyon luniger			p							
Endeodes collaris								X		
Aleochara sulcicollis										X
Bledius monstratus				X	X					X
Bledius ornatus			X	X			X		X	
Bledius					p				X	
Cafius canescens			X	X						X
Cafius			X				p		X	X
Pontomalota terminalia					X					
Tarphiota fucicola					X		p		p	
Tarphiota geniculata		X							p	
Thinopinus pictus	X									
Coelus ciliatus						X				
Tenebrionidae (f)				X					X	
Fucellia	X		p	p		p	p		X	X
Trichoceridae(f)					X					
Pteromalidae(f)					X					
Arthropoda										
Eohaustorius dillonensis			X							
Eohaustorius sawyeri							X			
Eohaustorius washingtonianus			**X**	**X**		X				X
Eohaustorius williamsi			X							
Cerapus							X			
Oedicerotidae (f)						X				
Grandifoxus grandis			X		X	X				X
Grandifoxus longirostris			X							
Mandibulophoxus gilesi			X		X	X				X

Table 5. (Con't.)

Megalorchestia benedicti	X	X	X	X	X	X	X	X	X	X
Megalorchestia californiana			X	X			X			
Megalorchestia columbiana	X				X	X		X		
Megalorchestia corniculata							X			**X**
Megalorchestia pugettensis	X	X					X	X		
Megalorchestia (juveniles)	X	X	X	X	X	X	**X**	**X**	X	**X**
Emerita analoga	X	**X**	**X**	**X**	**X**	X	X	X	X	X
Penaeidae (f)									X	p
Alloniscus perconvexus	X			X	X	X		X		X
Alloniscus								X		
Excirolana chiltoni			X	**X**						
Excirolana linguifrons			**X**	X	X	**X**	X		X	X
Excirolana			p	X						X
Acanthomysis californica			X							
Archaeomysis grebnitzki			**X**	**X**	X	X	X			X
Mollusca										
Olivella biplicata			X	X						
Nemertea										
Nemertea (p)	X	X		X				X		
Total (gamma) Richness	**11**	**10**	**26**	**25**	**17**	**14**	**15**	**11**	**15**	**20**

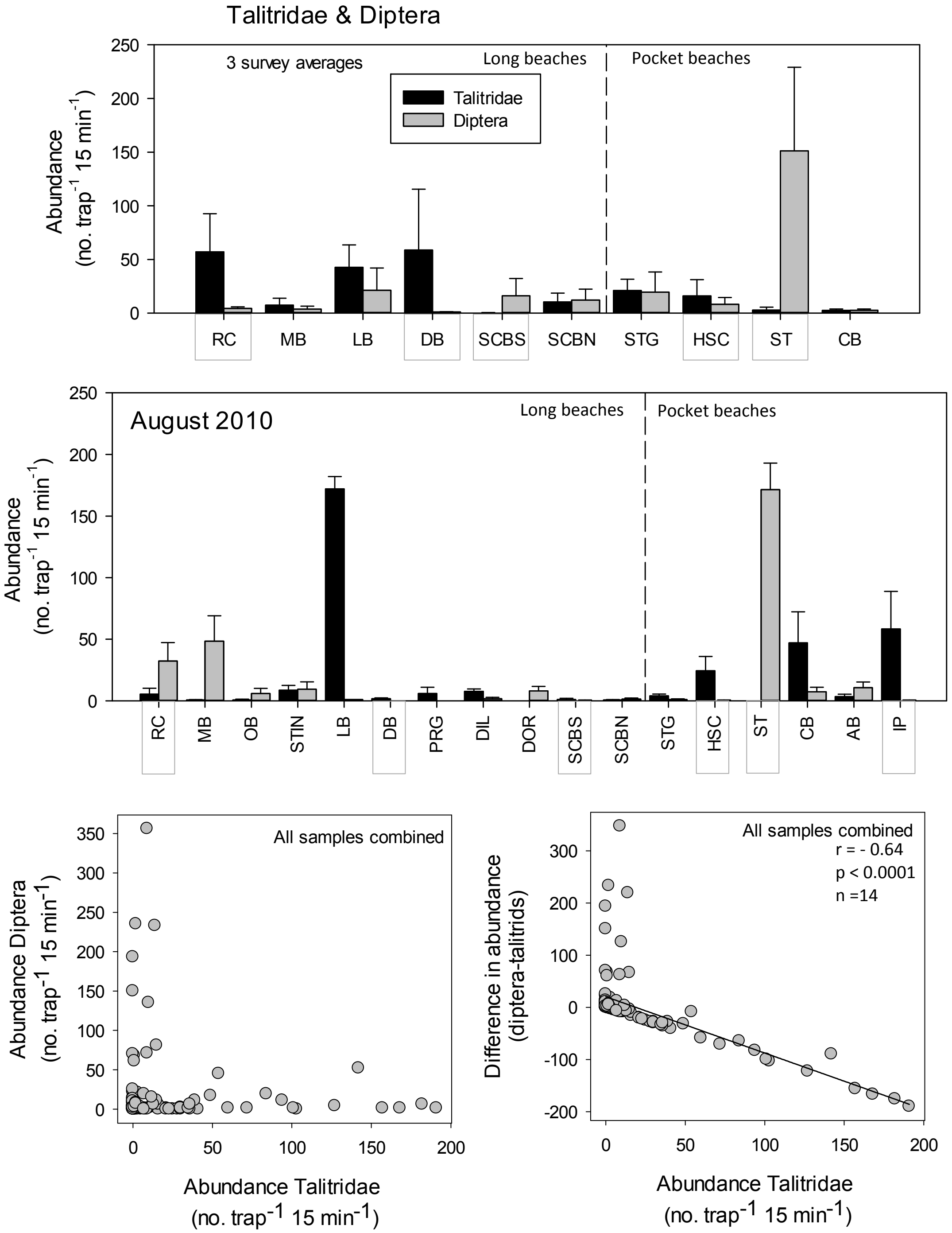


Figure 20. Abundance of talitrid amphipods and dipteran flies caught on sticky traps. Data are presented as averages (+SE) of three sampling dates for our 10 focal beaches and from a single survey of 17 beaches. For the top two panels, beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). Abundances from the two sticky traps collected on each transect were averaged before calculating site averages and standard errors. The data in the lower two graphs are the abundances from each sticky trap (sample). All data are averages (+ SE).

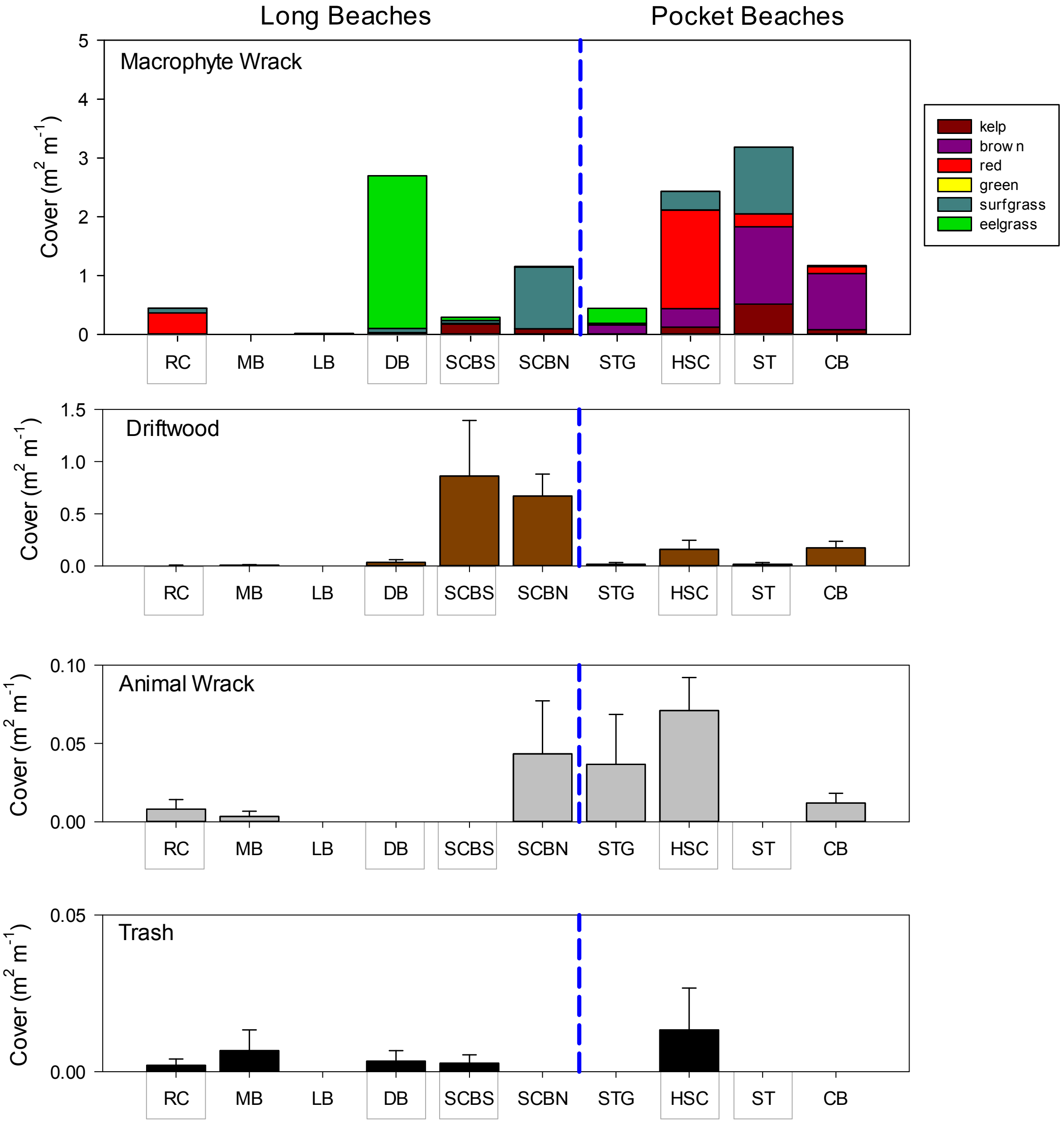


Figure 21. Cover of macrophyte and other beach wrack during the biodiversity surveys. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages (+ SE).

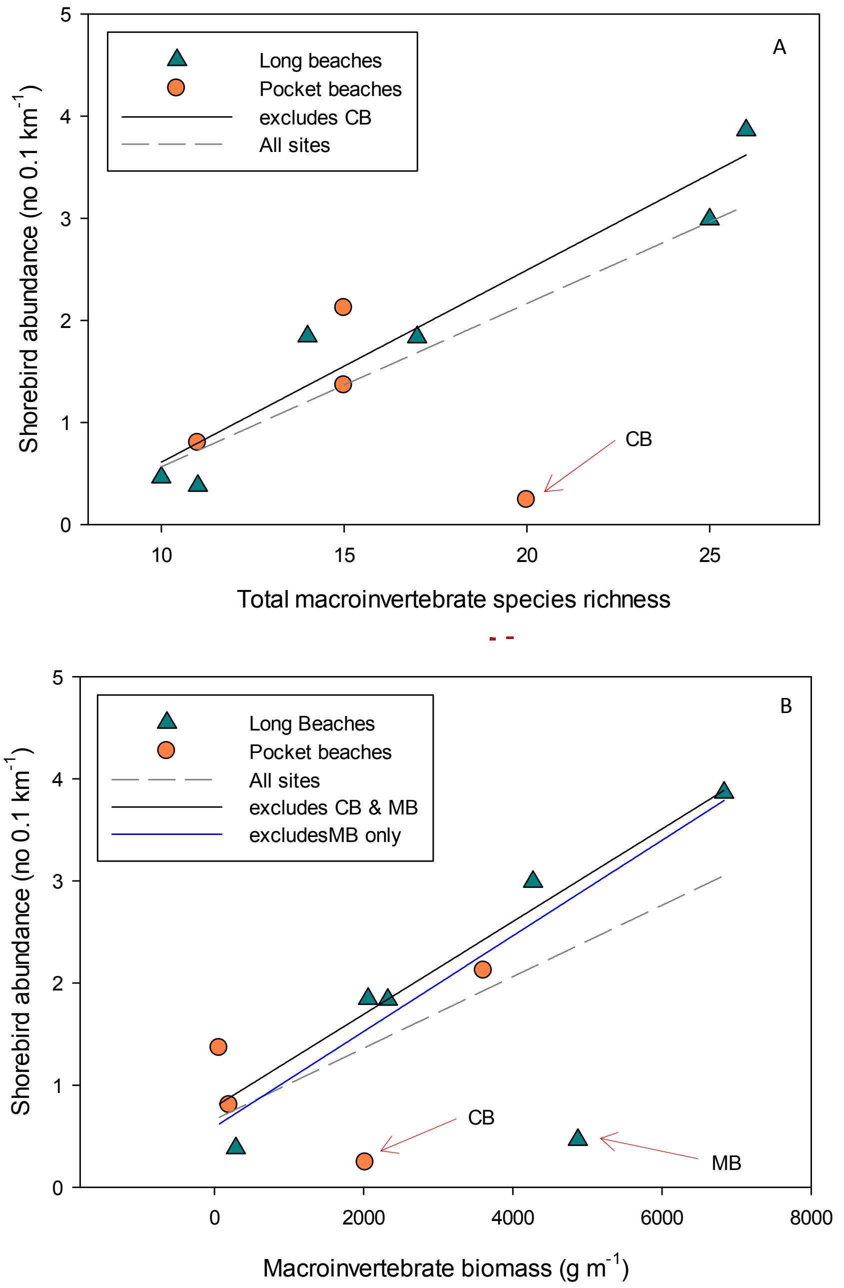


Figure 22. Average shorebird abundance as a function of total macroinvertebrate biomass and species richness on 10 focal beaches. Correlations and corresponding p-values are given for each hypothesized functional relationship (linear equations from ordinary least squares (OLS) regression are also presented). A) Correlations of average shorebird abundance and total macroinvertebrate species richness for all sites: r = 0.75, p-value =0.0081, (y = -1.032 + 0.160x); and excluding the outlier site Cooks Beach (CB): r = 0.95, p-value < 0.0001 (y = -1.27+ 0.188x). B) Correlations of average shorebird abundance and macroinvertebrate biomass for all sites: r = 0.66, p-value < 0.0285 (y = 0.663 + 0.0003x); excluding the outliers sites Cooks Beach (CB) and Montara Beach (MB): r = 0.95, p-value = 0.0001 (y = 0.786+ 0.0005x); and excluding MB only: r = 0.88, p-value = 0.0008 (y = 0.590+ 0.0005x). See text for additional details.

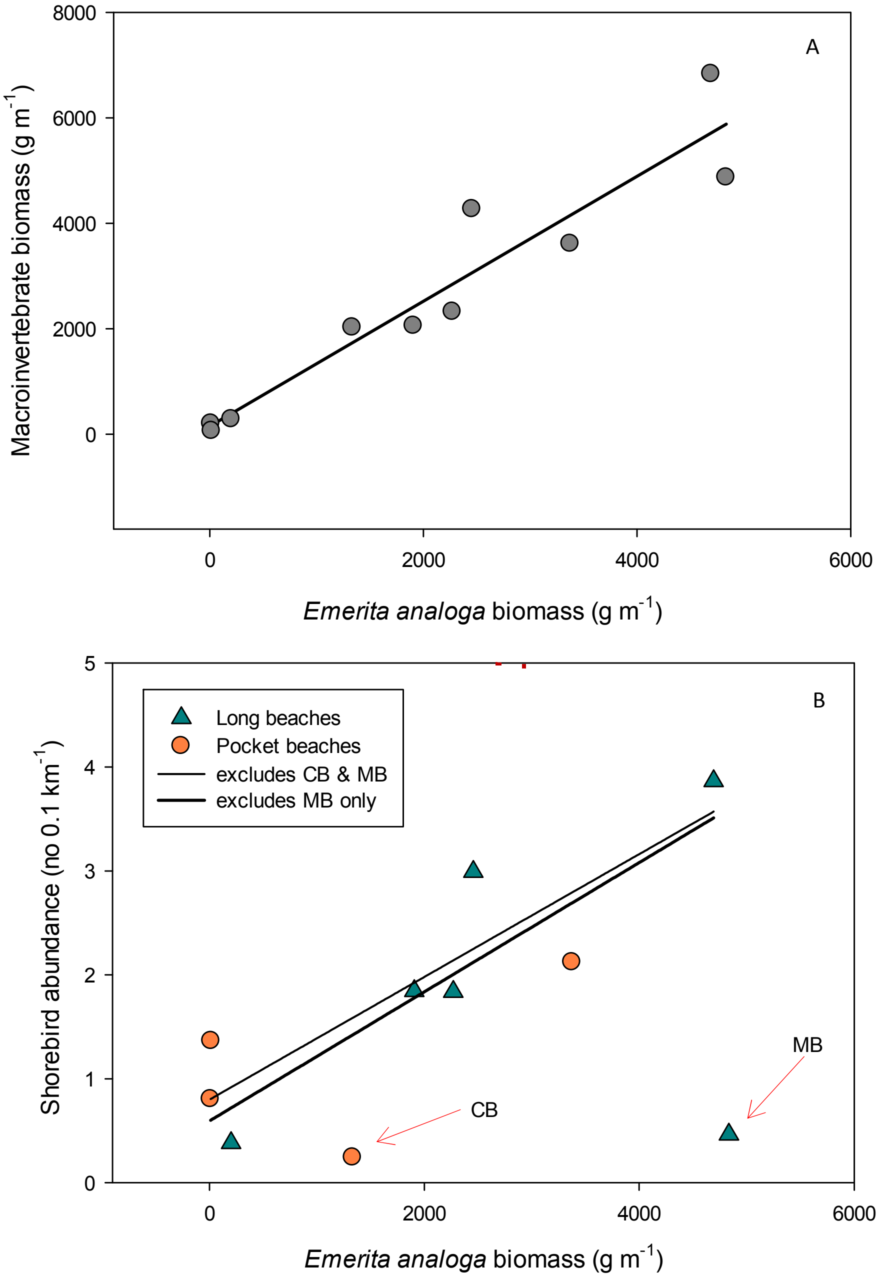


Figure 23. Total macroinvertebrate biomass and average shorebird abundance as a function of *Emerita analoga* biomass. Correlations and corresponding p-values are given for each hypothesized functional relationship (linear equations from OLS regression are also presented). A) Correlation of total macroinvertebrate biomass and average *Emerita analoga* biomass for 10 focal beaches: r =0.95, p-value <0.0001) (y = 154.6 + 1.185x). B) Correlation of average shorebird abundance and *Emerita analoga* biomass excluding the outliers Cooks Beach (CB) and Montara Beach (MB): r = 0.89 p-value = 0.0011 (y = 0.800+ 0.0006x); and excluding only MB: r = 0.84, p-value = 0.0025 (y = 0.593+ 0.0006x). The correlation including all 10 sites was not statistically significant: r = 0.49, p-value = 0.1261. Both CB and MB have high human and dog visitation and are surrounded by high cliffs or bluffs that might make these beaches less hospitable to shorebirds. MB also has the shortest shoreline extent of our long beaches.

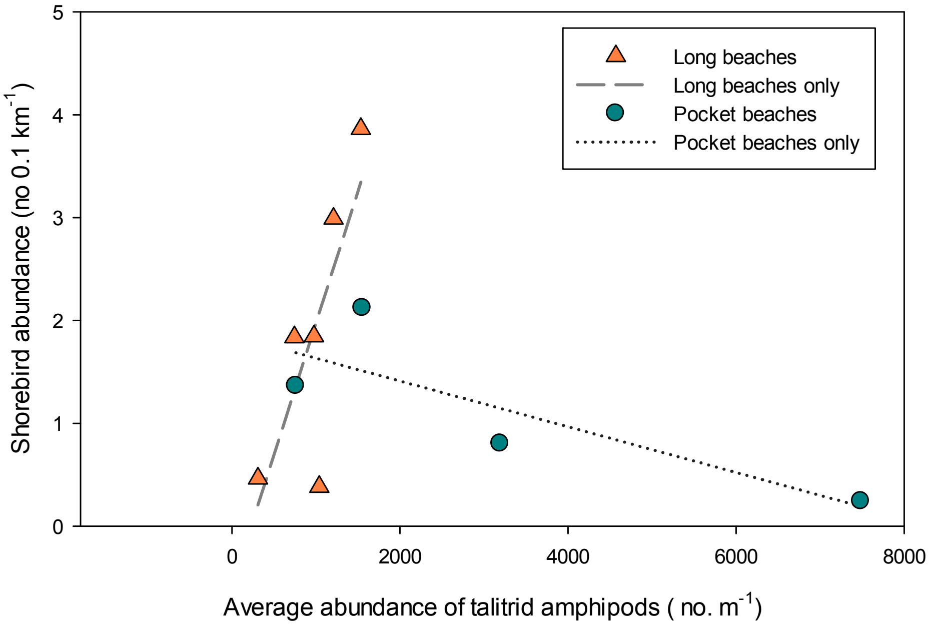


Figure 24. Average shorebird abundance as a function of the abundance of the talitrid amphipods (*Megalorchestia* spp.). Correlations and corresponding p-values are given for each hypothesized functional relationship (linear equations from OLS regression are also presented). Correlations for long beaches: $r = 0.78$, p-value = 0.0382 ($y = -0.588 + 0.003x$) and pocket beaches: $r = -0.83$, p-value = 0.0815 ($y = 1.85 - 0.0002x$).

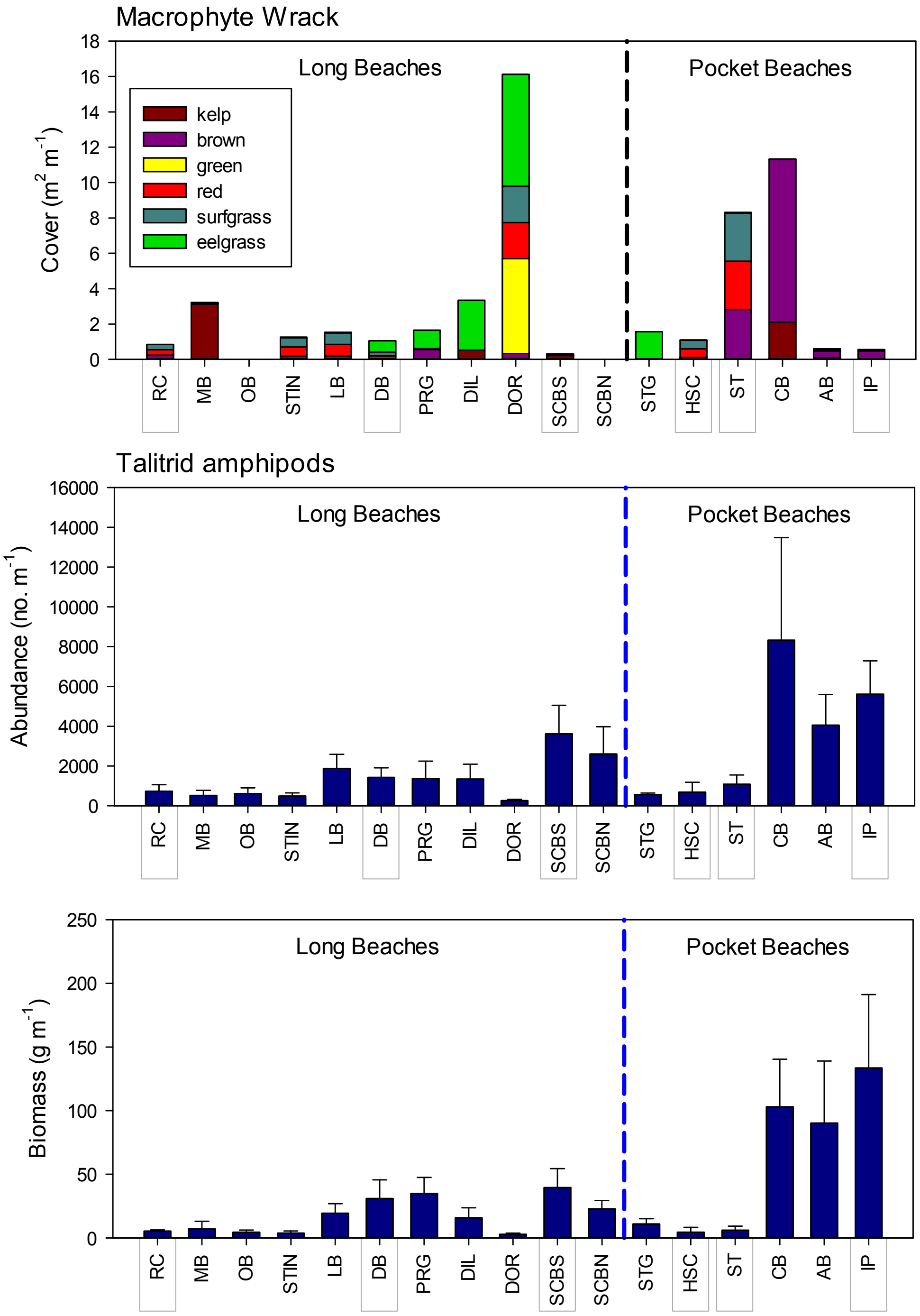


Figure 25. Abundance of macrophyte wrack and talitrid amphipods in August 2010. Data are the averages from three shore-normal transects and are expressed as total cover (m^2), number or grams wet weight per meter of shoreline. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches). All data are averages + SE.

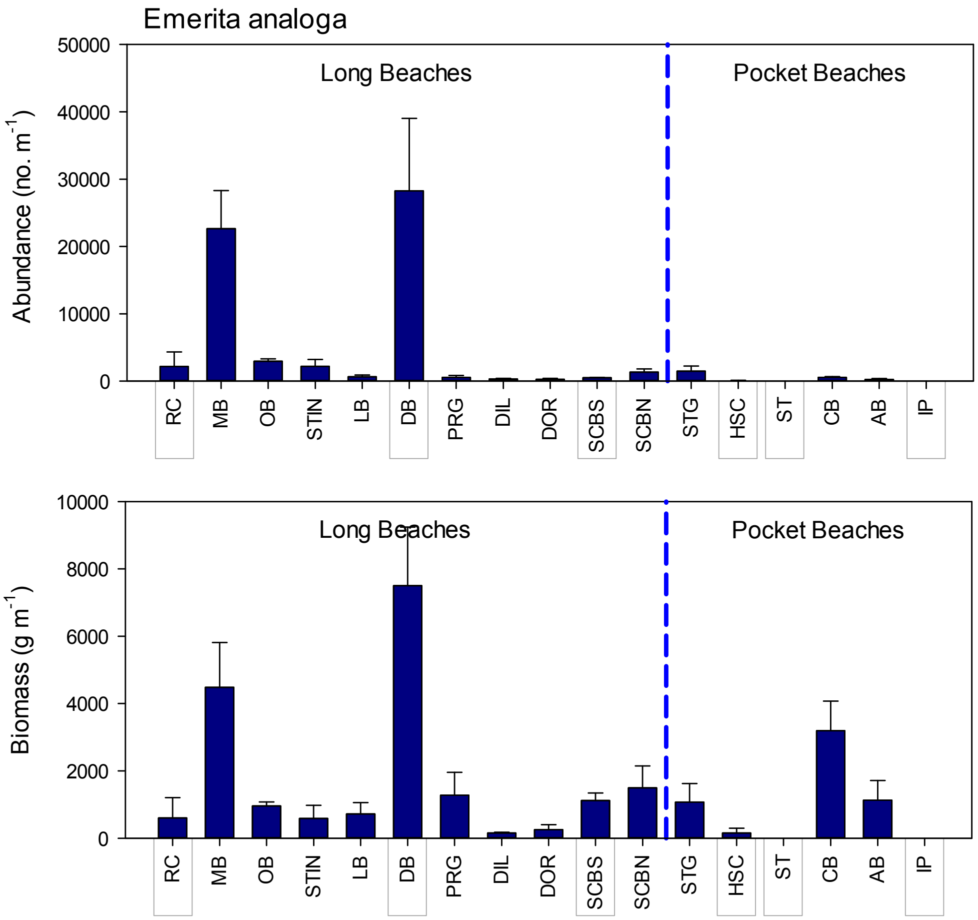


Figure 26. Abundance and biomass of *Emerita analoga* in August 2010. Data are as in Fig. 25.

COMMUNITY PATTERNS AND PROCESSES

Point Reyes and Salmon Creek beaches

At the two pairs of beaches where surfzone fishes were surveyed, we were able to evaluate potential trophic linkages of surfperch with seabirds and sand crabs. The pairs of beaches occur in different bioregions, and the circulation patterns, grain size and other physical characteristics differ considerably for them, making this comparison particularly interesting.

Seabirds, Surf Scoters and sand crabs all were more abundant at the pair of beaches to the south of Point Reyes, whereas surfperches were more abundant to the north of Point Reyes (Fig. 27). A recirculation cell forms in the upwelling shadow in the lee of Point Reyes during prevailing upwelling-favorable winds, concentrating plankton (Wing et al. 1998) and making this retention zone a productive hot spot for sand crabs, piscivorous seabirds and invertebrate-foraging Surf Scoters. A similar phenomenon occurs on either side of Point Arguello with piscivorous seabirds generally being more abundant in the lee of the headland (Robinette et al. 2012). Shorebirds, especially godwits and willets, also were more abundant in the lee of the headland (Figs. 8 & 11) due to the greater abundance of macroinvertebrates, especially sand crabs, most polychaetes and olive snails (Table 5). In turn, reduced wave action (Fig. 3) coupled with high productivity in the shelter of the headland accounts for the greater abundance of these macroinvertebrates.

In contrast, surfperches did not appear to be trophically linked to the high abundance of macroinvertebrates in the lee of the headland (Fig. 27). Barred surfperch do not range beyond Point Reyes, and Redtail and Silver surfperch may prefer greater wave action.

Community structure among 10 focal beaches

We used multivariate community analyses including non-metric multidimensional scaling (MDS) and hierarchical clustering to assess the degree of similarity in the taxonomic composition of the macroinvertebrate and bird assemblages and standing crop of macrophyte wrack among the 10 focal beaches. We were also interested in assessing whether or not pocket and long beaches differed substantially from each other when considering all species together, and whether or not the baseline ecological state of beaches inside and outside the NCC MPAs were similar or not. We used PERMANOVA analyses to address these latter questions. We also investigated the relationships between each of these three, ecologically and trophically linked assemblages to see if they would co-vary in a way that mirrored prior knowledge of how sandy beach ecosystems are structured including their documented relationship to the physical characteristics of the beaches themselves, including the surf and swash zones. We used the RELATE procedure to assess these potential relationships among the different ecosystem components. We present these analyses in three sections, ordered by trophic level, focusing first on the macrophyte wrack assemblage, followed by the macroinvertebrates and lastly on birds.

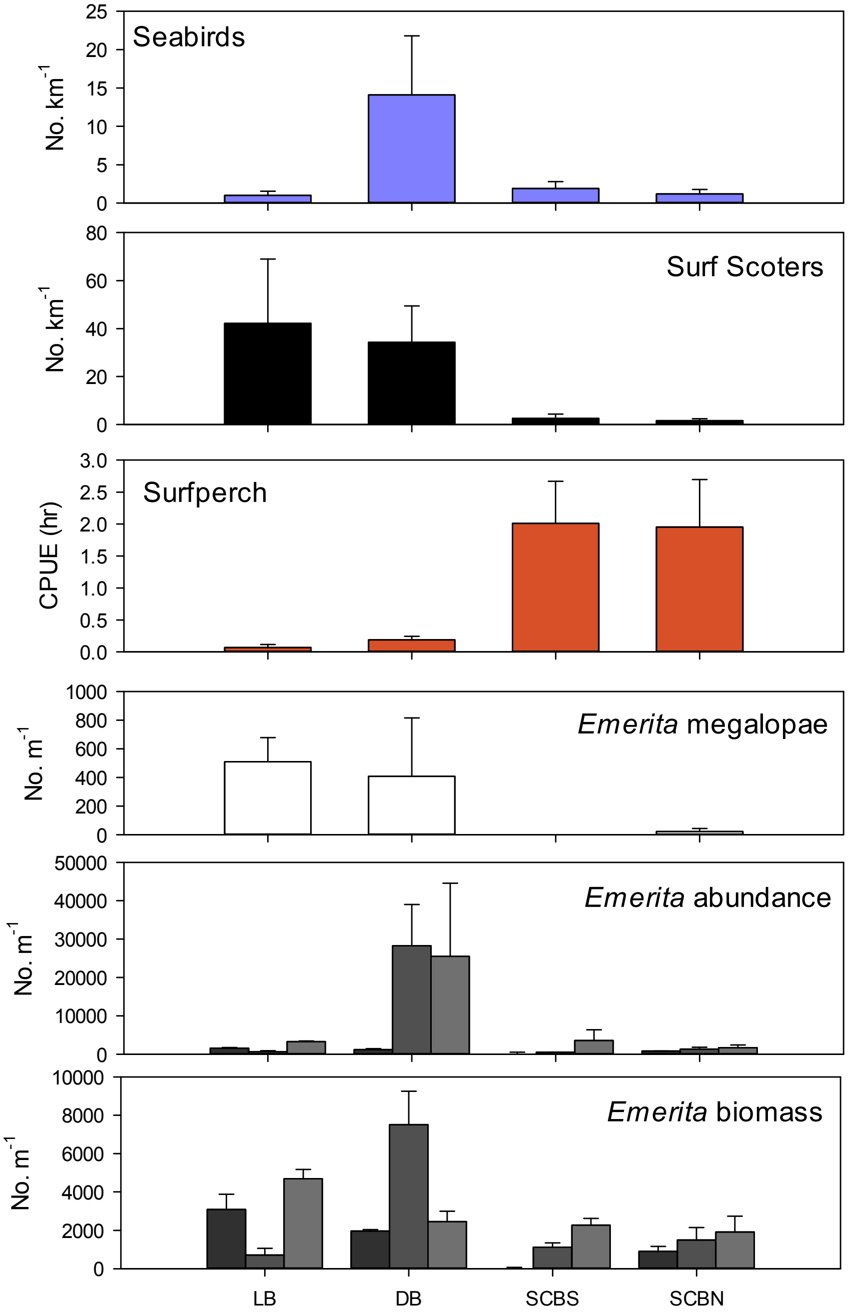


Figure 27. Abundance of seabirds (fish-eating), Surf Scoters, surfperch and sand crabs. Sand crab abundance and biomass data were collected at 10 focal beaches in June and August 2010 and July 2011 (averages from each survey in darkest to lightest gray bars, respectively); megalopae were only found in June 2010. Surf zone seabird data are averages from 11 monthly surveys between June 2010 and May 2011 from a standard 1 km shoreline transect. Surfperch data were collected by a citizen-scientist monitoring program between 2011 and 2012. All data are averages + SE.

Macrophyte wrack

Kelp, brown algae, and eelgrass strongly contributed to defining the spatial distribution of 10 focal beaches in the two-dimensional MDS space and appeared to be associated with several physical conditions (significant wave height, surfzone width, beach width), shorebirds, gulls and species richness of birds (Fig. 28, Table 5). However, hierarchical clustering failed to yield any distinctive grouping of beaches based on the abundance and composition of macrophyte wrack alone based on a similarity profile analysis (SIMPROF) (Fig. 29).

We also used PERMANOVA to test hypotheses that the beaches differed by MPA status, MPA bioregion (north or south) or beach type (pocket or long). We found no evidence that they could be distinguished based on wrack composition alone for any of these comparisons (all p-values >> 0.05).

In setting up this monitoring program we had *a priori* expectations based on prior research (Dugan et al. 2003, Lastra et al. 2008) that the abundance of macrophyte wrack would be related to the abundance of target invertebrate taxa, especially talitrid amphipods, and the shorebirds that feed on target invertebrate taxa (including both talitrid amphipods and sand crabs). In order to test the association between the wrack composition and the physical characteristics of the beach and surf zone, the shorebirds, and the biomass of target macroinvertebrate taxa, we calculating the respective Spearman rho-values and their statistical significance by comparing each pair of these resemblance matrices using the RELATE routine of PRIMER-E (Plymouth Marine Laboratory) (Clarke 1993). Both shorebirds and target invertebrates, but not physical characteristics were strongly related to macrophyte wrack (rho = 0.32, p-value = 0.022; rho = 0.355, p-value = 0.017; and rho = 0.147, p-value = 0.154, respectively).

Macroinvertebrates

A suite of low-zone polychaete worms and crustaceans, intertidal isopods and wrack-associated invertebrates all contributed strongly to defining the spatial distribution of 10 focal beaches in the two-dimensional MDS space (Fig. 30, Table 7). The low zone taxa include the polychaetes: *Saccocirrus sonomacus, Dispio uncinata, Lumbrineris* spp., *Euspilotus scissus, Arabella* spp. and *Nephtys californiensis*; mysids including *Archaeomysis grebnitzki*; the amphipod *Eohaustorius washingtonianus*; and penaeids (probably *Crangon* spp.). The wrack associated invertebrates included a diverse group of species: three species of macrophyte wrack consuming, tallitrid amphipods (*Megalorchestia pugettensis*, *M. benedicti* and *M. californiana)*, a saprophagous weevil, *Emphyastes fucicola*, the predatory psuedoscorpion, *Garypus californicus* and two predatory rove beetles (*Bledius ornatus and Cafius canescens).* The two intertidal isopods *Excirolana linguifrons* and *Alloniscus perconvexus* were correlated but not with the same axis

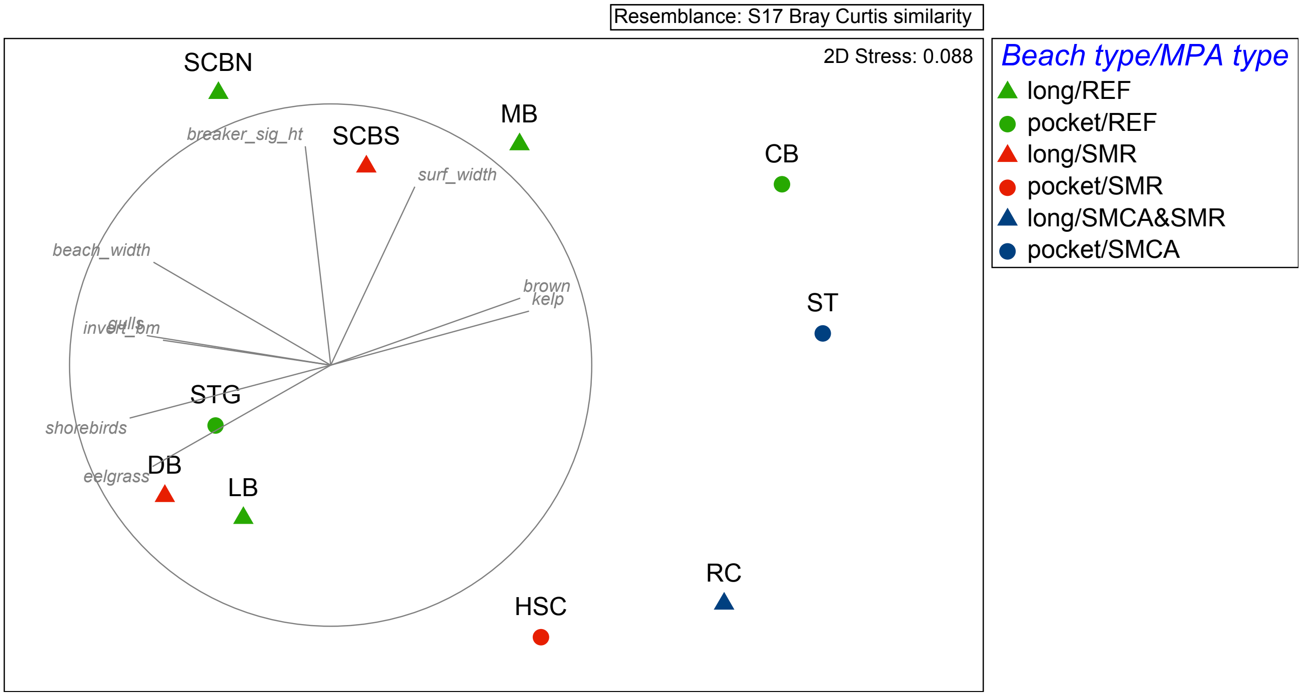


Figure 28. MDS plot of beaches based on average abundances ($m^2\ m^{-1}$ shoreline) of major macrophyte taxonomic groups at 10 focal beaches. The data are averages from 11 monthly surveys of the following groups: kelp (Laminariales), red algae (Rhodophyta), green algae (Chlorophyta), eelgrass (*Zostera* spp.), surfgrass (*Phyllospadix* spp.) and other brown algae (primarily *Cystoseira osmundacea* and other Fucales). MDS analysis was done on a Bray-Curtis similarity matrix. Beaches are identified by site codes and symbols indicate the type (pocket or long) and MPA designation (SMR or SMCA). The vectors of correlation between wrack types (and other co-variates, see Tables 5 & 6) and the MDS axes where $|r| > 7$ for one axis are overlaid as vectors in gray. Beach_width = width of the beach from bluff, cliff, terrestrial vegetation line to lowest swash zone[m], breaker_sig_ht = significant breaker height [m], and surf_width is the width of the surf zone [m]), the abundance (no. km^{-1} shoreline) of major bird groups, and the biomass of target and all macroinvertebrate groups (invert_bm=total macroinvertebrate biomass). See text for additional details.

Table 5. Correlates of the two axes describing the distribution of beaches in MDS space (Fig. 1) based on the abundance of macrophyte wrack groups at 10 focal beaches. Only those factors with |r|> 0.7 are shown and p-values are provided ***only*** as an indication of the relative strength of the relationship and should ***not*** be interpreted as statistically significant (no corrections were made for multiple comparisons). Factors assessed include the individual abundances of species/taxa/groups used in the MDS analysis and those listed in Table 6.

Wrack Cover MDS: Axis Correlates	**r**	**p**	**axis**
Macrophytes			
Kelp	0.8	0.0108	1
Brown algae	0.7	0.0174	1
Eelgrass	-0.7	0.0296	1
Beach & Surf zone characteristics			
Breaker height, significant	0.8	0.0025	2
Surf zone width	0.7	0.0295	2
Beach width	-0.7	0.0309	1
Bird			
Shorebirds	-0.8	0.0092	1
Gulls	-0.7	0.0230	1
Target invertebrates			
none			
Species richness of macroinvertebrates and birds			
Total species richness of shorebirds	-0.8	0.0092	1

Hierarchical clustering revealed three distinctive groups of beaches based on the abundance and composition of macroinvertebrates based on a similarity profile analysis (SIMPROF, PRIMER-E (Plymouth Marine Laboratory) (Fig. 31). Horseshoe Cove (HS), Ross Cove (RC) and Montara Beach (MB) formed a cluster, Salmon Creek Beaches (SCBN & SCBS), Drake’s and Limantour Beaches (DB & LB), Cooks Beach (CB) and Shorttail Gulch (STG) beach formed a second cluster and Stump Beach (ST) was unique. The relative abundance of polychaete worms seems to distinguish the first two clusters and they are also associated with differences in shorebird abundances, mean sand grain size, beach slope and Dean’s parameter (omega; a synthetic variable that indicates the morphodynamic state of the beach), while wrack-associated invertebrates and abundance of kelp wrack and terrestrial birds appear to distinguish Stump Beach from the rest (*cf.* Figs. 30, 31 and Table 7).

We used PERMANOVA to test hypotheses that the beaches differed by MPA status, MPA bio region (north or south) or beach type (pocket or long). We found no evidence that they could be distinguished based on the structure of the macroinvertebrate assemblage alone for any of these comparisons (all p-values >> 0.05).

We had *a priori* expectations that physical characteristics of the beach, such as mean sand grain size, would be a factor influencing the distribution and abundance of macroinvertebrates among beaches (McLachlan and Brown 2006). We also proposed, based on prior research (Dugan et al. 2003) that two taxa, talitrid amphipods and *E. analoga,* would be potentially good indicator species of the overall 'ecological condition' of sandy beaches in the NCC region as they are constitute a major food source for several species of shorebirds and seabirds. In order to test the association between macroinvertebrates and the physical characteristics of the beach and surf zone, the seabird and shorebirds observed on these beaches, and the biomass of target macroinvertebrate taxa, we calculated the respective Spearman rho-values and their statistical significance by comparing each pair of these resemblance matrices using the RELATE routine of PRIMER-E (Plymouth Marine Laboratory) (Clarke 1993). As anticipated, the physical characteristics of the beaches were strongly related to macroinvertebrate community structure (rho= 0.46, p-value = 0.006). The biomass of our two target taxa were also strongly related to overall invertebrate community structure (rho= 0.478, p-value = 0.011). As were all birds as a whole (rho = 0.350, p-value = 0.023), but this was driven primarily by the seabirds (rho = 0.447, p-value = 0.008; shorebirds, gulls, and terrestrial birds alone each had rho < 0.25 and p-values > 0.05).

This result for shorebirds contrasts with results we obtained using univariate analyses comparing total macroinvertebrate biomass and richness to shorebird abundances, where the correlations between these variables were strong. Importantly though, these analyses emphasize taxonomic composition and assemblage structure rather than abundances per se. Moreover, shorebird richness on these beaches was relatively low compared to southern California beaches, and also was not correlated with macroinvertebrate abundance or biomass. Thus, these results are not inconsistent with the strong functional and trophic linkages that we identified earlier through assessment of targeted, hypothesized univariate relationships that were based on natural history observations and prior research on the important ecological relationships that organize sandy beach ecosystem in general.

Birds

The MDS ordination of sites based on bird species (Fig. 32) was strongly correlated along the horizontal axis (MDS 1) with the total abundance of shorebirds and along the vertical axis (MDS 2) with terrestrial birds (Table 8). The shorebirds, Semipalmated Plover, Black Turnstone, Black Oystercatcher and Sanderling and a diverse suite of terrestrial birds including Black Phoebe, Cliff Swallow, Mallard, Brewer's Blackbird, Raven, Snowy Egret and Great Blue Heron were all correlated with the MDS axes. Physical characteristics of the beach, mean sand grain size and total macroinvertebrate species richness were all positively associated with the horizontal axis, while red algae was negatively associated. The vertical axis was more strongly linked to the abundance of the other macrophyte taxa including kelp, other brown algae and surfgrass. The composition and abundance of birds differed between pocket and long beaches (Fig. 4; PERMANOVA, p-value = 0.029). Almost all the beaches we initially classified as long beaches clustered together with respect to their birds, except for Ross Cove beach where the birds were more similar to those observed on pocket beaches (Fig. 33). Stump Beach stood out as being unique in its bird assemblage relative to the other nine beaches we surveyed (Fig. 33). The sites did not differ in their bird assemblages based on MPA status or bioregion (north or south) (all p-values >> 0.05).

All birds (collectively) were distributed among sites in way that co-varied with wrack abundance (RELATE, rho= 0.425, p-value = 0.006). The only taxonomic grouping of birds that did not exhibit a relationship was gulls (RELATE, rho=0.077, p-value = 0.291), while terrestrial birds had the strongest relationship (RELATE, rho=0.421, p-value = 0.004). As discussed above for macroinvertebrates, macroinvertebrate abundances and birds were tightly linked. And as anticipated, the biomass of taxa we considered good indicators of food availability for shorebirds and seabirds (sand crabs and talitrid amphipods) showed a strong relationship as well to all birds collectively (RELATE, rho=0.574, p-value = 0.004). The strongest link was to terrestrial birds (RELATE, rho=0.706, p-value = 0.002), followed by seabirds (RELATE, rho=0.381, p-value = 0.046), but the structure of shorebird assemblages (RELATE, rho=0.24, p-value = 0.089) did not appear to follow the biomass of these target taxa. Gulls, as might be expected, were also not linked to the biomass of talitrid amphipods and sand crabs (RELATE, rho=0.177, p-value = 0.245). See the discussion above in the section on macroinvertebrate assemblages for more information regarding their relationship between macroinvertebrates and shorebirds. There was no evidence from this analysis that the physical parameters we used to describe the beach and surf zone were associated with the abundance of birds as a whole (RELATE, rho=0.247, p-value = 0.096), however, gulls were strongly linked to these variables (RELATE, rho=0.453, p-value = 0.007).

Table 6.

List of variables considered as possible MDS axis correlates
Beach & Surf zone characteristics
Dean's parameter (omega)
Mean sand grain size @ HTSL
Mean sand grain size @ WTO
Beach slope @ HTSL
Beach slope @ WTO
Total beach width
Surf zone width
Breaker height (significant)
Breaker period
Macrophyte wrack (by operational taxonomic groups)
Kelp (Laminariales) abundance
Brown algal (primarily Fucales, Desmarestiales) abundance
Red algal (Rhodophyta) abundance
Green algal (Chlorophyta) abundance
Surfgrass (*Phyllospadix* spp.) abundance
Eelgrass (*Zostera* spp.) abundance
Birds (by operational taxonomic groupings)
Shorebird abundance
Seabird abundance
Gull abundance
Terrestrial bird abundance (all others)
Target and total macroinvertebrate biomass
Total macroinvertebrate biomass
Emerita analoga biomass
Talitrid amphipod biomass
Species richness of macroinvertebrates and birds
Total species richness of macroinvertebrates
Total species richness of wrack-associated macroinvertebrates
Total species richness of birds

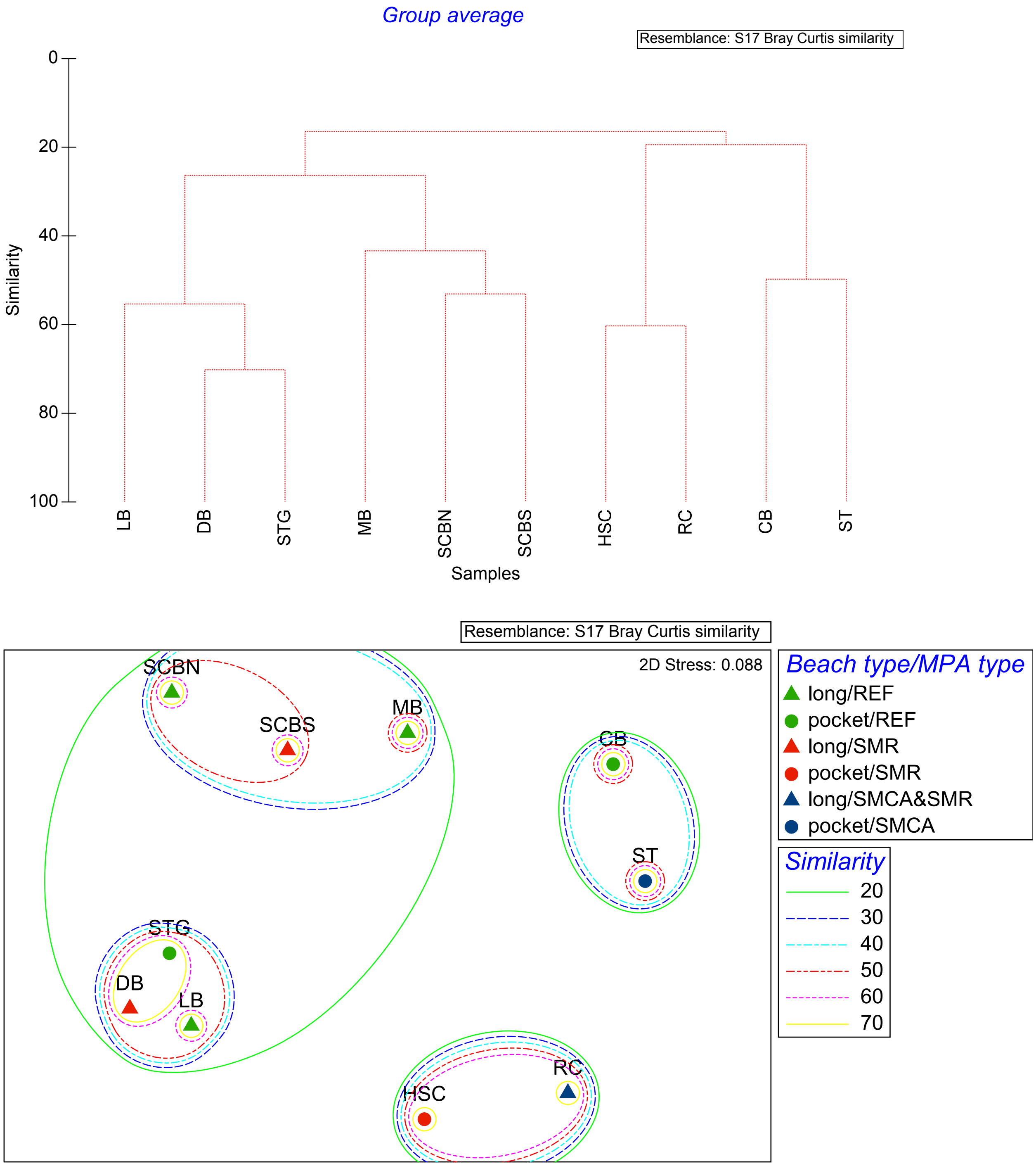


Figure 29. Heirarchical cluster analysis of average macrophyte wrack abundance (m^2 m^{-1} shoreline) from 11 monthly surveys of 10 focal beaches. Clustering was done on a Bray-Curtis similarity matrix using the group averaging method. No statistically significant groups could be distinguished using the similarity profile routine (SIMPROF, PRIMER-E, Plymouth Marine Laboratory). Similarity value contours (in steps of 10%) from the clustering analysis that grouped at least two and did not include all sites are superimposed on the MDS plot.

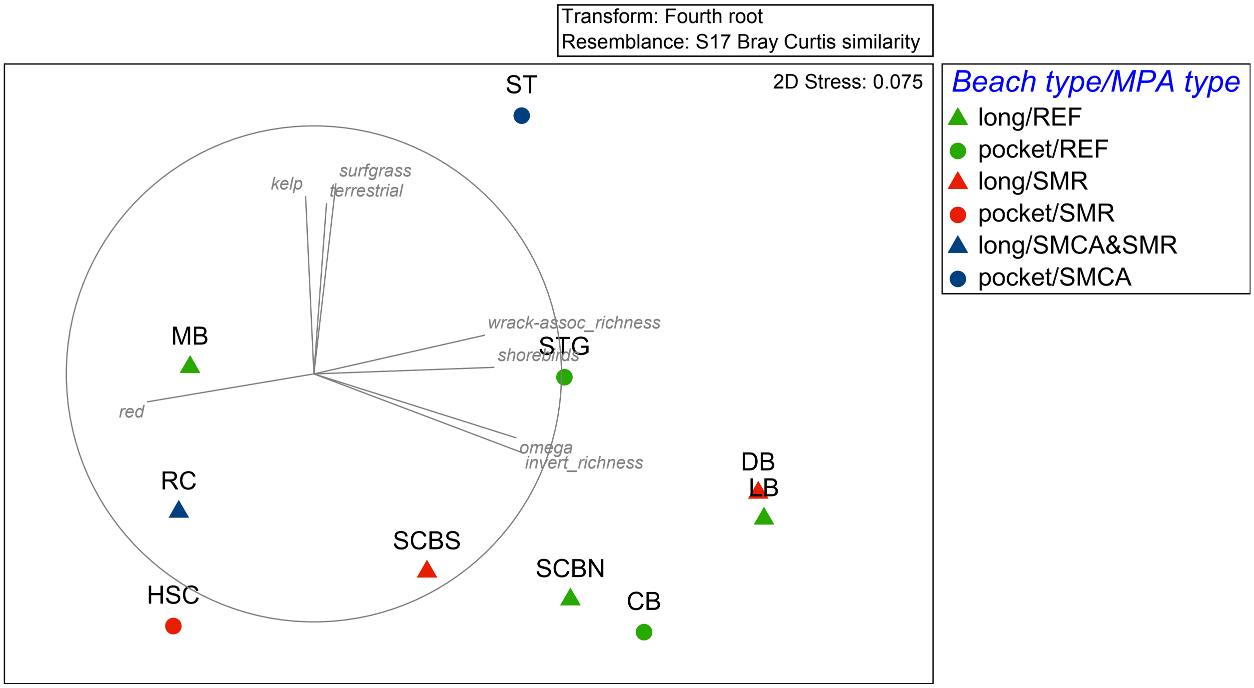


Figure 30. MDS plot of beaches based on macroinvertebrate abundances (no. m^{-1} shoreline) from biodiversity surveys. Invertebrate abundance data were fourth-root transformed prior to MDS analysis on a Bray-Curtis similarity matrix. Beaches are identified by site codes and symbols indicate the type (pocket or long) and MPA designation (SMR or SMCA). A subset of covariates (Table 7) strongly correlated with the MDS axis scores and are overlaid as vectors in gray (red = Rhodophyta; kelp = Laminariales; surfgrass = *Phyllospadix* spp.; terrestrial birds = all birds other than shorebirds, gulls and seabirds; omega = Dean's parameter). Macroinvertebrate species correlated with the axes are described in the text and in Table 7.

Table 7. Correlates of the two axes describing the distribution of beaches in MDS space (Fig. 3) based on the abudnance of macroinvertebrates. Only those factors with |r|> 0.7 are shown and p-values are provided ***only*** as an indication of the relative strength of the relationship and should not be interpreted as statistically significant (no corrections were made for multiple comparisons). Factors assessed as in Table 6.

Macroinvertebrate abundance MDS: Axis Correlates	**r**	**p**	**axis**
Macroinvertebrates			
Worms			
Nephtys californiensis	0.9	0.0011	1
Saccocirrus sonomacus	-0.8	0.0037	1
Euspilotus scissus	0.8	0.0044	2
Arabella spp.	0.8	0.0044	2
Lumbrineris spp.	0.7	0.0156	2
Dispio uncinata	0.7	0.0189	1
Crustaceans (not wrack-associated)			
Excirolana linguifrons	0.9	0.0001	1
Mysidae	0.8	0.0031	1
Archaeomysis grebnitzki	0.8	0.0033	1
Penaeidae	0.8	0.0044	2
Eohaustorius washingtonianus	0.7	0.0138	1
Alloniscus perconvexus	-0.7	0.0140	2
Wrack-associated arthropods			
Megalorchestia pugettensis	-0.8	0.0040	1
Garypus californicus	0.8	0.0047	2
Megalorchestia benedicti	-0.7	0.0248	2
Bledius ornatus	0.7	0.0280	1
Emphyastes fucicola	0.7	0.0331	1
Megalorchestia californiana	0.7	0.0382	1
Cafius canescens	0.7	0.0407	1
Beach & Surf zone characteristics			
Beach slope @ HTSL	-0.9	0.0001	1
Beach slope @ WTO	-0.9	0.0011	1
Mean sand grain size @ HTSL	-0.8	0.0018	1
Mean sand grain size @ WTO	-0.8	0.0032	1
Dean's parameter (omega)	0.8	0.0039	1
Beach width	0.7	0.0370	1
Bird			
Shorebirds	0.7	0.0167	1
Terrestrial	-0.7	0.0277	2

Table 7. (con't).

Macrophyte wrack			
Surfgrass (*Phyllospadix* spp.)	-0.8	0.0093	2
Kelp (Laminariales)	-0.7	0.0194	2
Red algae (Rhodophyta)	-0.7	0.0325	1
Target invertebrates			
None			
Species richness of macroinvertebrates and birds			
Total species richness of macroinvertebrates	0.8	0.0023	1
Total species richness of wrack-associated macroinvertebrates	0.7	0.0272	1

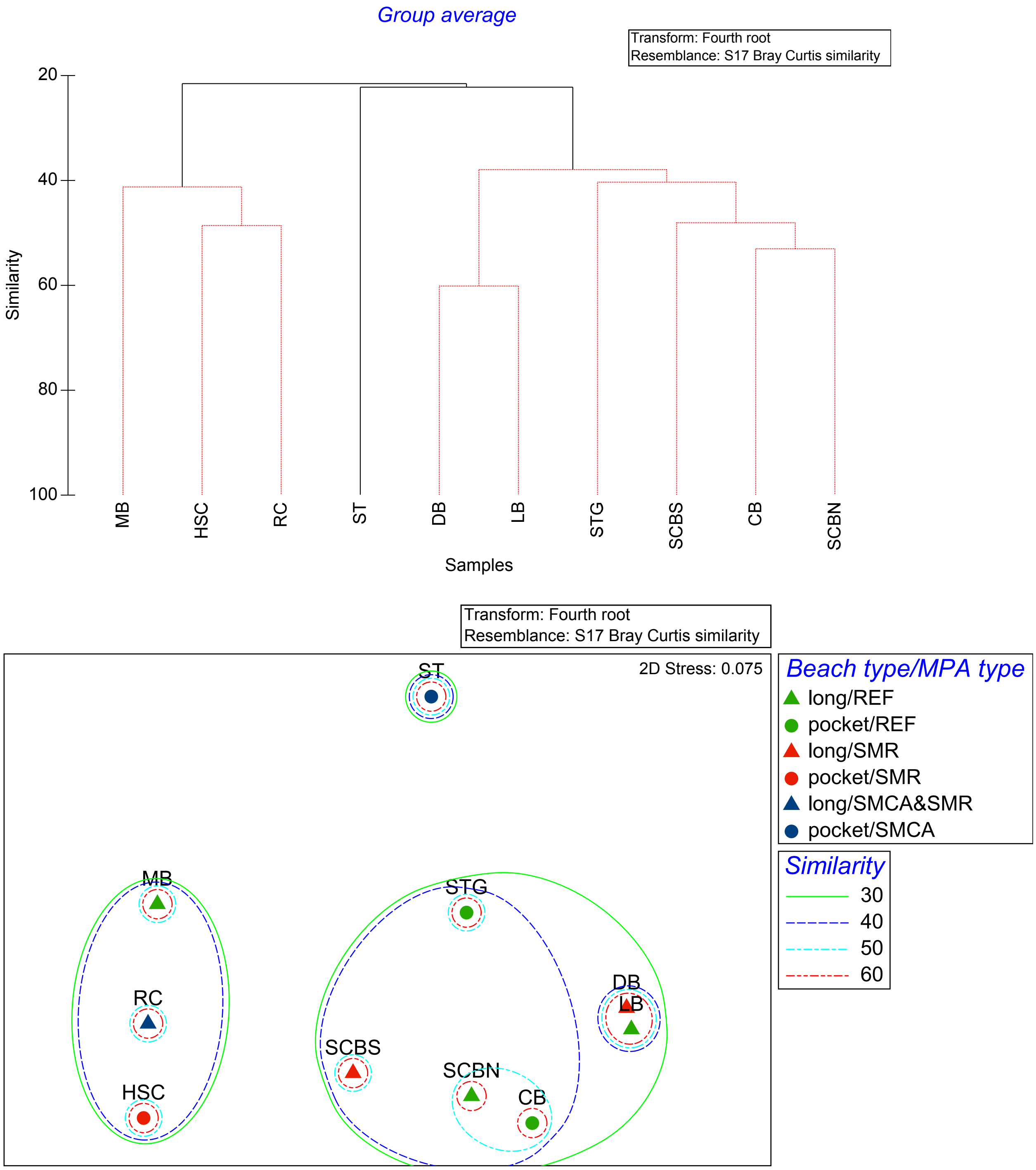


Figure 31. Heirarchical cluster analysis of macroinvertebrate abundances (no. m^{-1} shoreline) from biodiversity surveys of 10 focal beaches. Invertebrate abundance data were fourth-root transformed prior to clustering based on a Bray-Curtis similarity matrix using the group averaging method. Three statistically significant clusters ($p<0.05$; indicated by red dashed lines) were determined using the similarity profile routine (SIMPROF). Similarity value contours (in steps of 10%) from the clustering analysis that grouped at least two sites and did not include all sites are superimposed on the MDS plot. See Fig. 28 and Table 6 for additional information on the physical factors and organisms associated with these groupings.

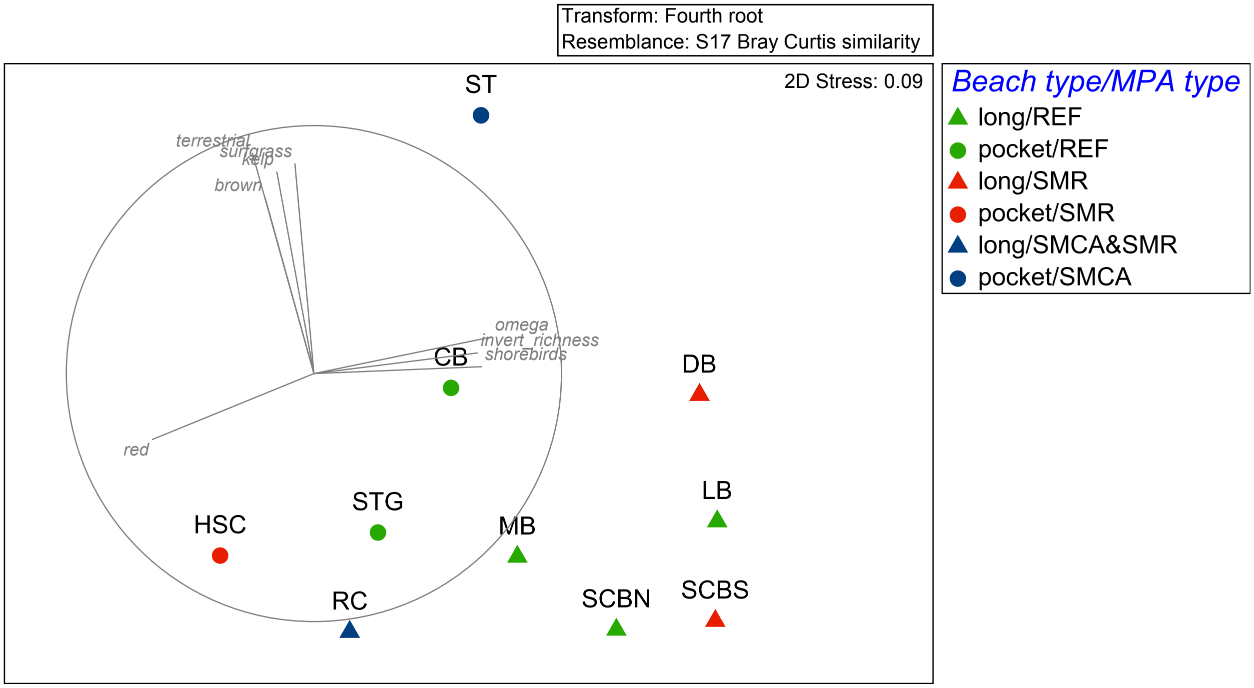


Figure 32. MDS plot of beaches based on bird abundances (no. m^{-1} shoreline) from monthly surveys of 10 focal beaches. Bird abundance data were fourth root transformed prior to MDS analysis on a Bray-Curtis similarity matrix. Beaches are identified by site codes and symbols indicate the type (pocket or long) and MPA designation (SMR or SMCA). A subset of statistically significant axis correlates from associated data sets (Table 8) on physical attributes of the beach and surf zone, the abundance (no. km^{-1} shoreline) of major bird groups, and the abundance of macrophyte wrack groups (m^2 m^{-1} shoreline) are overlaid as vectors in gray (red = Rhodophyta; surfgrass = Phyllospadix spp.; kelp = Laminariales; brown = other brown algae; terrestrial birds = all birds other than shorebirds, gulls and seabirds; omega = Dean's parameter). Bird species correlated with the axes could not be clearly plotted on this figure and are described in more detail in the text.

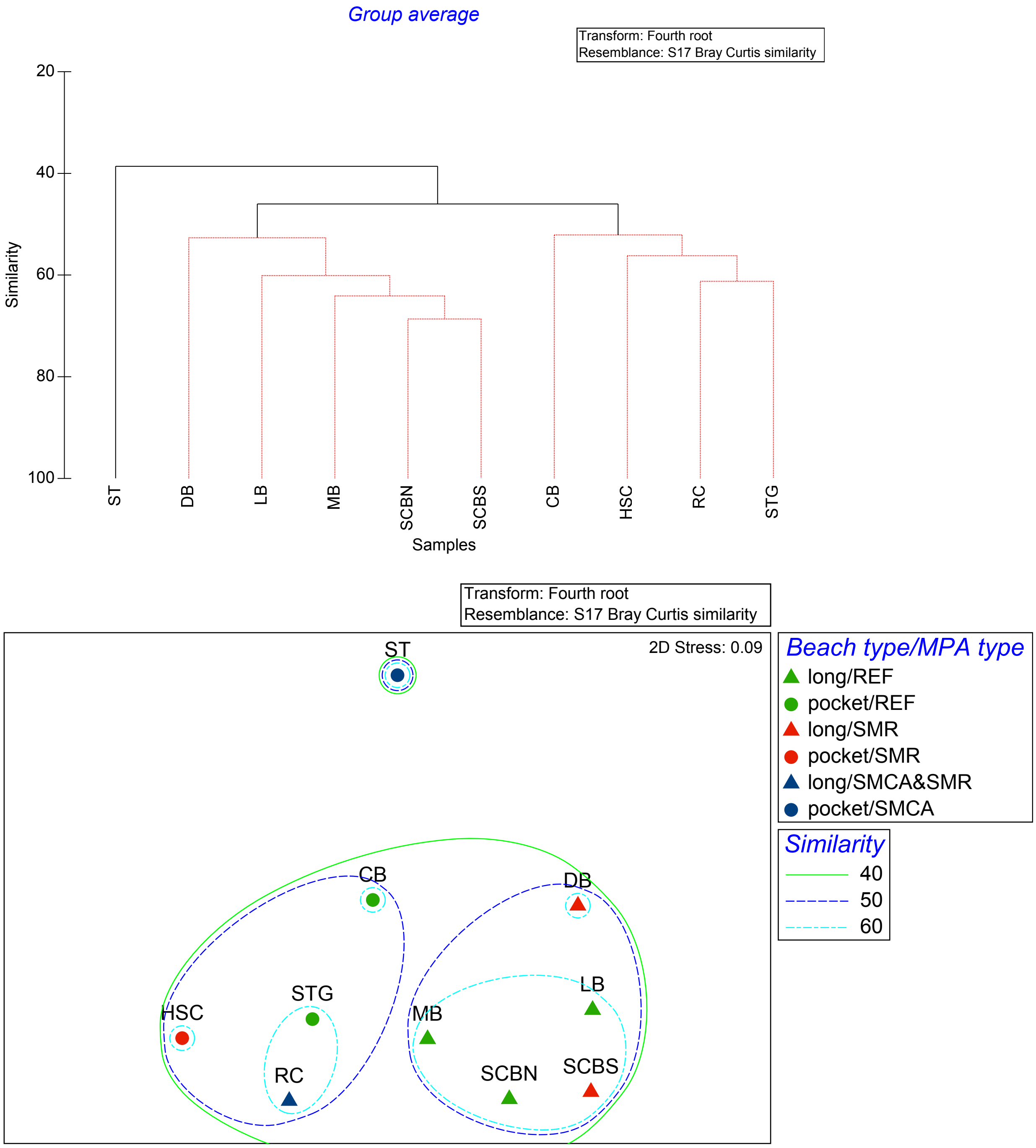


Figure 33. Heirarchical cluster analysis of bird abundances (no. km^{-1} shoreline) from monthly surveys of 10 focal beaches. Bird abundance data were fourth-root transformed prior to clustering based on a Bray-Curtis similarity matrix using the group averaging method. Three statistically significant clusters ($p<0.05$; indicated by red dashed lines) were determined using the similarity profile routine (SIMPROF). Similarity value contours (in steps of 10%) from the clustering analysis that grouped at least two sites and did not include all sites are superimposed on the MDS plot. See Fig. 32 and Table 8 for additional information on the physical factors and organisms associated with these groupings.

Table 8. Only those factors with |r|> 0.7 are shown and p-values are provided ***only*** as an indication of the relative strength of the relationship and should not be interpreted as statistically significant (no corrections were made for multiple comparisons). Factors assessed as in Table 6.

Bird abundance MDS: Axis Correlates	**r**	**p**	**axis**
Birds			
Shorebirds (all)	0.7	0.0311	1
Sanderling	0.9	0.0007	1
Black Oystercatcher	-0.8	0.0019	1
Black Turnstone	-0.8	0.0051	1
Marbled Godwit	0.8	0.0083	1
Semipalmated Plover	-0.8	0.0094	2
Western Snowy Plover	0.7	0.0286	1
Seabirds			
none			
Gulls			
Heermann's gull	0.8	0.0069	1
Terrestrial birds (all)	-0.9	0.0006	2
Mallard	-0.8	0.0025	2
Cliff Swallow	-0.8	0.0025	2
Black Phoebe	-0.7	0.0132	2
Brewer's Blackbird	-0.7	0.0157	2
Raven	-0.7	0.0185	2
Snowy Egret	-0.7	0.0187	1
Great Blue Heron	-0.7	0.0235	1
Osprey	-0.7	0.0252	2
Beach & Surf zone characteristics			
Beach width	0.8	0.0061	1
Dean's parameter (omega)	0.7	0.0192	1
Mean sand grain size @ HTSL	0.7	0.0217	1
Mean sand grain size @ WTO	0.7	0.0270	1
Beach slope @ high tide strand line (HTSL)	0.6	0.0435	1
Macrophyte wrack			
Surfgrass (*Phyllospadix* spp.)	0.8	0.0019	2
Kelp (Laminariales)	0.8	0.0041	2
Brown algae (primarily Fucales, Desmarestiales)	0.7	0.0217	2
Red algae (Rhodophyta)	0.7	0.0401	1
Target invertebrates			
none			
Species richness of macroinvertebrates and birds			
Total species richness of macroinvertebrates	0.7	0.0373	1

CONCLUSIONS

Physical characteristics of the 17 beaches differed considerably with no consistent differences between MPA and reference beaches, bioregions north and south of Point Reyes or long and pocket beaches. Four of the 17 and two of the 10 focal beaches were characterized as reflective beaches and the rest were intermediate beaches; dissipative beaches did not occur in the region.

We identified 51 species of birds that were seasonally abundant on beaches. The abundance of birds at MPA and reference beaches did not differ for shorebirds and seabirds, but gulls were more abundant on long MPA beaches and pocket reference beaches.

Human use of beaches was categorized in decreasing order as nature walks, resting or socializing, water sports and beach sports or play. Popular activities in all four categories were more common at reference than MPA sites and long than pocket beaches. In a one-time survey during the summer, human use was one to two orders of magnitude greater on a sunny weekend from 10 am to 2 pm than weekday mornings.

Beach wrack differed seasonally and spatially among beaches. Macrophyte wrack was most abundant from June to December and varied up to several orders of magnitude among beaches depending on the taxon, likely due to the proximity to rocky reefs and circulation patterns. Other types of wrack (driftwood, animal, trash) were far less abundant and had very different spatial and seasonal patterns than macrophyte wrack. Wrack abundance and composition did not differ between MPA and reference beaches and but was extremely heterogeneous among beaches.

We identified over 67 taxa of macroinvertebrates on beaches in the region. The total abundance, biomass and richness of macroinvertebrates did not differ between MPA and reference beaches or long and pocket beaches, although biomass tended to be greater on long beaches. However, the biomass of sand crabs was greater on reference beaches than MPA beaches. The abundance and biomass of wrack-associated invertebrates, such as talitrid amphipods, tended to be greater at pocket beaches, but the abundance and biomass of sand crabs tended to be greater at long beaches.

The abundance of shorebirds was positively related to the total biomass and species richness of all macroinvertebrates combined and to the biomass of sand crabs alone. They also tended to be positively related to talitrid amphipods on long beaches. However, species richness of shorebirds was not related to any of the variables.

Multivariate analysis of the relationships among physical and biological characteristics of beaches sampled over a year of one-time and monthly surveys revealed the following:

- Taxonomic composition of macrophyte wrack, macroinvertebates, the two indicator invertebrates and shorebirds generally were closely related, indicating trophic linkages.
- The assemblage of terrestrial birds was especially tightly linked to macrophyte wrack and macroinvertebrates composition, followed by seabirds, but the structure of shorebird and gull assemblages were not related to them.

- Macroinvertebrate community structure was strongly related to physical characteristics of beaches, but birds and macrophyte wrack were not.
- The structure of macrophyte wrack assemblages, macroinvertebrate communities, the two target invertebrates and shorebirds did not differ between MPA and reference beaches, long and pocket beaches or bioregions north and south of Point Reyes, but the composition and abundance of birds differed between pocket and long beaches.

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II. A citizen science survey of surf zone fishes along Drake's Bay and the Sonoma Coast

INTRODUCTION

Surf zone fishes are an integral part of sandy beach communities. Surfperches (Embiotocidae) were chosen as potential indicators, because they are targeted by recreational fishers and were expected to benefit from the network of MPAs. Surfperches are viviparous, giving birth to less than 100 young per female for large species during spring and summer. Most individuals remain within the same mile of coastline for long periods of time, and females often migrate to nearby estuaries to give birth.

Four species of surfperches – Barred (*Amphistichus argenteus*), Redtail (*Amphistichus rhodoterus*), Silver (*Hyperprosopon ellipticum*), and Walleye (*Hyperprosopon argenteum*) – have historically been the most frequently landed species that are recreationally shore fished in northern and central California. The recreational fishery for surfperch far exceeds the commercial fishery; Barred and Redtail surfperch are the most economically important commercially fished surfperches. Surfperches appear to be in long-term decline and some species (Redtail, Barred) have decreased in size. In response, daily catch of most species of surfperches was limited to five fish in 2002, and a minimum size limit was enacted for Redtail surfperch. Although surfperch populations continue to be monitored by CDFW, an effective and economical monitoring protocol is needed to determine the status of populations of surf zone fishes within the network of MPAs. Underwater visual censuses using SCUBA is the most common approach to surveying fishes, but it often is not feasible in turbulent surf zones. Seining, trawling, and hook and line surveys are practical in southern California, but only hook and line is feasible year around in the large surf of northern California.

Citizen science, which is broadly defined as a process by which citizens are involved in science as researchers, may be a cost-effective approach to monitoring networks of MPAs. Ecologists and conservationists have been among those to benefit from the public's interest in participating in science, while the public gains an informal education in the motivating issue, study system and scientific process. Growing engagement of citizens in science has been attributed to its cost-effectiveness, ability to cover large geographic scales, and the public's burgeoning interest in environmental protection and stewardship. Skilled citizen scientists also can provide valuable insights to the study, while improving relationships among scientists, managers and stakeholders.

We adopted a community-based monitoring approach to engage concerned citizens, fishing clubs, universities and scientists from CDFW to collaborate on an environmental issue of shared concern: the implementation of the network of MPAs along the coast of California. Our goal was to develop a protocol that may be used as a low-cost option for monitoring surf zone fishes in the network of MPAs over time to determine whether the objectives of the MLPA are being met. A catch-and-release, hook-and-line protocol was developed with considerable input from fishing enthusiasts and scientists from the CDFW, which enlists recreational anglers to assist with surf zone surveys. It was refined while gathering baseline data on surf zone fishes at two pairs of reference and MPA sites during the fall for two consecutive years (2011, 2012) in the north central region of California's MPA network.

GOALS

1. Develop a protocol that may be used as a low-cost option for monitoring surf zone fishes in the network of MPAs over time to determine whether the objectives of the MLPA are being met. A hook-and-line protocol was developed with considerable input from fishing enthusiasts and scientists from the CDFW, which enlists recreational anglers to assist with surf zone surveys

2. Gather baseline data on surf zone fishes at two pairs of MPA and reference locations in the NCC region of the network.

MATERIALS AND METHODS

Anglers were recruited to our study by addressing local fishing clubs at their meetings. Interested anglers were invited to a follow-up organizational meeting and feedback on our sampling protocol was solicited.

Surf zone fishes methods

Data were collected in collaboration with citizen scientists at two pairs of MPAs and neighboring reference sites in 2011 and 2012. One pair of sites was located at Salmon Creek Beach, where the southern end (1.7 km) was part of the Bodega Head Marine Reserve and the northern end (2.5 km) was outside the MPA. The other pair of sites formed Drakes Bay. Drakes Beach is part of the Drakes Bay Marine Reserve and is located to the southwest of Drakes Estero. Drakes Beach is 6.6 km, excluding the end of Limantour spit that is not easily accessed. We sampled about 2 km the central part of the beach near the Drakes Beach Visitor Center. Limantour Beach is on the other side of the estero and outside the MPA. It is 6.1 km, and we sampled the western half of it.

Collective experience suggested that catch rates were greatest during the summer, parturition season while fishes were close to shore. However, we elected to sample from late summer through fall to avoid interfering with parturition and to sample when surf is usually smallest. Sampling was conducted when wave height was less than 2 m for safe, effective fishing. We avoided sampling during dense algal blooms when catch is often poor.

During each trip, we sampled for four consecutive hours centered around daytime low slack tides when tidal height was less than 0.3 m. Anglers targeted areas where surfperch concentrate, including calm waters (e.g., holes, troughs, channels, riffles), seams (e.g., foam lines, calm side of rips), bars, swash zones and seaward of rolling waves. They were cautioned not to wade into water that was above their waist and to avoid hazards, such as sleeper waves, strong undertow, rip currents, steep beach profiles, drop offs, ledges, outer reefs, soft sediment, submerged logs and other debris, They also were advised to be vigilant for surfers and marine mammals. Wearing a personal flotation device was recommended as a precaution.

Sampling teams consisted of five to 14 anglers and one or two scientists, depending on the number of anglers. Anglers surveyed the study area as a loose group, leap-frogging along the length of the beach. If fish did not strike the tackle after about five casts or 10 min, then the angler moved farther down the beach. Anglers remained in a spot as long as they continued to catch fish. Occasionally, the group would become too spread out, and scientists communicated by handheld radios to relay information and coordinate fishing, especially regarding the locations of fish aggregations. Signs were attached to buckets informing the public of the purpose of the study, and scientists answered all questions.

Baited hook-and-line and fly fishing was used to sample the rough surf zone of the region and increase participation by the angler community. Anglers brought their own fishing gear. Surfperch are by far the dominant species caught by anglers, and we targeted them using #2 thin-wire, barbless, circle hooks to ease removal from fish and enhance survival. Several hooks per rod often were used to increase catch. Hooks were baited with standardized organic artificial bait (Berkeley Gulp 2-inch sandworms) to eliminate 1) the need to collect live bait within MPAs, 2) the time needed to collect live bait and 3) the possibility of introducing nonnative species and their pathogens.

Surfperch are not selective, and we gave fly fishers some leeway in their choice of flies within the following guidelines. Flies consisted of small, compact fly patterns tied on #2-8 hooks to ensure that even small fish will be caught. Simple flies were tied with ice chenille, natural hair or artificial fiber and they were either weighted or not weighted. Material color included black, brown, olive, tan, orange and red.

Scientists led the team and retrieved fishes from anglers. Hemostats were used to remove hooks from fish’s mouths when necessary, and fish were placed into buckets filled with seawater to reduce stress. Date were recorded for each fish caught, including tackle used to catch the fish, time the fish was caught, species, sex, fork length and weight. Fish were weighed using a digital hanging scale and measuring board. Digital photographs of each fish with a date and time stamp, a ruler and a card designating the sex of the fish was taken for our records. All fishes were released quickly, and they all swam away. Crabs (*Cancer* spp.) sometimes were caught but data were not recorded.

Scientists also recorded physical data during each sampling trip. Water temperature was taken using a digital thermometer. Air temperature, average and maximum wind speed and wind chill were recorded using a handheld anemometer. Beach slope was measured at the water table outcrop at three widespread locations along the beach. Other data recorded included wind direction, estimated maximum wave height, weather conditions.

RESULTS

Baseline data

A total of 49 anglers participated in 38 trips and contributed 353 h of fishing during the baseline surveys. More effort was expended sampling the pair of sites at Salmon Creek Beach (North: 17 trips, 120.7 h; South: 11 trips, 64 h) than the pair of sites in Drakes Bay (Drakes: five trips, 81.0 h: Limantour: five trips, 87.6, h). Sites at Salmon Creek Beach were sampled more because the CPUE at the sites in Drakes Bay was quite low (Table 9).

Table 9. Summary of all surfperch trips 2011-2012.

Site	Limantour	Drakes	Salmon North	Salmon South
MPA Status	Outside	Inside	Outside	Inside
Location	Point Reyes	Point Reyes	Salmon Creek	Salmon Creek
Number of trips	5	5	17	11
Fishing effort (hours)	81.00	87.55	120.72	64.10
Number of fish caught	9	16	115	132

Only surfperches were caught. Consistent differences in catch inside and outside MPAs were not evident (Fig. 34). Silver and Redtail surfperch were the most common species caught (Fig. 35). Barred and Calico (*Amphistichus koelzi*) surfperch were only caught at Point Reyes, and Spotfin (*Hyperprosopon anale*) and walleye (*Hyperprosopon argenteum*) surfperch were only caught at Salmon Creek. The latter four species were not included in analyses because few were caught.

The length and weight of surfperch were similar inside and outside MPAs except when sample sizes were low (Fig. 36). The sex ratio of surfperch was balanced at the four study sites except at Salmon South in 2012, where the proportion of females was higher than expected in 2011 and lower than expected in 2012 (Fig. 37).

For the two most abundant species, the sex ratio of Silver surfperch was balanced, but more male Redtails were caught than females (Fig. 38). However, the number of Silver surfperch caught was nearly double that of Redtails. Silver surfperch were caught at a roughly 1:1 male to female ratio at Salmon Creek, regardless of whether they were caught inside or outside the MPA (Fig. 39).

Protocol development

The two types of tackle did not affect catch rates (Fig. 40). However, anecdotal evidence suggests that bait fishing was more effective in turbid conditions when fishes may have been less able to see lures and windy, high surf conditions when fly fishers could not cast as far. Insufficient data were collected to evaluate these trends.

To determine the effect of physical conditions on catch, we analyzed catch per unit effort (CPUE) and environmental variables using data for Salmon Creek Beach North and South where we collected the most data. CPUE was not significantly related to any environmental factor tested, except time from low slack tide. Most surfperch were caught during the two hours following low slack tide and especially closer to slack tide, making this the most efficient time to fish (Fig. 41).

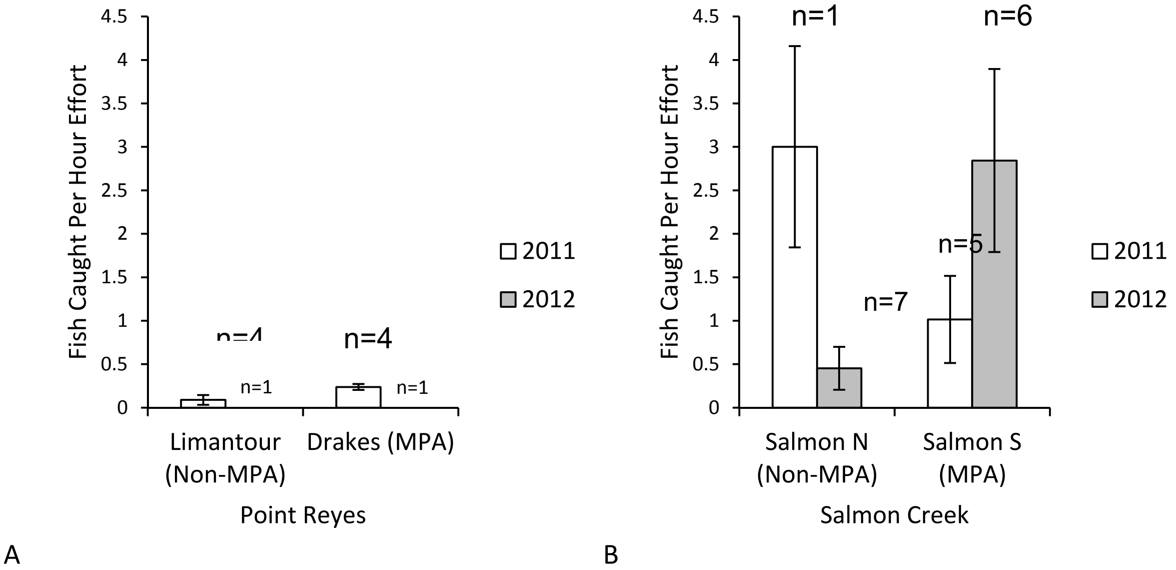

Figure 34. Surfperch caught per hour of effort (± SE) at four beaches in 2011 and 2012 at Point Reyes (A) and Salmon Creek (B). The number of trips to a beach per year is indicated above each bar.

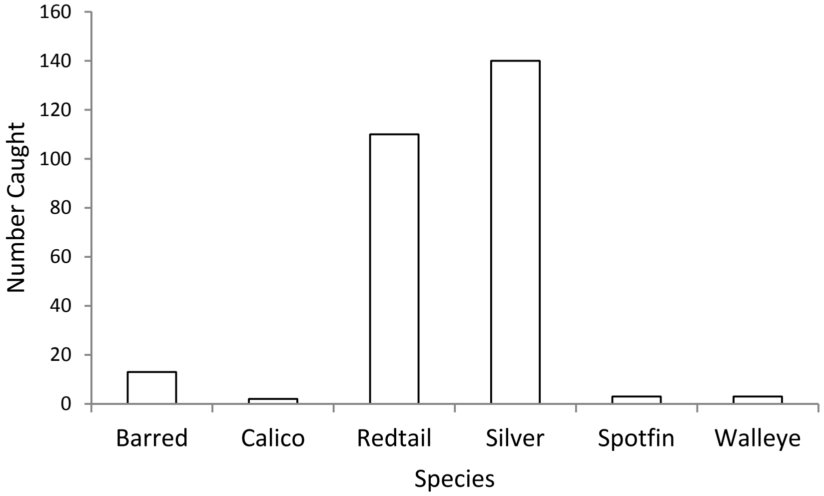

Figure 35. Species diversity and number of fish caught over all trips (n = 38) in 2011-2012.

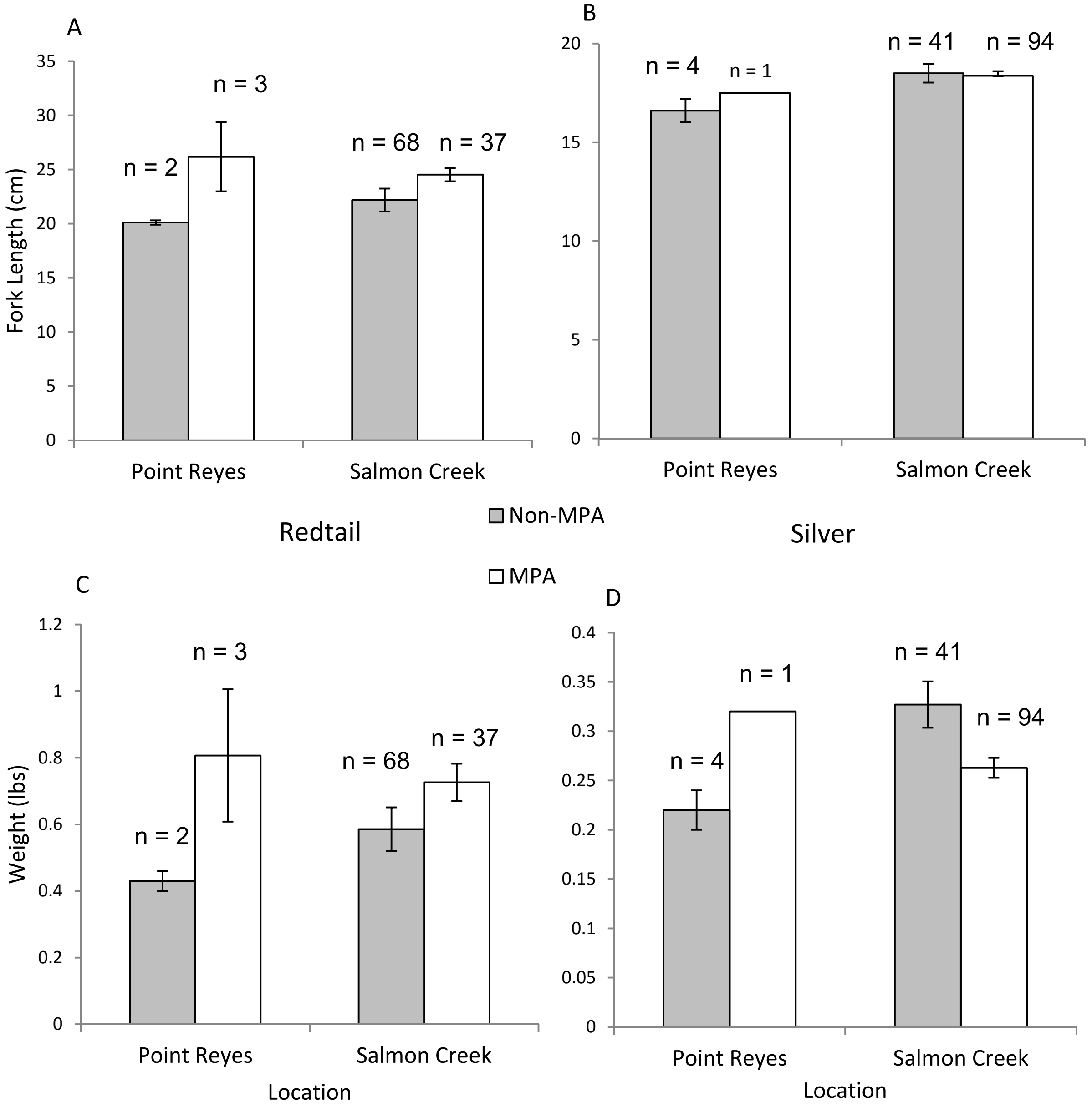

Figure 36. Mean fork length (cm) and weight (lb) (± SE) of Redtail (A, C) and Silver surfperch (B, D). The number of each species caught at each site is displayed over their respective bars. Note the difference in scale between Redtail and Silver surfperch.

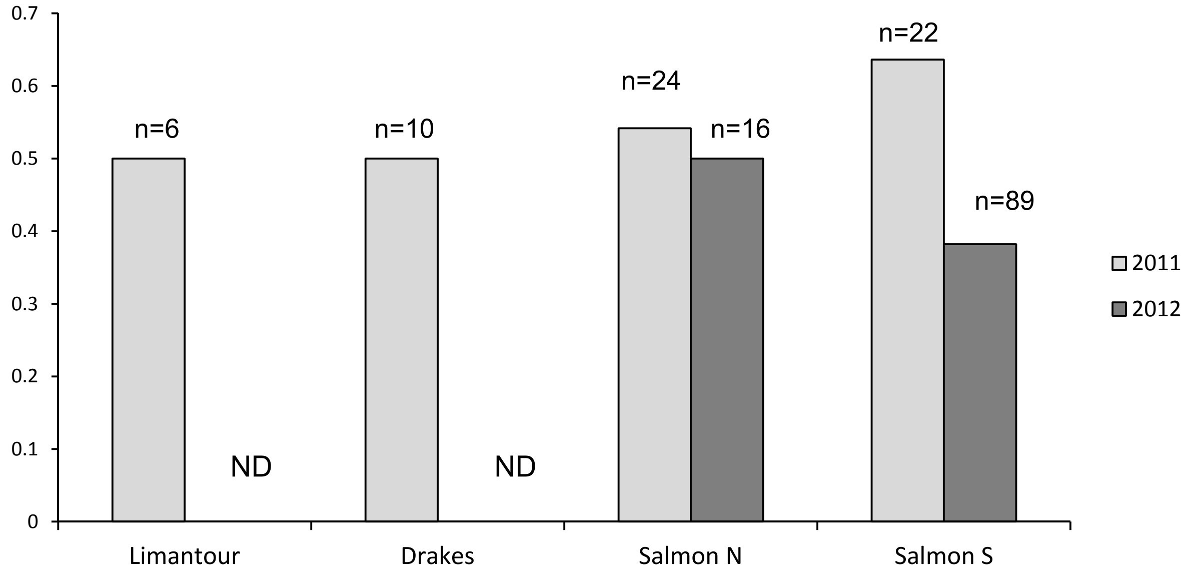

Figure 37. Proportion of female surfperch caught in 2011 and 2012. The total number of surfperch (n) for which sex was determined (n) in the two years is located above bars.

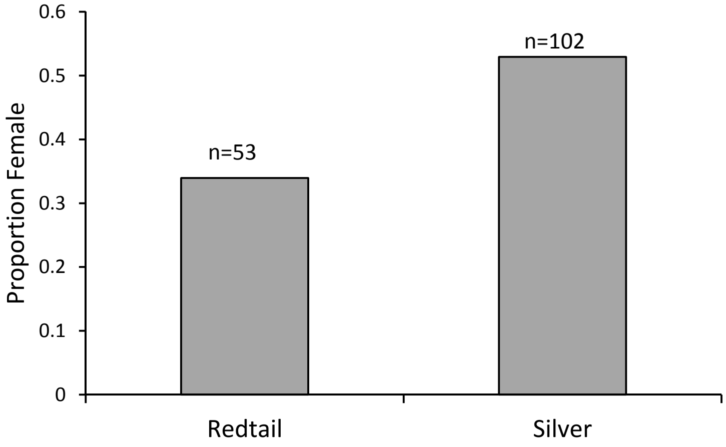

Figure 38. Proportion of female Redtail and Silver surfperch combined for both years. The number of surfperch for which sex was determined is above the bar.

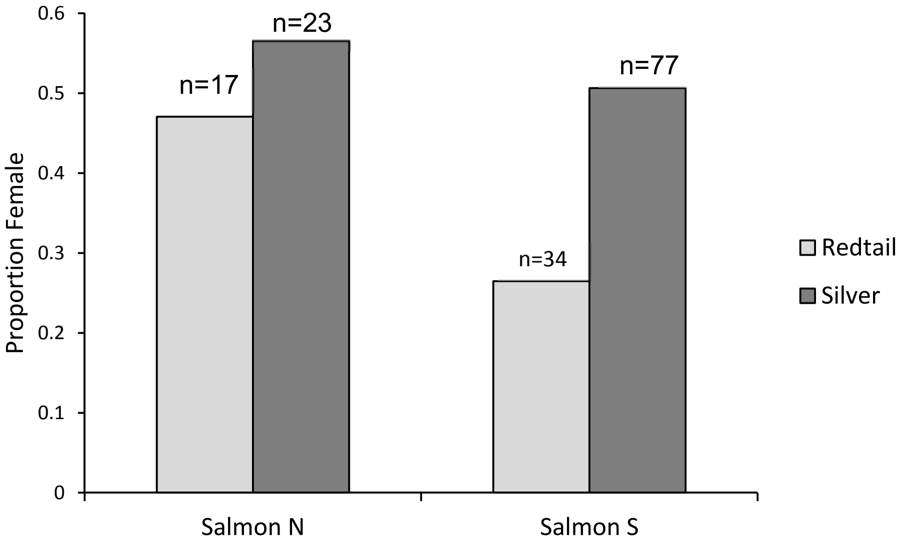

Figure 39. Proportion of female Redtail and Silver surfperch for which sex was identified at Salmon North and Salmon South in 2011 and 2012 combined. The number of surfperch caught is indicated above the bars (n).

We examined the cumulative catch of surfperch during the course of each trip to determine whether most fish were caught in close succession when schools were encountered. Periods of high catch punctuated long periods of little to no catch. For example during one trip, two periods of high catch occurred: at 20 to 60 minutes and 120 to 130 minutes (Fig. 42). Conversely, catch was low from 60 to 120 minutes and 130 minutes to the end of the trip. To demonstrate that this trend was common, we calculated the probability of a consecutive fish catch in five-minute intervals for all trips to Salmon Creek trips (north and south in both years), where we caught the most fish. The probability of catching a second fish based on the time since the first catch. As the time after a catch increased, the probability of catching another fish decreased markedly after 10 minutes (Fig. 43). When accounting for the number of anglers, surfperch were still most often caught within 20 minutes of the previous catch (Fig. 44).

We also determined the probability of catching the same species in clusters to indicate whether schools were homogenous or heterospecific. For the two most abundant species where most fish were caught, when one species was caught in high numbers the other species was absent, suggesting that these species did not form mixed schools.

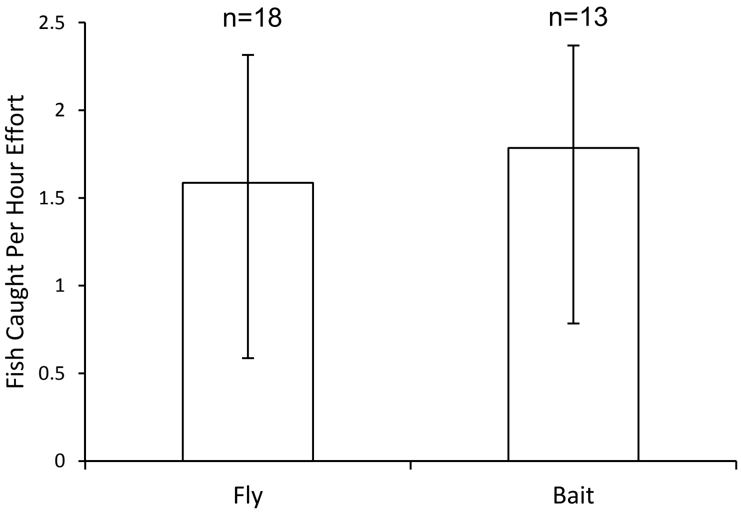

Figure 40. Catch per hour of effort by anglers using lures or bait (± SE). n represents the number of trips for which tackle type was recorded.

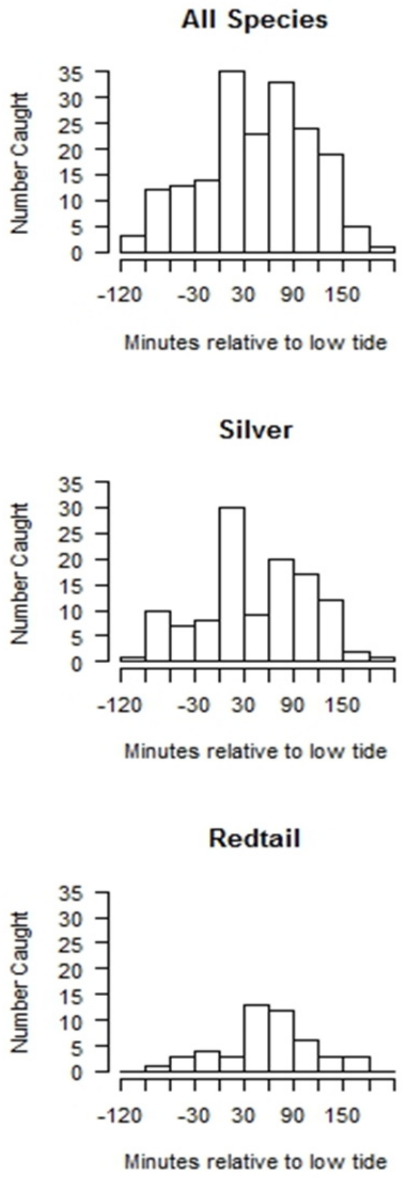

Figure 41. Number of surfperch caught (all species combined, Silvers only, Redtails only) relative to low tide for 38 sampling trips.

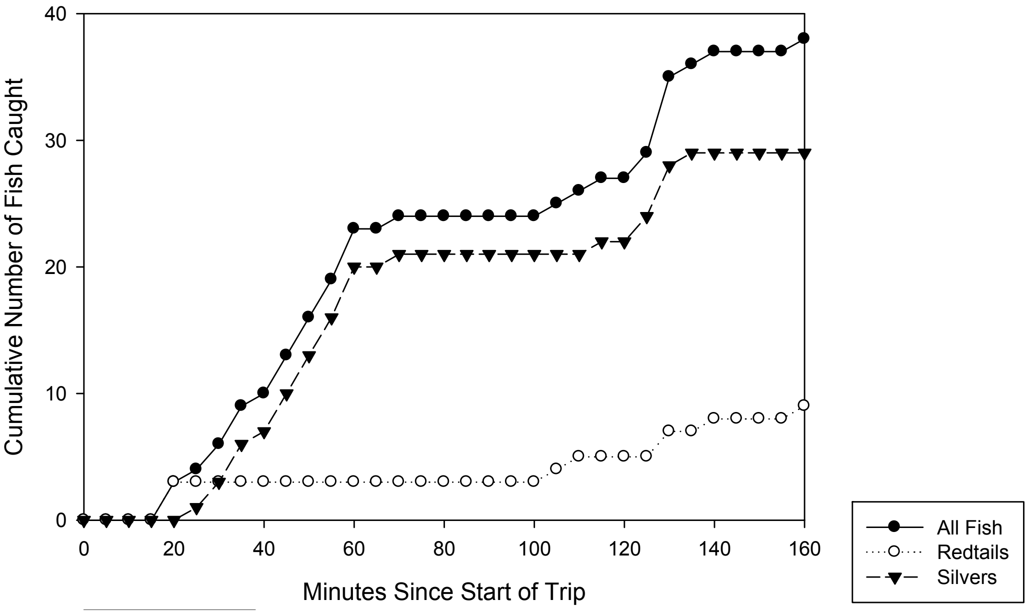

Figure 42. Timing of fish caught on 15 September 2012 at Salmon South.

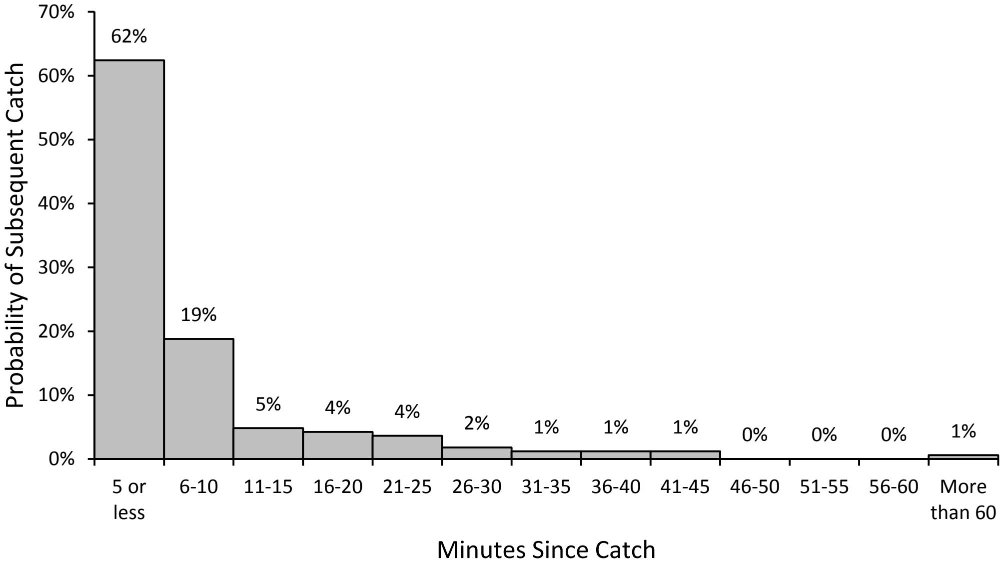

Figure 43. The probability of catching a second fish based on the time since the first catch for all Salmon Creek trips.

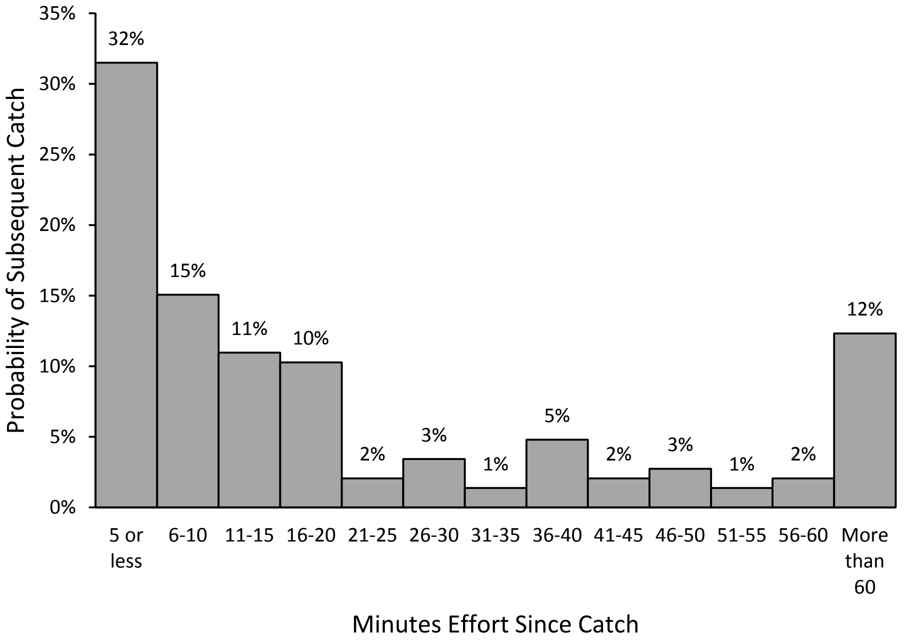

Figure 44. The probability of catching a second fish based on the minutes fished since the first catch for all Salmon Creek trips.

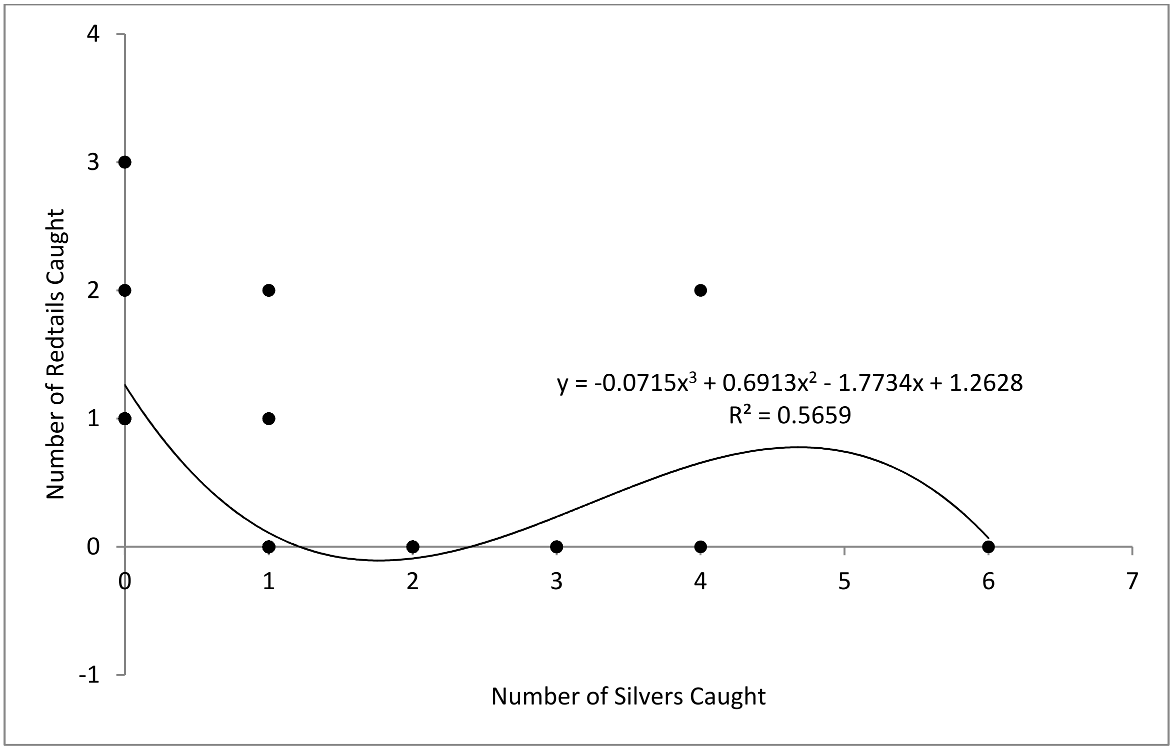

Figure 45. The number of Silver and Redtail surfperch caught within a given five-minute interval, for all trips to Salmon Creek (North and South) in 2011 and 2012 for which time and species data were available.

CONCLUSION

We developed a cost-effective catch-and-release protocol to sample surf zone fishes by hook and line in the rough surf zones of central and northern California. Seining may be an effective alternative sampling approach in the calmer surf zones of southern California.

Baseline data was obtained for two pairs of MPAs and reference sites, and no consistent differences in surfperch populations were evident. Engaging citizen scientists appeared to foster a better understanding of the rationale for the newly implemented network of MPAs. In addition, interesting new information on the population biology of surfperches for this poorly understood group.

Our protocol was developed in close consultation with the California Department of Fish and Wildlife so that data from their ongoing sampling program can be merged with efforts to monitor the network of MPAs. CDFW declined to provide their data for a joint publication on surfperch populations at beaches across the entire coast of California, which would have provided robust baseline data for the network of MPAs. We did obtain eight years of data for the central and north-central coast from an avid angler who played an important role in our project. These data will be included in our forthcoming publication but have not been presented here, because these data were not part of our proposed baseline survey.

ACKNOWLEDGMENTS

This study could not have been conducted without the participation of many citizen scientists, including anglers (R. Baker, A.-M. Bakker, J. Banovich, C. Bongio, A. Cason, Chio Saephan, J. Ellis, S. Foster, M. Gravem, S. Gravem, A. Kreuzpaintner, K. Koths, L. Lack, W. Lee, J. Lenio, K. Magoon, J. Mascovich, K. Moore, T. Moore, M. Norgaard, M. Oristian, N. Rader, S. Roland, D. Rosario, D. Rothenberg, T. Slocum, L. Soares, Stompe, M.B. Taggart, R. Urry, L. Vivian, A. Vitale, S. Wallen, M. Whalen and W. Wellever) and students assisting with data collection (S. Gravem, T. Manger, K. Mascovitch, E. Satterthwaite and K. Vedder). We thank the many fishing clubs that opened their doors to recruiting anglers for the study, including the Russian River Fly Fishers, Golden West Women Fly Fishers, Sonoma State Fishing Club, Mt. Tamalpais Fly Fishers, Diablo Valley Fly Fishermen, Grizzly Peak Fly Fishers and Golden Gate Casting Club. K. Oda, R. Ketley and T. Moore played an important role in helping us design the study. We thank B. Becker and D. Jones for facilitating studies at Point Reyes National Seashore and Salmon Creek State Park. Special thanks to Mark Won who helped design and conduct the study and recruit anglers. This research was funded by California Sea Grant (R/FISH218) and the National Science Foundation (Biological Oceanography award (OCE-0326110). This is a contribution of the Bodega Marine Laboratory.

III. Collaborative sand crab monitoring with the Gulf of the Farallones National Marine Sanctuary's LiMPETS education and outreach program

INTRODUCTION

Citizen science, which is broadly defined as a process by which citizens are involved in science as researchers, may be a cost-effective approach to monitoring networks of MPAs. As described in the prior section scientists, conservationists and natural resource managers can benefit from the public's interest in engaging in the collection of ecological data and the general public and society in general benefit's from informal education in the motivating issues, the study system and scientific process. With the growing engagement of K-12 students in active learning exercises and emphasis on engagement hands-on research experiences, school kids and university students are also becoming a potentially valuable network of junior citizen-scientists. The Long-term Monitoring Program and Experiential Training for Students or 'LiMPETS' program is a relatively new junior citizen-scientist monitoring network that was established in 2002 by the Gulf of the Farallones (GoF) National Marine Sanctuary (NMS) as an education and outreach program for local K-12 and community college students[4]. The LiMPETS program was already monitoring sand crabs (one of our proposed indicator species) in the region so we sought to collaborate and build on this existing monitoring program.

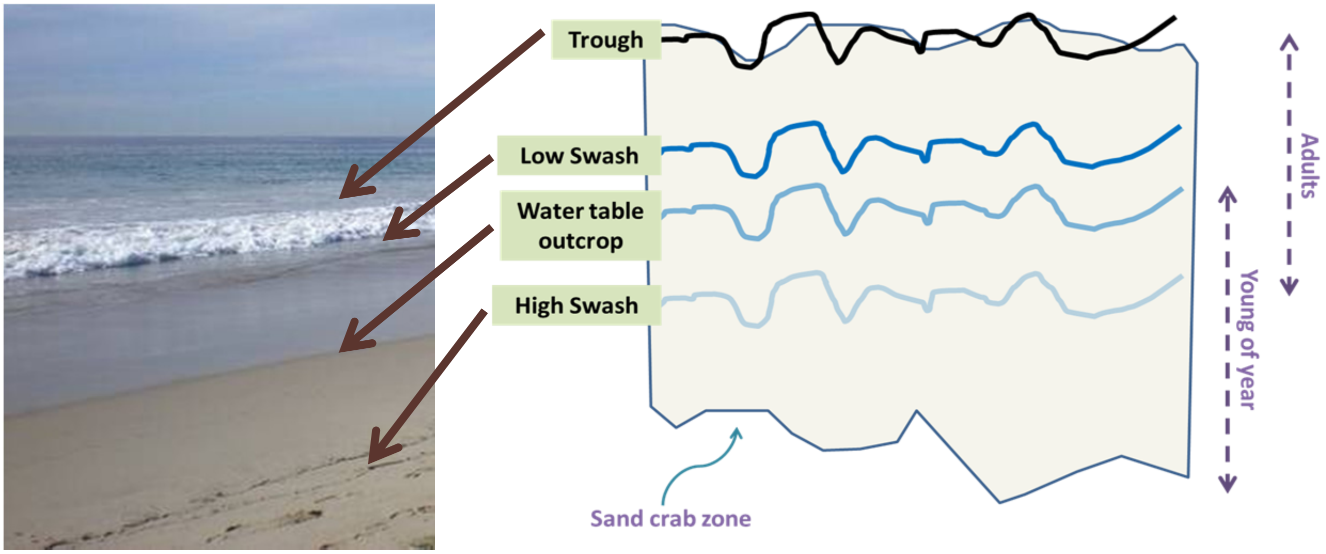

Figure 46. Sand crab distribution across the shore by age class and with reference to beach profile landmarks.

Sand crabs are highly mobile and have a very variable distribution in both the across and alongshore dimensions of a beach, as well as seasonally. Adults and young of year sand crabs occupy different intertidal zones during the summer months (Fig. 46) and often move to offshore sand bars in the winter months. Excessive trampling in the swash zone may cause crabs to flee the local area. Accurate population estimates require sampling across the entire distribution of crabs on the beach,

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[4] Additional details about this program can be found on this web page: http://limpetsmonitoring.org/sandy_beach.php

into the lower swash zone (Fig. 46), thus any sampling effort has some inherent dangers, especially on days or sites with strong surf or high wave energy, and on steep beaches with coarse sediments. A program that engages the general public and school kids needs to use a sampling protocol that accounts for the safety of younger and less experienced participants to a greater degree than a scientific research team with more extensive training and experience working in the surf zone under different conditions of sea state.

The primary objectives, and thus the protocols, for programs with an emphasis on education and outreach versus scientific monitoring may not be equivalent. In this case, the protocols for standard monitoring used by LiMPETS and our baseline monitoring efforts used in ecological studies to assess population abundances were similar but differed in several aspects. The LiMPETS protocol is described in detail on their web page: http://limpetsmonitoring.org/sb_methods.php and summarized in Figure 47. The baseline methods are detailed in the previous section and a general schematic comparing the two protocols is provided in Figure 48. Briefly, the LiMPETS protocol sets out a 50 m alongshore transect above the high swash zone and selects five random location on the transect to set up 10 m cross-shore transects. The LiMPETS specifies the 10 m transect should start five meters above the top of the swash zone a single core sample is collected every meter along each across-shore transect for a total of 50 samples. In contrast, the baseline monitoring protocol identifies the zone of sand crab occurrence first, and then samples across the entire zone and through the low swash zone to as close the trough as possible. The width of the zone typically varies with surf zone conditions and the beach profile, including the slope of beach. As a result sand crab densities can vary markedly from day to day and from beach to beach even if the population size is the same.

To compare the LiMPETs sand crab sampling method (initially designed to serve an educational mission but with long-term monitoring in mind) to the method we used in our baseline monitoring program, we collaborated in a replicated, side-by-side sampling effort at three different beaches (Salmon Creek Beach (N), Limantour Beach & Montara Beach) that engaged undergraduate marine ecology university students from Sonoma State University and Bodega Marine Laboratory (University of California, Davis), high school students from Lake County participating in the LiMPETS program as well as staff from the LiMPETS program. The aim of this effort was twofold: first, we wanted to cross-

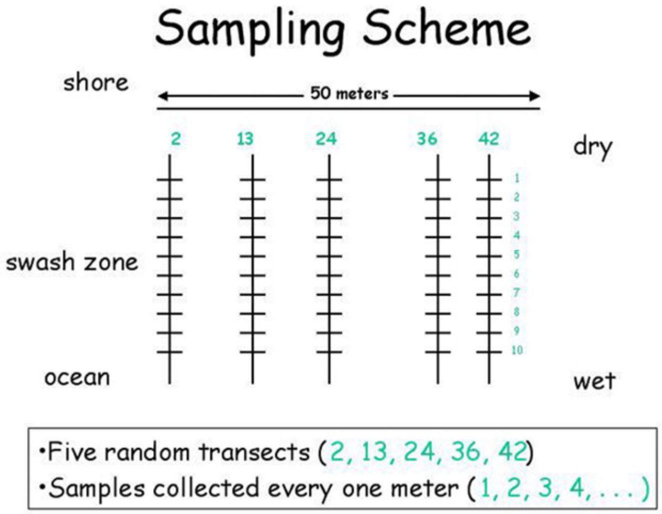

Figure 47. LiMPETS sampling design copied from the program's web page: (http://limpetsmonitoring.org/sb_methods.php) where methods are described in detail

calibrate our different methods (if possible) to make the best possible use of existing regional data[5] collected by the LiMPETS program with school kids since 2002 and second, to recommend adjustments to the LiMPETS protocol, if needed, to improve its scientific efficacy as a long-term, citizen science monitoring program for regional sandy beaches (in addition to serving its equally valuable educational mission).

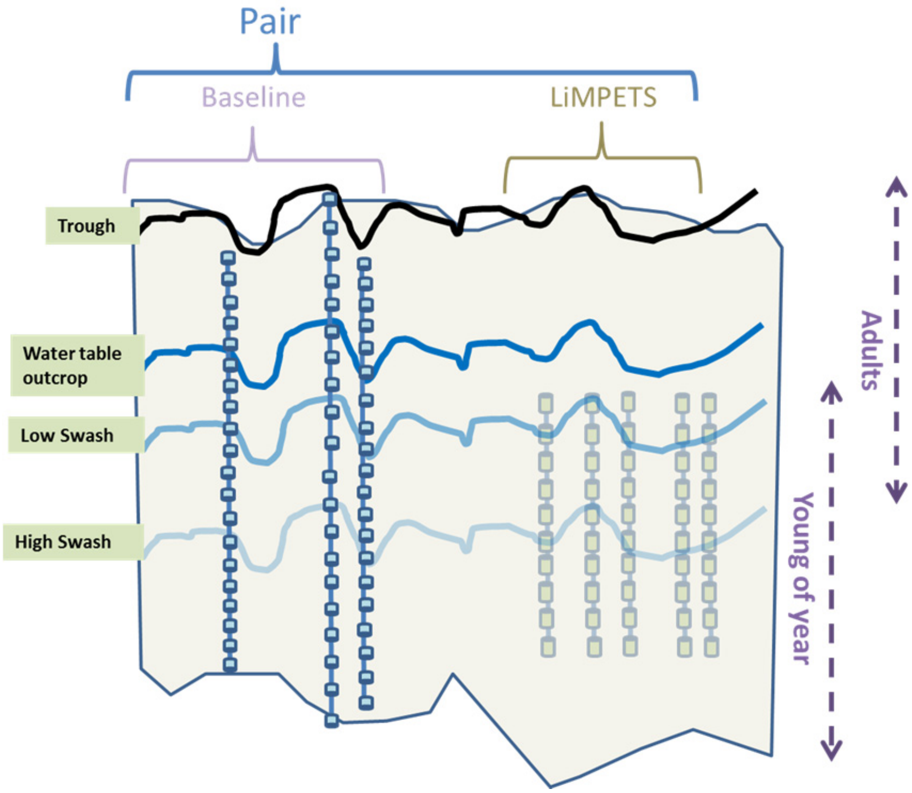

Figure 48. Schematic of the LiMPETS and baseline protocols and the paired experimental design used to compare population estimates derived from the two different sampling methods.

We sampled at three beaches with different beach slopes and sand grain sizes at sampling locations already used by the LiMPETS program: Salmon Creek Beach (N), Limantour Beach and Montara Beach (Tables 1 & 2, Fig. 2). We used a paired sampling design, pairing five and three transects for the LiMPETS and baseline protocols, respectively within a block or pair (transect were randomly located within a beach segment for each protocol) (Fig. 48), and then each block was replicated 2-3 times at randomized locations at each beach. We also recorded the slope of the water table outcrop (WTO) for each transect to include as a covariate in the analysis to control for difference in the physical habitat among transects and beaches. We measured the sand crabs to estimate the abundances of young of year (YOY) crabs and adult crabs separately since they occupy different intertidal zones. We hypothesized the two sampling protocols would yield different estimates of abundance for adult and young of year crabs. Data were converted to numerical abundances per meter of shoreline based on the width of the zone of sampled, the area of the core sample and the core spacing.

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[5] Data collected by the LiMPETS program are freely accessible via this web page: http://limpetsmonitoring.org/data_entry.php

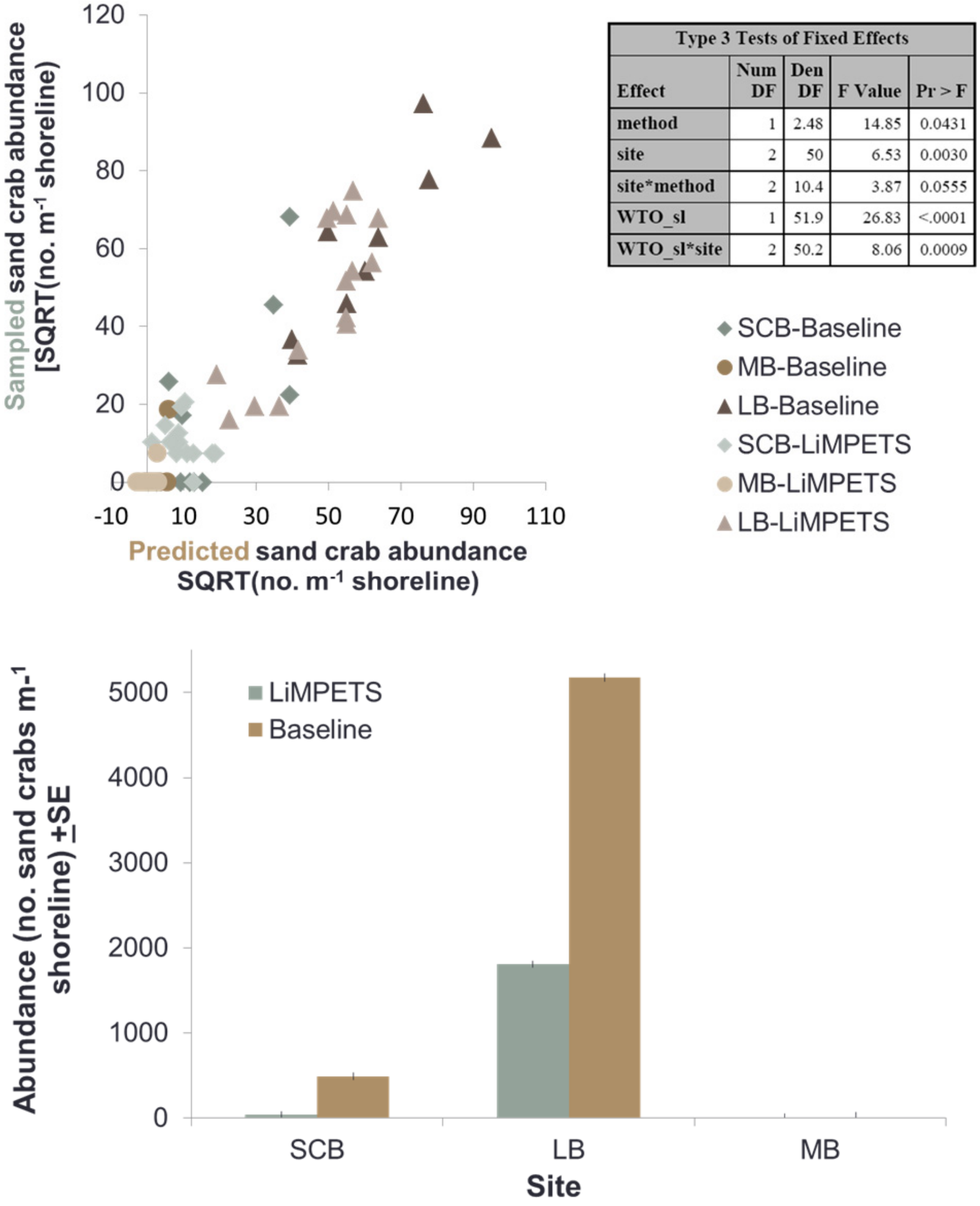
We analyzed the data using a mixed linear model with method, site and slope of water table outcrop as fixed effects. Transects were nested within blocks and blocks were nested within sites and modeled as random effects. We used an information theoretic approach to model selection using AIC_c weights to compare models. Maximum likelihood estimates were used to compare models with different fixed effects and then restricted maximum likelihood (ReML) estimation was used for the final model fit. We compared a nested set of models from fully saturated to no interactions at all with and without including the slope of the water table outcrop as covariate (a fully saturated model includes all these effects: site, method, WTO, site x method, site x WTO, method x WTO and site x method x WTO).

RESULTS

Estimates of the abundance of YOY sand crabs varied strongly with the slope of the WTO, but this effect varied among sites ($p = 0.0009$, Fig. 49). Abundance of YOY sand crabs also varied depending on the method used with substantially higher estimates (> double) derived from the baseline method ($p = 0.0431$, Fig. 49). However, ranked abundance relationships were not sensitive to the method used and remained intact in this analysis (Fig. 49).

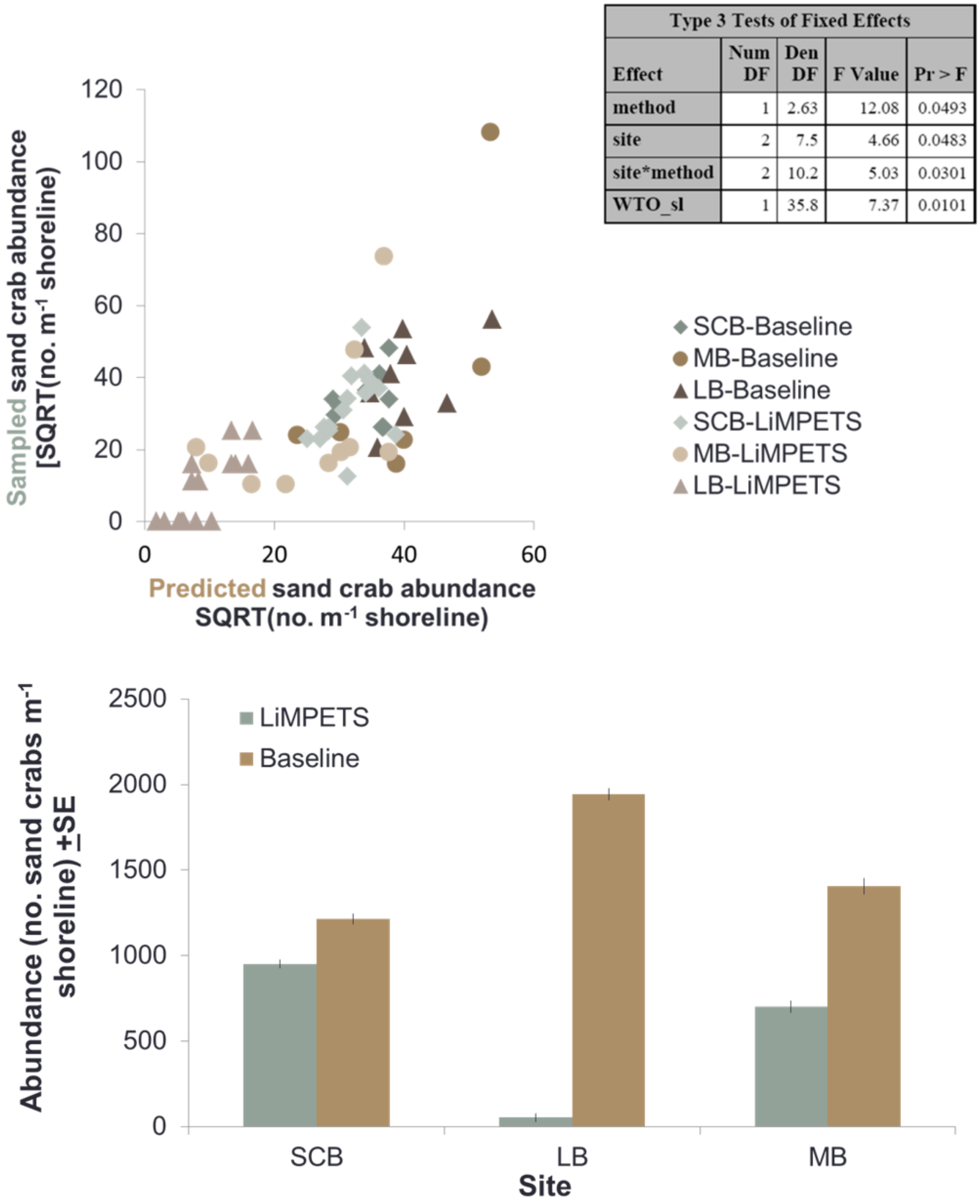
The results for adult sand crabs differed somewhat. Similar to the analysis for YOY crabs, the slope of the beach at the WTO had a strong influence on the estimated abundances, but for adult crabs the effect was the same across all three sites ($p = 0.0101$, Fig. 50; note the interaction term between slope and site was not retained). However, the method used had a strong effect on the estimated abundance of adult crabs and this effect was not consistent among sites ($p =0.0301$, Fig. 50). The LiMPETS method also underestimated the abundances of adult sand crabs relative to the baseline method, similar to the results from the analysis of the YOY crabs. However, more importantly, the rank abundance estimates were very different between the two methods (Fig. 50). The highest abundance of adult crabs among the three beaches was found at Limantour Beach using the baseline protocol, while the opposite conclusion emerges from the abundance estimates made using the LiMPETS protocol (Fig. 50).

The analysis of total sand crab abundance estimates is somewhat more complex. While slope of the WTO remains an important explanatory factor, its effect varies with the protocol used ($p = 0.0093$, Fig. 51). Furthermore the effect of the protocol used varies from site to site ($p = 0.0354$, Fig. 51). Again, the absolute abundance estimates are underestimated by the LiMPETS method, overall (Fig. 51). Although the rank abundances are the same from the two protocols, there are apparently big differences in the relative abundance estimates between the two methods that vary from site to site, as indicated by the significant site x method interaction term (Fig. 51).



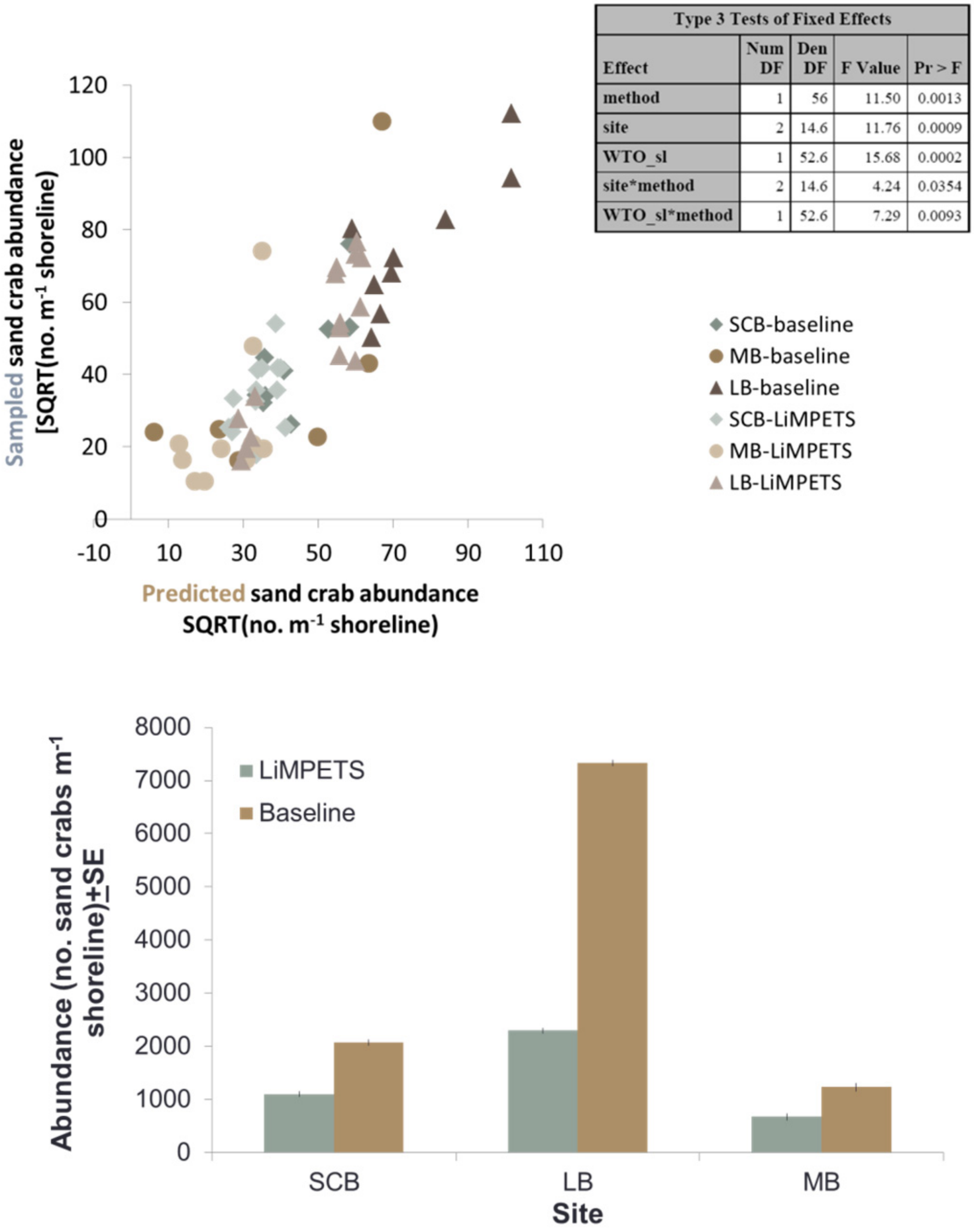
Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
method	1	2.48	14.85	0.0431
site	2	50	6.53	0.0030
site*method	2	10.4	3.87	0.0555
WTO_sl	1	51.9	26.83	<.0001
WTO_sl*site	2	50.2	8.06	0.0009

Figure 49. Analysis of **young of year (YOY)** sand crabs as a function of sampling protocol (baseline or LiMPETS), site and slope of the water table outcrop. Top panel shows the fit of the statistical model fit. Data were square root transformed to meet model assumptions. SCB = Salmon Creek Beach (N), MB = Montara Beach and LB = Limantour Beach; WTO_sl = the slope of the water table outcrop in degrees. Lower panel data are the the back-transformed estimates (after accounting for the random effects) from the mixed model analysis for each method by site, at the average slope of the WTO for each beach.



Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
method	1	2.63	12.08	0.0493
site	2	7.5	4.66	0.0483
site*method	2	10.2	5.03	0.0301
WTO_sl	1	35.8	7.37	0.0101

Figure 50. Analysis of **adult** sand crabs as a function of sampling protocol, site and slope of the water table outcrop. All other information as in caption for Fig. 49.



Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
method	1	56	11.50	0.0013
site	2	14.6	11.76	0.0009
WTO_sl	1	52.6	15.68	0.0002
site*method	2	14.6	4.24	0.0354
WTO_sl*method	1	52.6	7.29	0.0093

Figure 51. Analysis of **total** sand crabs as a function of sampling protocol, site and slope of the water table outcrop. All other information as in caption for Fig. 49.

CONCLUSIONS

Sand crab abundances were negatively correlated with slope of the water table outcrop at all sites. The LiMPETS method underestimates the absolute abundance of sand crabs relative to the baseline method primarily because of under sampling of adult sand crabs, but also due to under sampling the zone of occurrence of sand crabs overall. The rank abundance estimates of total and YOY crabs are similar between methods, but this was not the case for adult sand crabs and was more reliable for YOY crabs. It is not possible for the LiMPETS program to sample across the entire zone of sand crab occurrence, and this is especially true on steep beaches, due to safety concerns. However, since the rank abundances of YOY crabs were accurate (probably because they occur higher on the shore) and the LiMPETS program regularly collects size data as part of their standard protocol, censoring the existing, historic data to focus on the abundance of juvenile crabs may be a reasonable way to use the existing data to estimate, at least, ranked and relative abundances of juvenile sand crabs among sites.

Furthermore, it may be possible to modify the LiMPETS protocol to increase the accuracy of its sand crab abundance estimates by collecting data on the slope of the beach at the water table outcrop and focusing on quantifying juvenile crabs, specifically. This would require training students or their teachers to identify the zone of occurrence, or perhaps more realistically, have scientists develop guidelines on easier to identify beach profile benchmarks to use as proxies to ensure sampling encompasses the zone of occurrence for YOY crabs. Toward that end, our research team reported the results of this analysis to LiMPETS staff and their science advisory team in a conference call. Dugan and Morgan are also both members of the LiMPETS science advisory team and will continue to provide guidance on protocol modifications.

ACKNOWLEDGEMENTS

We thank Amy Dean and the Gulf of the Farallones LiMPETS program staff for collaborating with us on this project. We also thank the 2011 spring semester marine ecology students from Sonoma State University and UC Davis & Bodega Marine Laboratory, and the high school students from Lake County for their enthusiastic participation in this sampling effort. For assistance with scientific permitting and facilitating site access we thank: Brian Owens (California Department of Fish and Wildlife), Ben Becker (Point Reyes National Seashore), Kevin Fleming (CA State Parks), Irina Kogan and Maria Brown (National Marine Sanctuaries). We thank John Collins from SSU's machine shop for manufacturing our sand corers.

IV. Conclusions and Recommendations

This study is the first comprehensive study of sandy beaches ecosystems in the NCC region. Sandy beaches make up approximately 51% of open coast shoreline in the region but are underrepresented in the NCC MPAs compared to rocky shores. A diverse array of marine organisms and human activities are supported by sandy beach ecosystems, and a set of studies was needed to characterize beaches in the region, including data collected by citizen scientist groups. The results yielded new insights into the role of pocket beaches, which are (< 1 km long and surrounded by rocky marine habitats) and are most common in the northern bioregion. This is notable as pocket beaches have not been a focus of marine ecological studies anywhere in the past. Most importantly, our baseline survey resulted in a set of indicator taxa and other variables appropriate for efficient, cost-effective, long-term monitoring of beaches.

Sandy beaches in the NCC region are very diverse both physically and ecologically with both long and pocket beaches present. Of the 17 beaches we studied, 11 were long beaches, six were pocket beaches, and three of each type were located within MPAs. Four of the 17 and two of the 10 focal beaches were characterized as reflective beaches, with coarse sand and narrow surf zones, and the rest were intermediate beaches; dissipative beaches did not occur in the NCC region. Sand grain size, beach slope, wave energy and other physical characteristics varied substantially among the 17 beaches, but there were no consistent differences between MPA and reference beaches, bioregions north and south of Point Reyes (as defined during the MPA planning process), or long and pocket beaches. Therefore, we conclude that based on physical characteristics alone, we selected appropriate reference beaches for comparison to MPA beaches.

Human visitation was episodically high, and by far, most activities were non-consumptive. We observed as many as 390 people and 53 dogs per km of shoreline and as few as none in our surveys. Private access beaches had consistently low rates of visitation. People primarily used beaches, for nature walks, resting/socializing, water sports and beach sports/play (in decreasing order of occurrence). Consumptive activities, such as fishing, were not common. Surfcasting was observed only eight times by 21 people, and only once in an MPA, by two people. Popular activities in all four categories were most common on long, non-MPA beaches, especially dog walking. MPA beaches were less frequently visited by people and their dogs, making them more attractive to shorebirds, even though there are no restrictions on human visitation or non-consumptive activities in these MPAs.

Birds were seasonally abundant with over 6,000 birds of 51 species observed on the 10 focal beaches we surveyed over one year. Shorebird abundance and richness were much lower in the NCC region than in central and southern California (Hubbard & Dugan 2003, Dugan et al. 2003 and Dugan et al. *in prep*). We observed 14 species of shorebirds and their mean abundance was only 18.3 km^{-1}.. Shorebird abundances and total richness from studies of other temperate sandy beaches are generally higher, ranging from 8.9-98.6 shorebirds km^{-1} and from 7-28 species (*cf.* Table 2 in Hubbard & Dugan 2003), but comparisons should be interpreted cautiously as there are differences in the area sampled and seasons surveyed among the studies. More species occurred on long compared to pocket beaches. The abundance of birds at MPA and reference beaches did not differ substantially for shorebirds and seabirds overall, although gulls were most abundant on long MPA beaches and pocket reference beaches. Although only a small proportion of the birds we observed were terrestrial (~ 5%), they were strikingly concentrated on pocket beaches, exceeding the average abundances of shorebirds, sea, birds and gulls on these beaches, only. They were also more abundant on beaches in MPAs, perhaps due to lower human use. Shorebirds on non-MPA pocket beaches were evidently most sensitive to concentrated use by people and dogs. Because dog walking and non-consumptive human activities are not restricted in NCC MPAs, this apparent benefit or protection for shorebirds in MPAs may not persist.

The abundance and species richness of shorebirds was correlated with the abundance and composition of macrophyte wrack, reflecting the (indirect) feeding and habitat relationships among these organisms. Shorebirds feed on talitrid amphipods, which feed on kelp plants and other drift seaweeds. As anticipated from prior research and natural history, the abundances of talitrid amphipods and shorebirds were positively correlated (Dugan et al. 2003); however the relationship was limited to long beaches, and the same relationship was not evident on pocket beaches. Interestingly though, the abundance of terrestrial birds was also tightly linked to the abundance and composition of macrophyte wrack and macroinvertebrates. Terrestrial birds dominated the bird fauna on pocket beaches, strongly suggesting wrack-associated marine invertebrates may provide a trophic subsidy to adjacent terrestrial ecosystems on pocket beaches. Surrounded by rocky marine habitats, pocket beaches may benefit more from local sources of drift kelps than long beaches. This proximity could potentially forge tighter connections between rocky and soft sediment ecological features of MPAs for pocket beaches.

Macrophyte wrack was most abundant on beaches from June to December but varied greatly in quantity and composition among beaches. Peak deposition of macrophyte wrack occurred in November and was especially high on pocket beaches in the northern bioregion. Standardized counts of fresh kelp plants made while walking along the shore were strong predictors of the total cover of kelp wrack on the beach, and thus could be used as an easy-to-measure indicator variable for long-term monitoring. Unlike some beaches in southern California that are heavily used by people, beaches in the NCC region are not regularly groomed to remove drift kelp plants and other macrophytes. Instead, the dominant influences on the composition and abundance of macrophyte wrack on NCC beaches are proximity to source habitats (i.e., rocky reefs, bays and estuaries), prevailing ocean currents and the consumption rates of wrack-associated invertebrates on the receiving beach (Hobday 2000, Lastra et al. 2008). Kelp wrack is consumed faster than other common macrophytes by wrack consumers and also decomposes more rapidly (Mews et al. 2006, Lastra et al. 2008). Since drift macrophytes (together with surf zone phytoplankton and detritus) form the trophic foundation of sandy beach ecosystems, large changes in these factors are likely to have a strong influence sandy beach ecosystems in the NCC region. Production of macrophytes in the region will depend on ocean conditions as well as the ecology and management of the source ecosystems. Therefore, all of these factors should be considered to make informed inferences about future changes that might be observed in these ecosystems.

We identified over 67 kinds of macroinvertebrates from the 10 focal beaches, which is similar to the total richness reported for sandy beaches in southern California (Dugan et al. 2003, Schooler et al. *in press, in prep.*). However, only our invertebrate indicator species were observed on all 10 focal beaches, and many macroinvertebrate species were observed on only one beach. The abundance and biomass of talitrid amphipods and other wrack-associated invertebrates tended to be greater on pocket beaches, probably because of the greater availability of macrophyte wrack. The abundance and biomass of sand crabs tended to be greater on long beaches. We also found that the biomass of sand crabs (*Emerita analoga*) is a strong predictor of total macroinvertebrate biomass. The abundance of shorebirds is tightly correlated with the species richness and biomass of macroinvertebrates as well as with the biomass of sand crabs alone, reflecting trophic links between beaches and wildlife. However, these relationships were not apparent on beaches with high human and dog visitation and those surrounded by high cliffs or bluffs with no safe refuge for foraging shorebirds. The overall abundance and composition of macroinvertebrates was, in turn, related to physical characteristics of beaches due to the influence of sand grain size on burrowing and energetics. The total abundance, biomass and richness of macroinvertebrates did not differ between MPA and reference beaches, long and pocket beaches or bioregions north and south of Point Reyes, indicating that diversity was similar among beaches. Thus, although the beaches are very diverse, the reference and MPA beaches used for the baseline characterization are representative of beaches in the NCC region. Furthermore, sand crabs and talirid amphipods appeared to represent the major ecological variation in macroinvertebrate abundance and diversity we observed in the NCC region, and confirming their usefulness as indicator taxa for long-term ecological monitoring.

Our work with two citizen scientist initiatives in the region provided excellent opportunities to share knowledge; compare, design and improve survey methods; and collect scientific data to assess the status of different sandy beach species in collaboration with local citizens and students. We collaborated with the LiMPETS citizen-scientist sand crab program to assess the comparability of their estimates of sand crab population sizes with those collected in this study. The LiMPETS program provides an important pathway for K-12 students to learn about the ecology of sandy beaches, MPAs and the use of scientific evidence to inform management of natural resources. They have been collecting sand crab population data on regional beaches since 2001 and are a potential source of historic and future monitoring data for sand crab populations. They also provide a useful model of citizen-science monitoring program. In comparison to our monitoring protocol, the LiMPETS protocol underestimated the absolute abundances of total sand crabs while yielding similar ranked abundances. This is primarily the result of a sampling design that was adjusted for the safety considerations of the children doing the sampling, and it was especially pronounced on steep sloped beaches. As a consequence, adult sand crabs in the lower swash zone are under-sampled. However, the LiMPETS protocol provides less biased estimates of young-of-the-year sand crabs that burrow shoreward of the swash zone. Our results provide sound guidance for the best use of existing data from the LiMPETS program (censoring to exclude adult crabs) and potential protocol modifications for accurate estimation of young-of-the-year sand crabs.

We also designed and implemented a citizen-scientist fishing survey with recreational anglers to monitor the abundance and surf zone fishes. Surfperches were the only fish caught and are most likely to benefit from MPAs. The anglers caught six species of surfperches at the two pairs of MPA and reference beaches (all long beaches), but only two species were abundant: Silver (*Hyperprosopon* *ellipticum*) and Redtail (*Amphistichus rhodoterus*) surfperch. Consistent differences between MPA and reference beaches were not evident for these fishes, but there were large differences in abundance and species composition between beaches located to the north of Bodega Head and those to the south of Point Reyes. Silver and Redtail surfperch were the most frequently caught overall. Barred and Calico (*Amphistichus koelzi*) surfperch were only caught at Point Reyes beaches, and Spotfin (*Hyperprosopon anale*) and walleye (*Hyperprosopon argenteum*) surfperch were only caught at Salmon Creek beaches. No evidence of trophic links between surfperches and the high abundance of macroinvertebrates found in the lee of the Point Reyes headland was found, in contrast to shorebirds and seabirds. Shorebirds and seabirds were most abundant in the lee of the Point Reyes and Bodega Head headlands. Macroinvertebrates associated with drift kelp in the surf zone may enhance foraging opportunities and the abundance of surf zone fishes (Robertson & Lenanton 1984). The data we collected in this study are not sufficient to evaluate this relationship; however the abundances of fresh kelp wrack and surfperch we observed on these beaches are consistent with this possibility. Redtail and Silver surfperch may also prefer the greater wave exposure and more complex bottom features present at the beaches to the north of Bodega Head. The close proximity of the paired MPA and reference beaches as well as their close similarities in the number and kinds of fishes caught, suggest the beach pairs may not have had distinct populations of surfperches. This may be an impediment to detecting differences due to MPA designation in the future. However, working together with 49 citizen-scientist anglers, we were successfully able to estimate differences in the abundance and diversity of surfperches on four beaches, providing a foundation for a further development of a long-term monitoring program in the NCC region.

In short, beaches in the NCC region were physically and ecologically diverse. Despite this variation, there were no striking or consistent ecological differences between MPA and reference beaches in the region, with the exception of visitation by people and their dogs. The most striking ecological differences occurred between long and pocket beaches. Sand crabs and shorebirds were more abundant on long beaches, whereas kelp wrack and wrack-associated invertebrates were more abundant and terrestrial birds were more dominant on pocket beaches. Pocket beaches may thus be areas of enhanced transfer from marine to terrestrial ecosystems. Because the ecology of pocket beaches has not been previously studied, these are new insights into the ecological functioning of different beach types in general and northern California shorelines in particular. The MPA planning process did not consider possible difference among beach types, but these differences should be taken into account when interpreting future ecological changes for adaptive management.

We recommend using our suite of ecological indicators, which includes sand crabs, talitrid amphipods, surfperch, fresh drift kelp plants, birds, people and dogs, for continued long-term monitoring of sandy beaches in the NCC. The monitoring can be conducted cost-effectively in collaboration with citizen scientists, provided that technical and administrative oversight and support together with a reliable and enthusiastic group of trained volunteers are available to ensure accuracy and consistency of the data collected. Standardized, monthly to seasonal observations (targeting fall and spring migration seasons) of birds, people, dogs and fresh kelp wrack on beaches could be made by volunteers walking an alongshore transect. Sand crabs and beach hoppers can be relatively quickly sampled, identified and quantified, with minimal training and access to some equipment and a small amount of wet lab space; a single survey in late summer is sufficient for a good population estimate. Standardized, seasonal fishing for surfperch by recreational anglers could also be readily implemented. Thus, this suite of indicators would provide a reliable, cost-effective approach to monitor the ecological state of sandy beaches in the region over time.

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